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# First Ethnobotanical Study Relating to Usage of Medicinal Plants in Province of Ain Defla Region, South-West of Algeria

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***Abstract***: The study was performed through 2019-2021 in Ain Defla province (South-west of Algeria) including 10 municipalities. Ain Defla has a wide diversity of plants used by their inhabitants for therapeutic aims. The data were collected and recorded using a feedback form, from a pre-established population, targeting on informants demographics, medicinal plants and parts used, method of treatment, and diseases treated. The collected information were analysed in terms of species use value, fidelity level and informant consensus factor. 180 people were interviewed; gender distributions (40%) ladies and 60% were men. The study recounted 65 medicinal plants belonging to 33 distinct families, of which the Lamiaceae are the most commonly used. The most used parts of plants are leaves. The most common mode for therapeutic preparations was infusion. The most frequently plant used was *T. munbyanus* with 1.07 following by *Allium cepa* was with 0.69 of use value, respectively. The highest fidelity level was recorded for *Petroselinum crispum* with 100% for treatments of cardiovascular diseases, follow by *Inula viscosa* with 86% for gastrointestinal diseases. The informant consensus factor varies from 0.75 to 0.96 and gastrointestinal diseases with 0.96 represented the highest informant consensus factor.

***Keywords***: Algeria, Ain Defla, Ethnobotanical, Medicinal plants, Therapeutic value

Throughout the world, plants have always been used as medicines. These herbal drugs are considered to be low in toxicity; mild compared to pharmaceutical drugs and also considered to be a promising source of bioactive compounds. In the absence of a modern medical system, medicinal plants still considered as a source of medical aid in developing countries. Pharmaceutical industries have an increasingly interested in ethnobotanical studies (Dibong et al 2011). More than 80% of the world's population use medicinal plants to deal with health problems and for the treatment of pain (Vital and Rivera 2009, Agisho et al 2014). Algeria is one of the Mediterranean countries that encompass considerable natural resources distributed in different ecosystems with considerable botanical diversity. This richness has aroused the curiosity of several researchers strengthening ethnobotanical research with the aim of listing medicinal plants and traditional recipes as well as the elaboration of a traditional Algerian pharmacopoeia including herbal medicines (Rebbas et al 2012, Boudjelal et al 2013, Miara et al 2013, Meddour and Meddour-Sahar 2015, Benarba et al 2015, Chermat and Gharzouli 2015, Lakhdari et al 2016, Ouelbani et al 2016, Miara et al 2019). The published literature examination indicates that in Ain Defla Province no ethnobotanical investigation has been conducted so far. In order to improve the ethnobotanical knowledge for the country, our opinion is that the present study is needed. The soil, topography and climatic conditions have favoured much diversified vegetation in the region of Ain Defla. This region has plants likely to provide active ingredients used in different fields for their properties: therapeutic (phytotherapy), fragrant (cosmetics), pharmaceutical (aromatherapy) and gustatory properties (diet therapy). However, the richness remains little explored, similarly describing to the use of medicinal plants and their traditional therapeutic importance. The objectives of the study were to: make accessible the ethnobotanical study outcome, promote crop growing medicinal plants as local flora, and to establish the importance of traditional medicine, and acquire ample information on their therapeutic uses.

## MATERIAL AND METHODS

**Study area:** Province of Ain Defla, located in the southwest of Algeria, at 145 km from the capital Algiers, with an area of 4544.28 km², situated in a longitude between 1 31' 30''E and 2 37' 38''E, at a latitude between 35 51' 27''N and 36 27' 19''N. Inhabitants of ten municipalities (Ain Defla, Bourached, Bathia, Rouina, Arib, El Abadia, Khemis, El Mekhatria, El Amra and El Attaf) participated in study. Ain Defla geographical localization is between the coastal region and the highlands, joining the western and eastern regions of the country. Ain Defla bounded to the following provinces: to the north Tipaza, northeast Blida, east Medea, west Chlef and south Tissemssilt (Fig. 1). The climate is semi-arid with harsh winters and dry hot summers with temperatures ranging from 46°C in July to 0°C in January (DWR, Ain Defla 2021).

**Ethnobotanical surveys:** The survey was carried out over a two-year period (2019-2021), established through a face-to-face interviews with the native population in public places frequented by the people. Prior to conducting the interview process, interviewee was verbal informed and confidentiality consent was obtained from each interviewer. Targeting informants with strong ethno-medicinal knowledge is important to enhance this kind of studies (Faruque et al 2019). The feedback form contains two parts, the first part includes the demographic characteristics of the informants (gender, age, family status, educational level), whereas, the second part focused on the use of medicinal plants, which incorporated plants names and types, plants parts used, preparation methods, use and treated diseases. The plants were collected after each interview for identification, reference specimens were deposited in the herbarium of the university. Botanical identification of the specimens was carried out using keys published by Quezel and Santa (1962). The nomenclature has been updated according to the synonymic index of North Africa (Dobignard and Chatelain, 2010), the African Plant Database http://africanplantdatabase.ch and www.theplantlist.org

**Data analysis:** Ethnobotanical data were analysed using various quantitative indices described further down frequently used in similar studies. (Kaval et al 2014, Zashim Uddin and Abul Hassan 2014, Eddouks et al 2016, Ouelbani et al 2016, Bulut et al 2017, Kidane et al 2018, Miara et al 2019, Nguyen et al 2019, Tefera and Kim 2019, Jadid et al 2020).

**Use value (UV):** indicates the relative importance of each plant species to the local population of the study area. Calculated according to the equation

$$\mathrm{UV} = \sum \frac{\mathrm{U}}{\mathrm{N}}$$

Where: UV corresponds to the use value of the species, U the number of citations per species; N: the total number of informants (Trotter and Logan 1986).

**Fidelity level (FL):** The level of fidelity is used to identify the species most frequently used by informants for a particular healing process. Calculated by the equation

$$\mathrm{FL}(\%) = \frac{\mathrm{Np}}{\mathrm{N}} \times 100$$

Where: Np is the total number of informants who listed the use of the plant to treat a particular illness and N is the total number of informants citing the plant as a medicine to treat any given disease (Friedman et al 1986).

**Informant Consensus Factor (ICF):** ICF determine the levels of consistency between the information provided by informants regarding the use of particular plants. Calculated

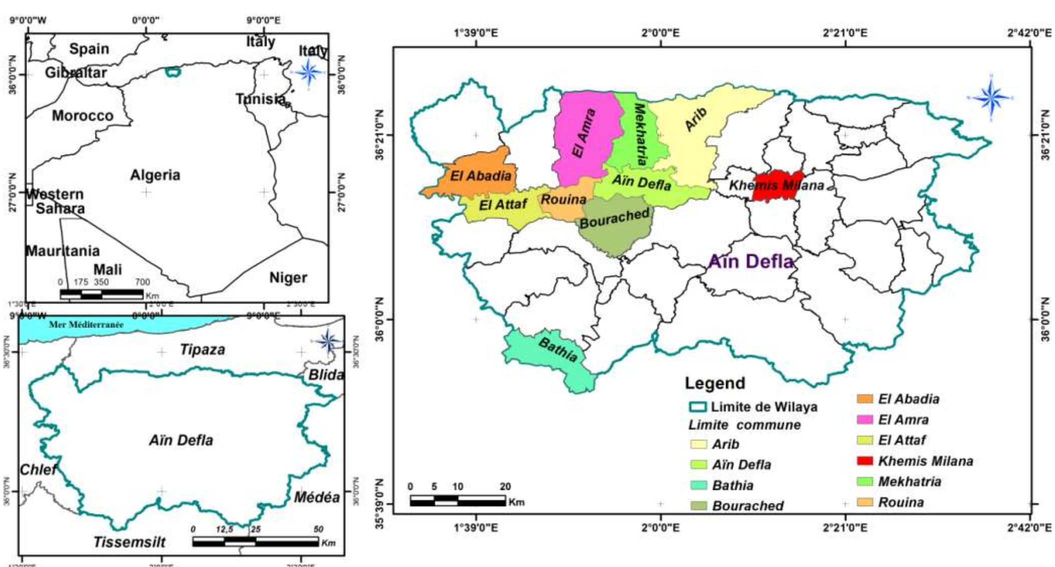


**Fig. 1.** Location of the study area Ain Defla Province, Algeria

according to the equation

$$ICF = \frac{(Nur - Nt)}{(Nur - 1)}$$

Where: Nur is the number of citations used in each category and Nt is the number of species used (Trotter and Logan 1986).

The ICF values are between zero and one. If the ICF value is close to zero, this explains why the plants are chosen at random or the informants do not exchange information on their use in the treatment category in question. A high value (close to one) indicates that there is a well-defined selection criterion in the community and/or if a large proportion of informants quote the information (Morvin Yabesh et al 2014).

## RESULTS AND DISCUSSION

**Demographics:** the demographic characteristics outcomes for individuals obtained during the investigation are shown in Table 1.

**Medicinal plants quoted by interviews:** Based on 180 completed questionnaires, an ethnobotanical catalogue was assembled (Table 2). The botanical analysis includes 65 plant species distributed into 33 botanical families. The Lamiaceae family (thirteen species) dominates the list, represented mostly by *T. munbyanus*, *O. vulgare*, *R. officinalis* and *M. pulegium*, followed by the Asteracea family (with seven species) represented mostly by *I. viscosa* and *A. absinthium* (Fig. 2).

**Part of the plant and method of preparation:** Plant parts used were quoted by the interviewed, underground part (roots, bulbs), and aerial part (leaves, stems, seeds, flowers, bark). However, the leaves represent the plant organ most used by the interviewed, with a rate exceeding 40% followed by other aerial parts (15.29%). Fruits and seeds register a relatively similar rate (12.94%) and (11.76%) respectively, followed by flowers and stems with a rate of 5.88%. Other parts, use of, bark, bulb and roots were quoted less than 4% (Fig. 3). The curative preparation modes are indicating in Figure 4. The infusion mode is the most used with a rate of 52.29%, followed by decoction (19.27%) and the cataplasm mode comes in third position (14.68%).

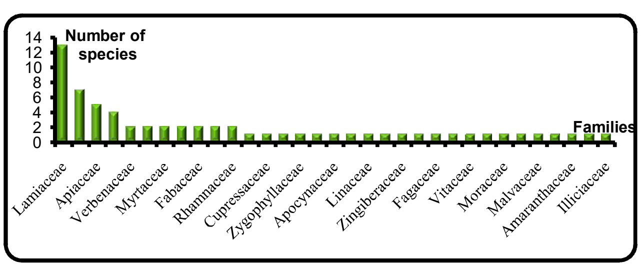


**Fig. 2.** Botanical families of medicinal plants and number of species

**Table 1.** Distribution of demographic characteristics age, gender and educational level

| Demographic characteristics | Number | % |
|---|---|---|
| Age | | |
| Less than 20 years | 8 | 4.44 |
| 20-40 years | 100 | 35.00 |
| 40-60 years | 63 | 55.56 |
| More than 60 years | 9 | 5.00 |
| Gender | | |
| Men | 108 | 60.00 |
| Women | 72 | 40.00 |
| Educational level | | |
| Primary | 5 | 2,78 |
| Secondary | 81 | 45.00 |
| University | 94 | 52.22 |

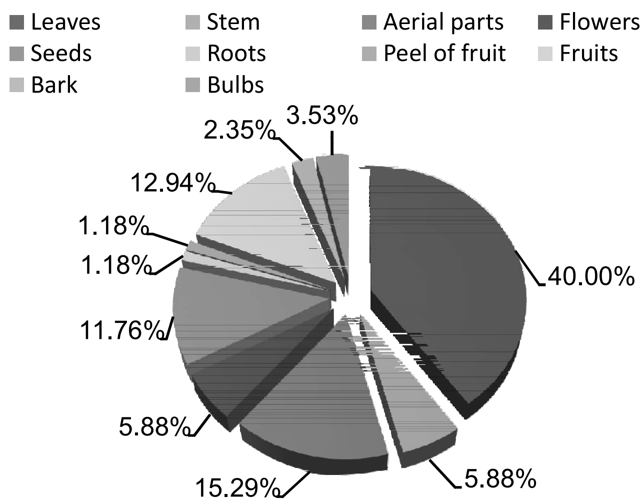


**Fig. 3.** Plant parts used in Ain Defla provimce

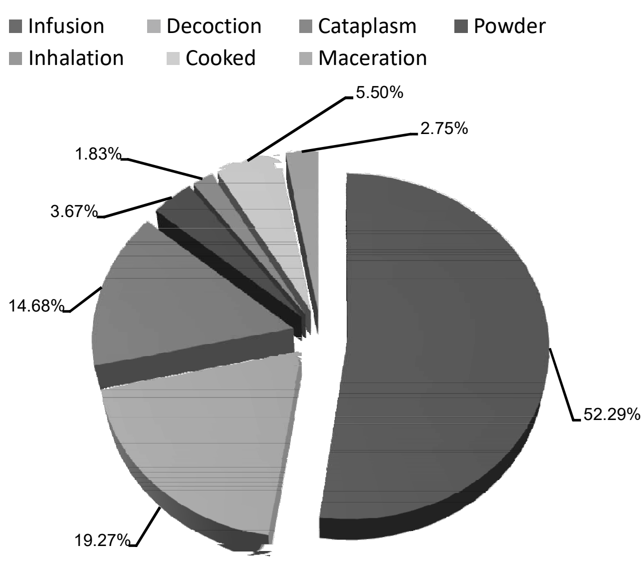


**Fig. 4.** Methods used in Ain Defla province

**Table 2.** Medicinal plants commonly used in Ain Defla region

| Species/voucher specimens | Family | Vernacular name | Part used | Preparation | Disease treated | UV |
|---|---|---|---|---|---|---|
| *Ajuga iva* L. [ZK-10] | Lamiaceae | Chendgoura | Aerial parts | Infusion | Digestive problems, eczema, antidiabetic, allergies | 0.10 |
| *Allium cepa* L. [ZK-32] | Amaryllidaceae | Basla | Bulbs | Infusion, cooked | Hypertension, hair loss, constipation respiratory problems, wounds anti-inflammatory | 0.69 |
| *Allium sativum* L. [ZK-31] | Amaryllidaceae | Thoume | Fruits | Decoction, cataplasm, cooked, maceration | Hypertension , hair loss, anti-inflammatory, cholesterol | 0.49 |
| *Anthemis cotula* L. [ZK-40] | Asteraceae | Okhouane | Flowers | Infusion, cataplasm | Rheumatism | 0.06 |
| *Anthemis nobilis* L. [ZK-38] | Asteraceae | Babounedj | Flowers | Infusion, cataplasm, maceration | Heart diseases, respiratory diseases | 0.06 |
| *Apium graveolens* L. [ZK-45] | Apiaceae | Krafess | Aerial parts | Infusion | Rheumatism, digestive problems | 0.15 |
| *Artemisia absinthium* L.[ZK-39] | Asteraceae | Chajrat Meriam | Leaves, stems | Infusion, decoction | anti-inflammatory, digestive, hypertension | 0.33 |
| *Beta vulgaris* L. [ZK-56] | Amaranthaceae | Chamandar | Bulbs | Infusion | Anaemia, digestive | 016 |
| *Bunium elatum* (Batt.) Batt. [ZK-42] | Apiaceae | Talghouda | Aerial parts | Infusion | Intestinal gas, goiter | 0.06 |
| *Ceratonia siliqua* L. [ZK-46] | Fabaceae | Kharoub | Leaves | Decoction | Rheumatism, cardiovascular disorders | 0.18 |
| *Chamaerops humilis* L. [ZK-54] | Arecaceae | El doume | Leaves, stem | Infusion | Anti-tumour | 0.01 |
| *Citrus limon* L. [ZK-24] | Rutaceae | Laymoun | Fruits | Infusion | Cough, digestive problems, influenza | 0.21 |
| *Coriandrum sativum* L. [ZK-41] | Apiaceae | Kosbar | Leaves, stem | Infusion | Intestinal gas, anaemia, nervous disorders | 0.27 |
| *Cydonia oblonga* Mill. [ZK-63] | Rosaceae | Sfarjel | Leaves, fruits | Infusion | Diarrhoea, cholesterol | 0.08 |
| *Echinops spinosus* L. [ZK-36] | Asteraceae | Tasekra | Leaves | Decoction | Digestive, diabetes | 0.05 |
| *Eucalyptus globulus* Labill. [ZK-27] | Myrtaceae | Kalitouss | Leaves | Infusion, decoction, inhalation | Respiratory problems, cough, fever | 0.17 |
| *Ficus carica* L. [ZK-57] | Moraceae | El karma | Fruits | Infusion | Diarrhoea, anaemia | 0.07 |
| *Foeniculum vulgare* Mill. [ZK-44] | Apiaceae | Besbas | Fruits, seeds | Infusion | Digestive problems, heart problems, colon pain | 0.25 |
| *Hordeum vulgare* L. [ZK-59] | Poaceae | El chaâire | Seeds | Infusion, decoction, maceration | Diabetes, anaemia, diarrhoea, kidney disorder | 0.35 |
| *Illicium verum* Hook. F. [ZK-14] | Schisandraceae | Najmat l-ard | Seeds | Infusion | Nervous system disorder, colon pain | 0.04 |
| *Inula viscosa* L. [ZK-37] | Asteraceae | Magramane | Leaves, flowers | Infusion, decoction | Headache, diarrhoea | 0.42 |
| *Juniperus phoenicea* L. [ZK-21] | Cupressaceae | Aârâr | Aerial parts, leaves, fruits | Infusion, decoction | Rheumatism, antiseptic | 0.12 |
| *Laurus nobilis* L. [ZK-23] | Lauraceae | Rand | Leaves | Infusion, decoction | Carminative, antiseptic, hypertension | 0.12 |
| *Lavandula officinalis* L. [ZK-03] | Lamiaceae | El khozama | Leaves | Infusion, decoction, cataplasm | Cholesterol, relieves pain, digestive problems, diarrhoea | 0.06 |

***Cont...***

**Table 2.** Medicinal plants commonly used in Ain Defla region

| Species/voucher specimens | Family | Vernacular name | Part used | Preparation | Disease treated | UV |
|---|---|---|---|---|---|---|
| *Lavandula stoechas* L. ZK-08 | Lamiaceae | Halhal | Leaves | Infusion | Antispasmodics nervous, cholesterol | 0.12 |
| *Lepidium sativum* L [ZK-50] | Brassicaceae | Haberr-achad | Leaves, seeds | Infusion | Rheumatism, hypoglycaemia | 0.08 |
| *Linum usitatissimum* L. [ZK-30] | Linaceae | Zarriât elkatane | Seeds | Infusion, inhalation | Digestive problems, cholesterol, diabetes | 0.21 |
| *Lippia citriodora* L. [ZK-19] | Verbenaceae | Lwiza | Leaves | Infusion | Influenza, nervous disorder, colds, constipation | 0.21 |
| *Malva sylvestris* L. [ZK-49] | Malvaceae | El Khobbeiz | Aerial parts | Infusion, cataplasm, cooked | Abdominal pains, constipation, urinary diseases | 0.18 |
| *Marrubium vulgare* L. [ZK-04] | Lamiaceae | Timaryout | Aerial parts | Infusion, decoction, cataplasm | Cold, cough, fever, antidiabetic, allergies, hypertension | 0.08 |
| *Mentha pulegium* L. [ZK-13] | Lamiaceae | Fliou | Leaves | Infusion | Anti-hypertensive, antispasmodic, diarrhoea | 0.23 |
| *Mentha spicata* L. [ZK-02] | Lamiaceae | Naanaa | Aerial parts | Infusion, cataplasm | Headaches, muscle pains, colds, digestive problems, hypertension, sedative, nervous disorders | 0.18 |
| *Myrtus communis* L. [ZK-28] | Myrtaceae | Errayhane | Leaves | Cataplasm | Digestive disorders, hypertension , allergies, eczema | 0.13 |
| *Nerium oleander* L. [ZK-26] | Apocynaceae | Defla | Leaves | Cataplasm | Skin rashes, respiratory problems | 0.10 |
| *Ocimum basilicum* L. [ZK-12] | Lamiaceae | Lahbaq | Leaves | Infusion | Antibacterial, influenza antitumor, hypertension | 0.24 |
| *Olea europaea* L. subsp *europea* [ZK-21] | Oleaceae | Zitoune | Leaves, fruits | Infusion, cataplasm | Heart disease, diabetes, cholesterol | 0.18 |
| *Opuntia ficus-indica* L. [ZK-58] | Cactaceae | El hendi | Leaves, fruits | Cataplasm | Diarrhoea, hair problems | 0.10 |
| *Origanum majorana* L. [ZK-11] | Lamiaceae | Mardkouche | Flowers, stem | Infusion | Hypertension, rheumatism pain, diabetes | 0.13 |
| *Origanum vulgare* subsp. *glandulosum* (Desf.) Ietsw. [ZK-09] | Lamiaceae | Zaâter | Aerial parts | Infusion, decoction | Eczema, hypertension, digestive problems, respiratory problem, antispasmodic, cold, antitumor | 0.56 |
| *Papaver rhoeas* L. [ZK-52] | Papaveraceae | Benaâmane | Flowers | Infusion | Digestive, antispasmodics, pulmonary diseases | 0.12 |
| *Paronychia argentea* Lam. [ZK-55] | Caryophyllaceae | Fatat lahjar | Leaves | Infusion | Kidney disorders | 0.02 |
| *Peganum harmala* L. [ZK-22] | Zygophylaceae | Harmel | Leaves | Decoction | Antispasmodic, respiratory problems, pains | 0.09 |
| *Petroselinum crispum* (Mill.) Fuss.[ZK-43] | Apiaceae | Maâdnousse | Aerial parts | Infusion | Hypertension, cholesterol | 0.31 |
| *Pinus halepensis* Mill. [ZK-29] | Pinaceae | Sanawber | Leaves, bark | Infusion, cataplasm | Antiseptic, wounds, urinary problems, respiratory problems, skin affections | 0.23 |
| *Pistacia lentiscus* L. [ZK-33] | Anacardiaceae | Edhrw | Leaves, seeds | Infusion, cataplasm | Digestive problems, antiseptic, rheumatism, antispasmodic | 0.19 |

***Cont...***

**Table 2.** Medicinal plants commonly used in Ain Defla region

| Species/voucher specimens | Family | Vernacular name | Part used | Preparation | Disease treated | UV |
|---|---|---|---|---|---|---|
| *Prunus armeniaca* L. [ZK-61] | Rosaceae | El michmiche | Fruits, seeds | Infusion, cooked | Digestive, anaemia | 0.04 |
| *Prunus persica* L. Batsch [ZK-62] | Rosaceae | Khoukhe | Fruits, seeds | Infusion, cooked | Heart diseases, constipation | 0.06 |
| *Punica granatum* L. [ZK-18] | Lythraceae | Romane | Peel of fruit | Infusion, powder | Gastric problem, anaemia, pain | 0.19 |
| *Quercus ilex* subsp. *ballota*(Desf.) Samp. [ZK-51] | Fagaceae | Balloute | Fruits, barks | Infusion, decoction | Anti-diarrheic, urinary problems, pains | 0.23 |
| *Rhamnus alaternus* L. [ZK-16] | Rhamnaceae | M'liles | Leaves, Aerial parts | Infusion, decoction | Cholesterol, anaemia, diarrhoea, rheumatism | 0.26 |
| *Rosmarinus officinalis* L. [ZK-01] | Lamiaceae | Eklile | Aerial parts | Infusion, decoction, cataplasm, cooked, maceration | Hypertension, diabetes, cholesterol, teeth pain | 0.26 |
| *Rubus ulmifolius* Schott. [ZK-64] | Rosaceae | El Aallaigue | Leaves | Infusion, decoction | Anti-inflammatory, diarrhoea | 0.08 |
| *Ruta chalepensis* L. [ZK-25] | Rutaceae | Fidjel | Leaves | Infusion, decoction | Antispasmodic, diabetes, respiratory problems | 0.16 |
| *Salvia officinalis* L. [ZK-06] | Lamiaceae | Marimya | Leaves | Infusion, cataplasm | Hypertension, cholesterol, wounds, pains, digestive, rheumatism, vomiting, hair loss, colon pains | 0.22 |
| *Scolymus hispanicus* L. [ZK-34] | Asteraceae | El garnina | Leaves | Cooked | Diabetes, digestive problems | 0.08 |
| *Scorzonera undulata* Vahl. [ZK-35] | Asteraceae | El talma | Aerial parts | Infusion | Urinary problems, digestive problems | 0.04 |
| *Teucrium polium* L. [ZK-05] | Lamiaceae | Elkhayata | Leaves | Infusion, cataplasm | Diabetes, digestive, wounds | 0.07 |
| *Thymus munbyanus* subsp.*coloratus* (Boiss. & Reut.) [ZK-07] | Lamiaceae | Zâaitra | Leaves, stem | Infusion | Diabetes, hypertension, digestive, colds rheumatism, influenza, | 1.07 |
| *Trigonella foenum-graecum* L. [ZK-47] | Fabaceae | Elhalba | Seeds | Infusion, decoction, powder | Appetite, anaemia, stomach pains | 0.28 |
| *Triticum durum* Desf. [ZK-60] | Poaceae | El kamh | Seeds | Infusion | Anaemia, digestive | 0.05 |
| *Urtica urens* L. [ZK-15] | Urticaceae | Horeig | Leaves, roots | Infusion, decoction | Rheumatism, hair loss anaemia | 0.26 |
| *Verbena officinalis* L. [ZK-20] | Verbenaceae | Verveine | Aerial parts | Infusion | Pains, colds | 0.13 |
| *Vitis vinifera* L. [ZK-53] | Vitaceae | El dalya | Leaves | Infusion, decoction | Digestive problems, rheumatism pain , hypertension | 0.36 |
| *Zingiber officinale* Roscoe. [ZK-48] | Zingiberaceae | Zandjabil | Bulbs | Infusion, powder | Cholesterol, calm stomach, hypertension, anti-rheumatism | 0.31 |
| *Ziziphus lotus* (L.) Lam. [ZK-17] | Rhamnaceae | Sedra | Leaves | Infusion, powder | Pulmonary diseases rheumatism | 0.14 |

**Use value (UV):** UV fluctuate from 0.01 to 1.07. *T. munbyanus* and *A. cepa* are the most important species with UV 1.07 and 0.69, respectively, followed by *O. vulgare*, *A. sativum* and *I. viscosa* with UV of 0.56, 0.49 and 0.42 respectively (Table 2).

**Fidelity level (FL):** FL was calculated for the most quoted the plants by the interviewed (10 species) (Table 3). Highest FL (100%) was for *P. crispum* for treatment of cardiovascular diseases, following by *A. sativum* (64.77%) and *Z. officinale* (61.82%). The FL value of 86% was for *I. viscosa* used for gastrointestinal diseases followed by *A. cepa* (60.00%), *H. vulgare* (50.79%) and *T. munbyanus* (41.45%). *O. vulgare* records a relatively similar FL value of 26.73 and 24.75%, for the treatment of gastrointestinal diseases and influenza respectively. To treat head pain and rheumatism *V. vinifera* and *A. absinthium* are most quoted with a FL of 36.67%.

**Informant consensus factor (ICF):** The ICF values calculated for diseases treated by the native population of the study area d ranged from 0.75 to 0.95 indicating the concordance of the use of these plants in the use categories (Table 4). The highest value (ICF = 0.95) was reported for gastrointestinal disorders (842 use ratios with 46 species), the most cited of which are *T. munbyanus*, *A. cepa* and *I. viscosa*. The same value is recorded for cardiovascular diseases treated with 27 species where the most frequently used were *A. sativum* and *P. crispum*. Diabetes is treated with 12 species, the most widely used of which is *T. munbyanus*. Eight other species used by interviews for the treatment of influenza and colds with ICF = 0.91 of which the most cited is *O. vulgare*. Headaches, respiratory tract infection and Colds are treated with 25 species and the most cited is *A. absinthium* with an ICF value = 0.90. Renal disorders, respiratory and dermatological disorders record the same value (ICF = 0.89). The latter are treated with 2, 10 and 11 species, respectively the most used of which are *H. vulgare* (Renal diseases), *P. halepensis*, *E. globulus* (respiratory diseases) and *U. urens* (dermatological disorders). Other categories such as tumours, anaemia and nervous problems record FIC values of 0.75, 0.77 and 0.79, respectively.

Ain Defla inhabitants have familiarity and interest in the use of medicinal plants. We recorded the predominance of men as high proportion of interviewed; it is in agreement with previous Algerian studies (Boudjelal et al 2013, Miara et al 2019). Similar remarks were reported from Turkey (Kaval et al 2014; Polat et al 2015). Traditional roots could explain the predominance of men. As in most Mediterranean societies,

**Table 4.** Category of ailments and their respectively values for Informant Consensus Factors (ICF)

| Categories of ailments | Nur | Nt | ICF |
|---|---|---|---|
| Gastrointestinal disorders | 842 | 46 | 0,95 |
| Cardiovascular disorder | 491 | 27 | 0,95 |
| Diabetes | 162 | 12 | 0,93 |
| Influenza and Rheum | 94 | 9 | 0,91 |
| Pain, headaches and rheumatism | 249 | 25 | 0,90 |
| Respiratory disorder | 86 | 10 | 0,89 |
| Renal disorders | 10 | 2 | 0,89 |
| Dermatological disorders | 123 | 15 | 0,89 |
| Nervous system | 20 | 5 | 0,79 |
| Anaemia | 40 | 10 | 0,77 |
| Tumours | 5 | 2 | 0,75 |

**Table 3.** Category of ailments, plants and their respectively values for the fidelity level (FL) for the most cited plants (10 species)

| Category of ailments | Plants | Np | N | FL (%) |
|---|---|---|---|---|
| Gastrointestinal disorders | *Inula viscosa* | 65 | 75 | 86.67 |
| | *Allium cepa* | 75 | 125 | 60.00 |
| | *Hordeum vulgare* | 32 | 63 | 50.79 |
| | *Thymus munbyanus* | 80 | 193 | 41.45 |
| | *Vitis vinifera* | 20 | 65 | 30.77 |
| | *Origanum vulgare* | 27 | 101 | 26.73 |
| Influenza and Rheum | *Origanum vulgare* | 25 | 101 | 24.75 |
| Cardiovascular disorder | *Petroselinum crispum* | 56 | 56 | 100.00 |
| | *Allium sativum* | 57 | 88 | 64.77 |
| | *Zingiber officinale* | 34 | 55 | 61.82 |
| | *Artemisia absinthium* | 21 | 60 | 35.00 |
| | *Origanum vulgare* | 21 | 101 | 20.79 |
| | *Allium cepa* | 25 | 125 | 20.00 |
| | *Vitis vinifera* | 13 | 65 | 20.00 |
| Pain, headaches and rheumatism | *Artemisia absinthium* | 22 | 60 | 36.67 |
| | *Vitis vinifera* | 32 | 65 | 49.23 |
| Dermatological disorder | *Allium sativum* | 21 | 88 | 23.86 |
| Diabetes | *Hordeum vulgare* | 21 | 63 | 33.33 |

traditional gender norms define women's role as basically relegated to the indoor duties this could create difficulties to communicate with women. Never the less other Algerian studies reported predominance of women (Benderradji et al 2014, Ramdane et al 2015, Negi et al 2020). Similar observations were reported for Morocco and Italy (Idm'hand et al 2020, Vitalini et al 2015). In present study, the dominant age is between 40 and 60 years (55.56%), in the same way other Algerian study (Miara et al 2019) indicated (50.98%) for age between 46 and 65 years. The majority of informants have a university level. Despite the fact, in other studies, authors reported the predominance of illiterate people, and few studies recorded the dominance of the primary level (Eddouks et al 2016, Lee et al 2018, Hu et al 2020). The 65 medicinal plant species were observed in Ain Defla province of 33 botanical families, with the highest rate of Lamiaceae with 13 and Asteraceae with seven species respectively. This agreed with previous Algerian studies conducted in Tizi-Ouzou province, were 98 plants were reported distributed in 48 families, Lamiaceae with 13 and Asteraceae with 12 species respectively (Meddour and Meddour-Sahar 2015). Likewise in M'Sila province, were documented 58 species fitting to 27 families, Lamiaceae (22.4%) and Asteraceae (20.7%) (Boudjelal et al 2013). In Algerian steppe (Miara et al 2018), recognized 97 species were found belonging to 42 families with the highest rate of Lamiaceae (18%) and Asteracea (15%). Studies on Hoggar province by Ramdane et al (2015) reported Lamiaceae as (35%) followed by Asteraceae (12%). In North-eastern and southern Algeria (Sahara) Chenopodiaceae was reported as dominant (Chermat and Gharzouli 2015)

In Italy and Spain, dominance of Asteraceae was reported, (Vitalini et al 2015, Rigat et al 2015, Negi et al 2020). For other geographical regions, authors reported the dominance of other families (Nizar et al 2015, Tefera and Kim 2019, Prabhu et al 2020, Yebouk et al 2020) indicated the dominance of the Fabaceae.

Leaves are the part most used. This is in agreement with previous ethnobotanical studies (Adnan et al 2014, Benderradji et al 2014, Sher et al 2015, Ouelbani et al 2016, Eddouks et al 2016, Debnath and Das 2019, Nguyen et al 2019, Tefera and Kim 2019, Yebouk et al 2020, Johnny et al 2022). The regular use of leaves could be explained for the reason that leaves are not difficult to see and are of quickly harvesting, medicines prepared with leaves could rapidly relieve ailments, photosynthesis take place in leaves and are storage for secondary metabolites with biological properties (Raterta et al 2014). Preparation methods may differs in other countries; e. g. in India Hu et al 2020, indicated use of the whole plant and in Spain Rigat et al (2015) reported flowering parts.The method commonly used is infusion. The present finding agreed with previous botanical surveys conducted in Algeria and other regions of the world (Ouelbani et al 2016, Bulut et al 2017, Miara et al 2019). Additionally large numbers of other methods such as decoction have been reported (Eddouks et al 2016, Lee et al 2018, Hu et al 2020, Mownika et al 2021, Johnny et al 2022).

The present study reported *T. munbyanus* with highest UV, this medicinal plant is little known in other regions, even though in the province of Ain Defla is frequently used against diabetes, blood pressure, deworming and stomachic. *A. cepa* traditionally used in Algeria for the treatment of cutaneous diseases, respiratory disorders, digestive problems, hair loss, hypertension and anti-inflammatory. Moreover in Adrar (south western Algeria) is utilized against back throbbing, skin injury and musculoskeletal illness (Yebouk et al 2020). In Spain, is used for cosmetologically, external antiseptic and antitoxic (Rigat et al 2015). In Mediterranean region *O. vulgare* is used; against rheumatic pain, antitumor, eczema, digestive problems, respiratory problems and antihypertension, Miara et al (2019) identical use in Bordj Bou Arreridj (highland region North-eastern Algeria). In Spain, is used against stomach upset, diarrhoea, enterobiasis, to heal wounds, sore throat, influenza, and to treat inflammation of the mucous membranes (Rigat et al 2015). The highest FL is recorded for *P. Crispum* for treatment of cardiovascular disease, this is a unique result not previously reported, probably could be explained as this species is specific for Ain Defla. *A. sativum* displayed FL of 64.77%, used for hypertension and also, used in Italy for high blood pressure (Vitalini et al 2015). In Morocco used against microbial infections Eddouks et al (2016), reported FL of 64 % for this plant and 61.81% for *Z. officinale*. In India (Hu et al 2020) mentioned 100% FL for *Z. Officinale* used for treatment of cough. *H. vulgare* account FL (33.33%). Other studies reported FL of 74.19% and 21.05% for treatment of renal disorders (Ouelbani et al 2016, Miara et al 2019). In terms of ICF, the highest value was for gastrointestinal and cardiovascular disorders (0.95), besides for diabetes (0.93), this agreed with other studies in Algeria, Morocco and Italy (Miara et al 2019, Eddouks et al 2016, Idm'hand et al 2020, Vitalini et al 2015).

## CONCLUSION

This is the first ethnobotanical study conducted in 10 municipalities of Ain Defla province, recording basic information on medicinal plants. The study identifies 65 plant species, distributed in 33 families, including *T. munbyanus* frequently used in Ain Defla, but little known in other regions. Numerous plants are used for alleviated different illnesses;

the most frequently cited are those associated with digestive and cardiovascular systems. Algerian inhabitants possess knowledge on medicinal plants growing in different regions, which are documented in previous studies, as well as in our study. The information collected in our study deliver elementary information on medicinal plants used by inhabitant of Ain Defla. The plant and the treatment for a specific disease we reported, should be investigated further involving, medicinal plants their bioactive compounds including phytochemical and pharmaceutical importance. The documented information could be useful for future research projects with the aim of establishing traditional pharmacopoeia.

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# Evaluation of Physiochemical Factors in Saffia Nature Reserve, Southern Iraqi Marshes, using Geographic Information System Techniques

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***Abstract:*** This survey was conducted during four seasons in nine stations representing the Saffia Nature Reserve (SNR) in Al-Hawizeh marsh, southern Iraq, which has 44 $km^2$. Physical and chemical parameters were monitored; including natural water quality parameters such as water temperature, pH, electric conductivity and dissolved oxygen in addition to levels of nutrients from September 2019 to August 2020. The current study discussed the possible use of spatial analysis techniques to characterize the temporal and spatial distribution of water prediction properties employing geographic information systems (GIS) to determine water quality parameters at SNR. In general, all parameters are within the acceptable limit of freshwater for aquatic life except electric conductivity. The current survey could serve as a basis for more monitoring and restoration of the marshland environment. The use of a geographic information system in evaluating the water quality depends on the laboratory values of water samples and spatial analysis of these properties employing inverse interpolation of the weighted distance. It was possible to map water quality indicators along the study area for nine sites and six water quality indicators. The production of water quality maps will improve monitoring and enforcement of standards and regulations for better management and control. This study suggested continuous monitoring of the physical and chemical characteristics of water marshes and water bodies, and the study of factors affecting the increase in the concentration of elements and nutrients and comparing them with environmental determinants.

***Keywords***: Physiochemical factors, Saffia Nature Reserve, Geographic Information System Techniques

Environmental studies occupy a vital space between basic, applied, and human sciences due to the occurrence of various processes between humans and ecological activities. Increasing pressure on natural resources raised great interest in evaluating, protecting, and maintaining ecosystems to become the foundations for future development processes (Al-Asadi and Maatouk 2013). With growing population growth and economic development, wetlands around the world are now decreasing and degrading (Davidson 2014, Dixon et al 2016). It is also reasonable to acknowledge wetlands as an indispensable resource for humans. In the Middle East and Western Europe, the Mesopotamian Marshlands are among the largest water bodies (Hussain et al 2012) as they occupied a wide area in southern Iraq, where the marshes of southern Iraq are considered to be the gardens of Aden on earth cos of their distinguishing characteristics and their beauty in a beautiful and picturesque environment. The marshes are considered a place for the emergence of the earth (Khalaf and Almukhtar 2005). The marshes of Mesopotamia are also classified as one of the largest bird and fish-rich natural reserves in the world, as there are reeds, sedge plants in the marshes but those plants in the marshes are considered to be among the most important areas for birds, their livelihoods, shelter and migration from different parts of the world (Kowais 2005). The Mesopotamian marshes consist of three large marsh complexes in Southwest Asia, including three main areas in the north, the Hawizeh Marsh, in the middle, the Central Marsh (Chibayish), and the Hammar Marshlands in the south, all of which are rich in natural resources and biodiversity. A unique wetland in the world during the forty sessions of the World Heritage Committee according to the third and fifth cultural criteria and the ninth and tenth natural standards in Istanbul in 2016. The conservation of invasive species, the most significant of which is the Convention on Biological Diversity, signed at the 1992 Earth Summit. The nature reserves are considered a natural center for researchers, university, and graduate students and exploit existing living organisms to conduct various scientific and medical studies and space for scientific experiments.

Water is the basic requirement of all species on the earth. Surface water tends to be an important water source because of the rise in its consumption for drinking, irrigation, water supply, and industrial uses, etc., a necessary resource is required. Rises in the agricultural and industrial sectors need more freshwater (Chen et al 2019). In order to assess the quality of water, it is necessary to specify the information on the state of water quality and to recognize factors that impact the effectiveness of water as well as the critical locations within the catchment. This can be accomplished by collecting water samples and then measuring the physical and chemical parameters at different sites in the research area (Ogbozige et al 2018).

GIS is necessary for the analysis of water bodies, to restore and manage water resources, including spatial and temporal data for all water sources, and to provide an effective database for a computer to store, manipulate and analyze data. For the past 30 years, GIS was used globally to obtain the requisite information to control different water bodies worldwide. Together with computer simulations, remote sensing and GIS software are effective tools to provide a solution for future management of the water sources, especially water quality control plans.

## MATERIAL AND METHODS

**Study Area:** Al-Hawizeh Marsh is currently located within the southeastern part of the alluvial plain, precisely before the Tigris River meets the Euphrates River at Al-Qurna, and administratively it follows the northern part of the marsh to Maysan Governorate. In contrast, the southern part follows the Basrah Governorate. The total area of the marsh in the flood season is more than 3500 km$^2$, and this area decreases to 650 km$^2$ during the Drought season, and the site of the marsh on the Iraqi side is up to 2350 km$^2$. About 1900 km$^2$ were re-flooded after 2003. The capacity of the marsh is 5896 million cubic meters, with a surface area of 1800 km$^2$ for a level of 7 meters above sea level. SNR is one of the largest reserves in Iraq (E: 47° 40.413 ', N: 31° 10.887'), located within Al-Saffia marsh, east of Al-Dasim marsh, is rectangular with an area of 44 km$^2$, length 11 km$^{2,}$ and width 4 km$^2$. A dam parallel to the border strip with the Iranian side and the west is a dam parallel to the border barrier, and it is connected with the Ajirda dam. SNR is one of the types of wetlands. It was established in 2006 by the Directorate of Agriculture in Basra Governorate to preserve biodiversity. Others, such as insects, crustaceans, and fish, especially during periods of migration, mating, and spawning as shown in Figure1. Locations of the sampling stations selected in the present study showed the most important sources of the Rivers, the source is the work of the researcher based on the administrative map of Iraq 1/1000000, the map of Basra Governorate 1/250000, and the USGS satellite map for the year 2021, using ArcMap Ver. 10.8.

**Water sample collection and analysis**: Water samples were collected from September 2019 to August 2020 from nine different stations in SNR, Al-Hawizeh Marsh (Fig. 1). The environmental variables, were recorded in the field, a standard thermometer for temperature within 10-100˚C, the potential of hydrogen ion (pH) and Electrical Conductivity (EC) (µs cm$^{-1}$) was measured by A Multiprobe type HANNA multimeter after calibrating the device before going to fieldwork with Buffer solutions, 4, 7 and 9, Milwaukee device to make the measurements of dissolved oxygen (mg L$^{-1}$). Water samples were taken from the field for the determination of $NO_3$ and $PO_4$ in the laboratory. Active nitrite $NO_3$ was measured according to American Public Health Association and active phosphate $PO_4$ by method of Strickland and Parsons (1976).

**Data map**: The base map of the study area is obtained by using ArcGIS 10.8 software. We pick WGS 1984 (Geographic Coordinate System) as a spatial reference map in the ArcGIS 10.8 program. Lastly, IDW was performed as an interpolation in spatial analyst. Interpolation is used to predict the value of attributes at un-sampled sites using values at locations within the same region

**Statistical analysis:** Data were statistically analyzed using Minitab ver.19, below the probability level of (0.05).

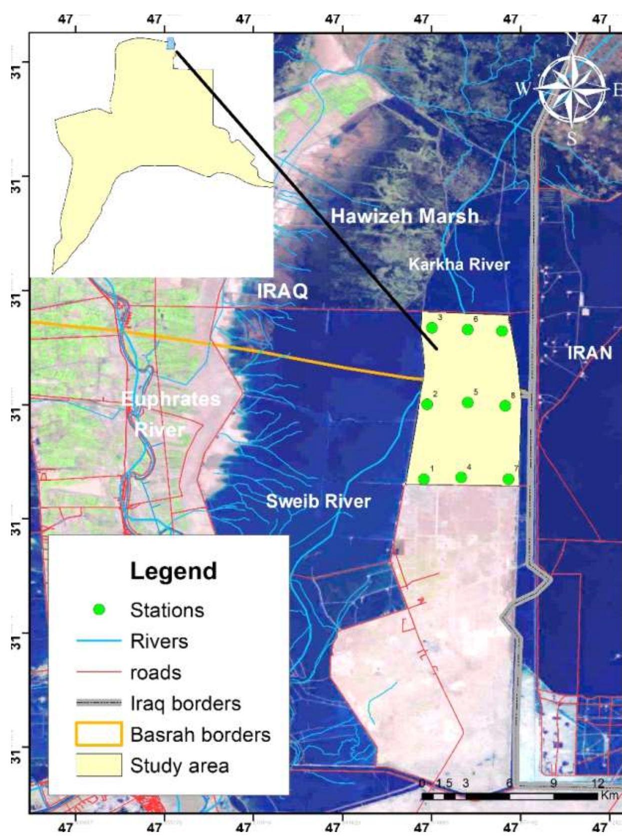


**Fig. 1**. Locations of the sampling stations selected in the present study and showing the most important sources of the Rivers

## RESULTS AND DISCUSSIONS

### Physical and Chemical Parameters

**Water temperatures:** The highest water temperature was 30.9°C in Station No.9 during the summer season, while the temperature decreased to its lowest levels in the winter season when it was 13.4°C in Station No. 3. Statistical analysis showed significant differences between seasons and no significant differences were observed between stations. This variation is due to the nature of the Iraqi climate in general, as thermal extremes characterize it, so it is hot and dry in the summer and cold and rainy in the winter may be to the intensity of solar radiation throughout the hours of the day, especially in the summer, slight differences or differences were recorded between the water temperatures on the surface and the lower layers inside the water column due to the shallow water in the marshes. This variation in water temperature helps in the abundance and growth of different species of organisms in the area (Douabul et al 2013). The local changes in water temperature may be due to the difference in the time of sampling, where the temperature is low in the early morning and then starts to rise as approach the middle of the day. In general, the waters of the marshes in southern Iraq is characterized by the difference in temperatures during the seasons of the year and this corresponds to the study of Al-Thahaibawi (2014) where the water temperature in the southern marshes ranged between 14.3 -35.6°C in winter and summer, respectively (Fig. 4 a-d). Mohammed (2010) in Al-Hammar marsh in southern Iraq observed that the temperature ranged from 15°C in February to 31°C) in August.

**Hydrogen ions (pH):** The pH value is one of the important measurements that determine water bodies' suitability for different purposes. It also plays a vital role in rivers (Al-Hassani et al 2006, Yousry et al 2009). The pH recorded in the present study was within a narrow range. They tended to be alkaline as it is common in Iraqi inland water due to Iraqi natural waters' with relatively high content of calcium bicarbonate (Fig. 4). The lowest pH values in the study area reached 7.8 in No.2 and No.6 during the summer season, while the highest was 8.7 in station No. 5 during the winter. There were significant differences between the seasons at the probability level as well as the presence of significant differences between the stations (Fig. 6 a-d). In the present study, alkalinity is the predominant characteristic of the water in the stations. These results are in agreement with the pH of freshwater in different regions of the world (Baudo and Beltrami 2001) as well as, with previous local studies on internal Iraqi waters (Hinton and Maulood 1980), The alkaline

**Fig. 2**. Saffia nature reserve

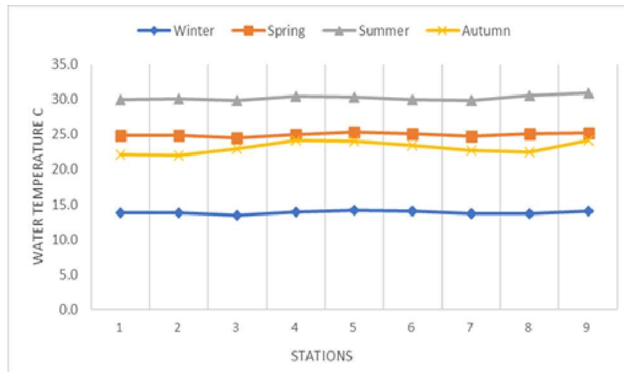


**Fig. 3.** Water temperature (°C) in SNR

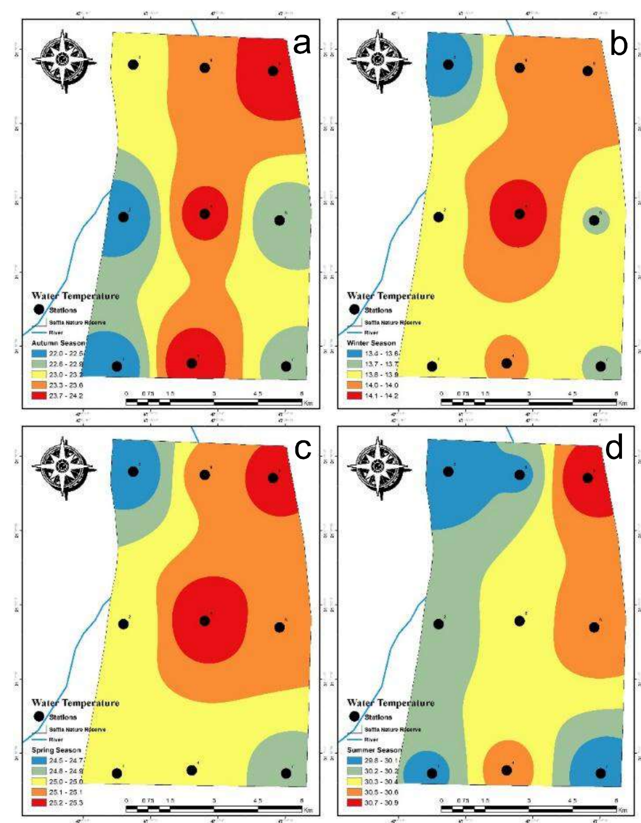


**Fig. 4**. Spatial distributions of WT using IDW interpolation: (a) autumn 2019, (b) winter 2020, (c) spring 2020, and (d) summer 2020

characteristic of Iraqi waters is mainly due to the nature of lime sediments of the marsh, so the lower pH values may be due to the nature of acid or the increase in the concentration of dissolved carbon dioxide as a result of the organic decomposition of the materials. Bora and Goswami (2015) indicated that the pH value of rivers depends on several factors, including local geology, the environment, as well as human influences. The runoff of alkaline substances due to heavy rains is one of the factors affecting the high pH value of water (Rubio-Arias et al 2013), Higher temperatures lead to an increase in evaporation rates, which leads to an increase in the concentration of dissolved salts in water, which raised the pH value in the base direction (Odjadjare and Okoh 2010).In general, the waters of the Iraqi marshes are characterized by a low pH value in summer and high in winter, and this agrees with (Mohammed 2010, Al-Kenzawi et al 2011, Al-Saboonchi et al 2011, Al-Rikabi and Al-Kubaisi 2014, Al-Abbawy and Al-Zaidi 2018). The current study of the pH values at Station No.5 during the winter season recorded a value higher than the permissible limits according to the World Health Organization (6.5 - 8.5).

**Electrical conductivity (EC):** Electrical conductivity (EC) is a measure of the ability of an aqueous solution to carry an electric current, depending on the ions, their equivalence, total concentration, and their movement, as well as on the temperature at the time of measurement. The highest value of electrical conductivity was 7.1 µS $cm^{-1}$ in station No.2 in the spring. The lowest value was 3.44 µS $cm^{-1}$ in station No.5 in the autumn season (Fig. 7). The statistical analysis showed that there was significant differences between the seasons and was noticed that there were no significant differences between the stations (Fig. 8 a-d). The seasonal and monthly differences in the electrical conductivity values is attributed to the fact that it is associated with a decrease in water levels and an increase in the rate of evaporation in the summer, which leads to the dissolved ions being more concentrated and this leads to an increase in the electrical conductivity values in the water (Al-Kenzawi et al 2011), The reason for the low values of electrical conductivity in the marshes water may be due to the dilution of salts by precipitation (Al-Saad et al 2010). The electrical conductivity value is also clearly related to the total soluble solids, as it reflects the water content of salts, nutrients, and organic materials (Parmar and Parmar 2010). It is well known that the Iraqi marshes were exposed to years of drought, which led to an increase in the concentration of salts in the sediments (Al-Abbawy and Al-Mayah 2010, Al-Abbawy et al 2011).

**Dissolved oxygen (DO):** Dissolved oxygen in water is the first evidence to prove the purity of natural water since most aquatic organisms depend on the presence of dissolved

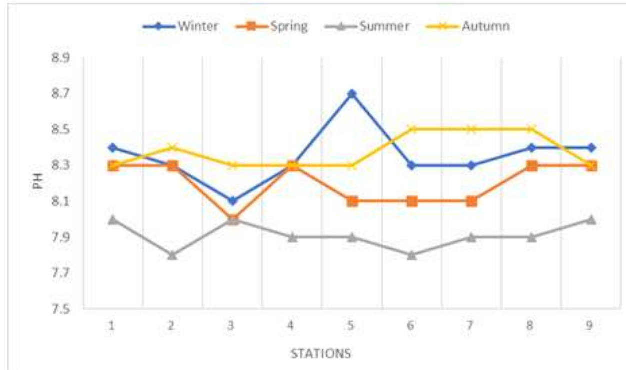


**Fig. 5.** Hydrogen ion concentration (pH) in SNR

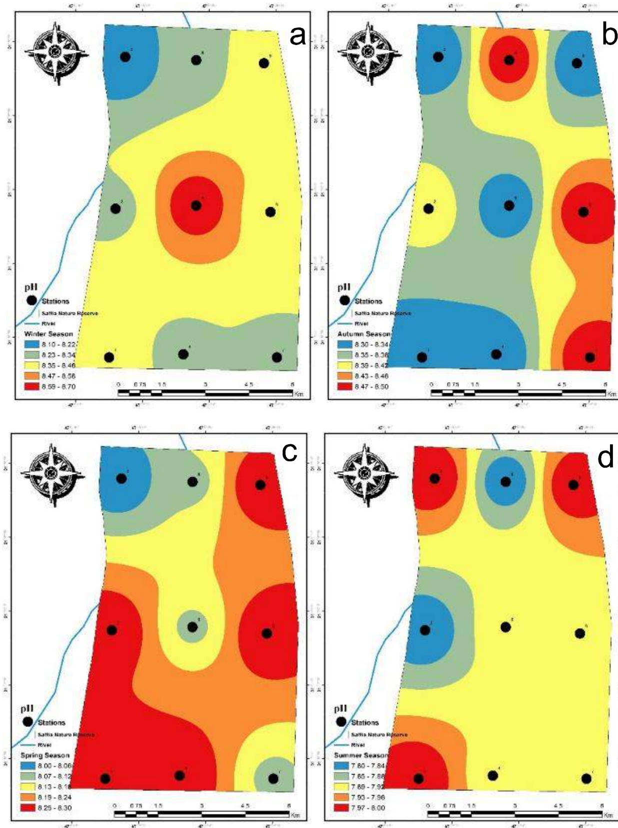


**Fig. 6.** Spatial distributions of pH values using IDW interpolation: (a) autumn 2019, (b) winter 2020, (c) spring 2020, and (d) summer 2020

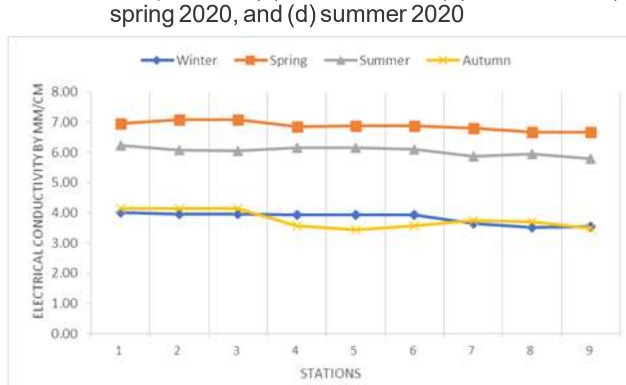


**Fig. 7.** Electrical Conductivity (EC) µm $cm^{-1}$ in SNR

oxygen to survive (Singanan et al 2008). For that reason, dissolved oxygen is one of the most critical factors that affect the quality and degree of water bodies of water-pollution in it (Yang et al 2007). The results of dissolved oxygen in the current study showed that the highest dissolved oxygen was (10.1 mg $l^{-1}$) in station No. 8 during the winter season (Fig. 9). The lowest value was in the summer season (5.5 mg $l^{-1}$) in stations No. 4 and 5. The statistical analysis showed the presence of significant differences between the seasons and no significant differences were observed between the stations. There is a significant correlation relationship. Negative between dissolved oxygen and temperature (Fig. 10 a-d). In general, the low value of dissolved oxygen concentrations recorded during the summer season and the highest values represented in the winter season (Mohammed 2010, Al-Kenzawi et al 2011, Al-Saboonchi et al 2011, Al-Zuwar et al 2012, Douabul et al 2013, Al-Rikabi and Al-Kubaisi 2014, Al-Asadi 2014, Al-Abbawy and Al-Zaidi 2018). The presence of dissolved oxygen in the aquatic environment is affected by many factors, including the amount of rain, water temperature, salinity, the decomposition of organic matter in the water, the presence of aquatic plants, and the presence of pollutants from 4 mg $l^{-1}$ (Cameron et al 2013). Most of the study results were for dissolved oxygen concentrations in the waters of SNR above the permissible limits according to the World Health Organization (6 mg $l^{-1}$).

**Nutrients**

**Active nitrate ($NO_3^-$):** The nitrate anion is one of the inorganic nitrogen forms in water and nitrate, and ammonia. It is also a significant nutrient that contributes to building the vital activities of most living organisms. The high nitrate value

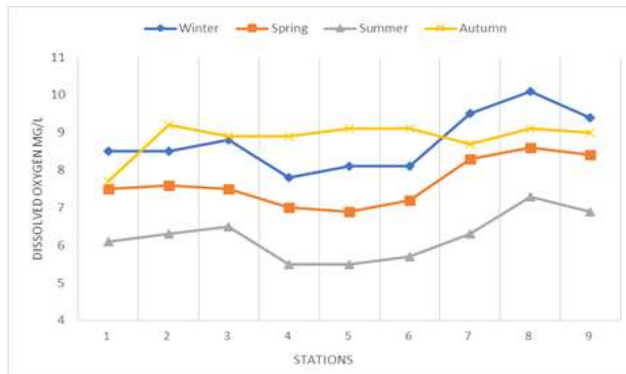


**Fig. 9.** Dissolved Oxygen (EC) mg $L^{-1}$ in SNR

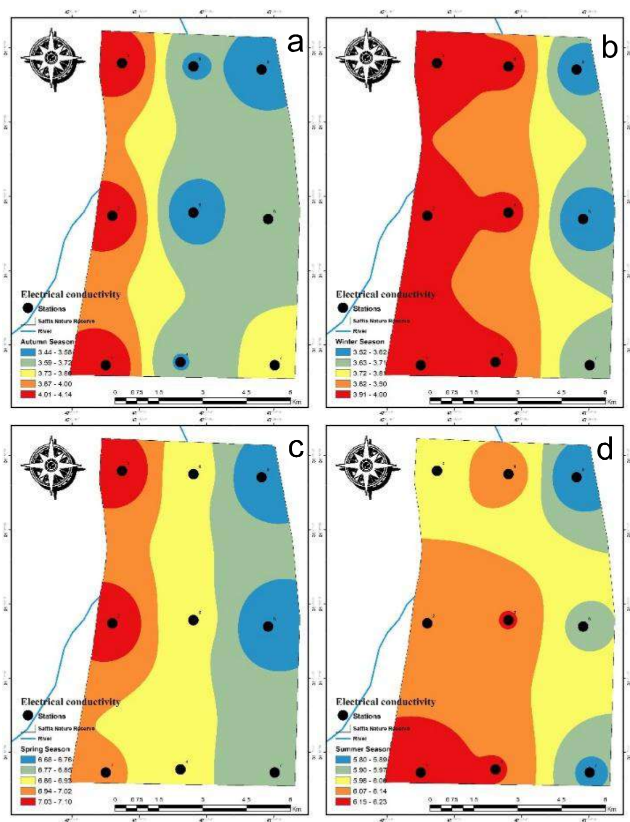


**Fig. 8**. Spatial distributions of E.C. values using IDW interpolation: (a) autumn 2019, (b) winter 2020, (c) spring 2020, and (d) summer 2020

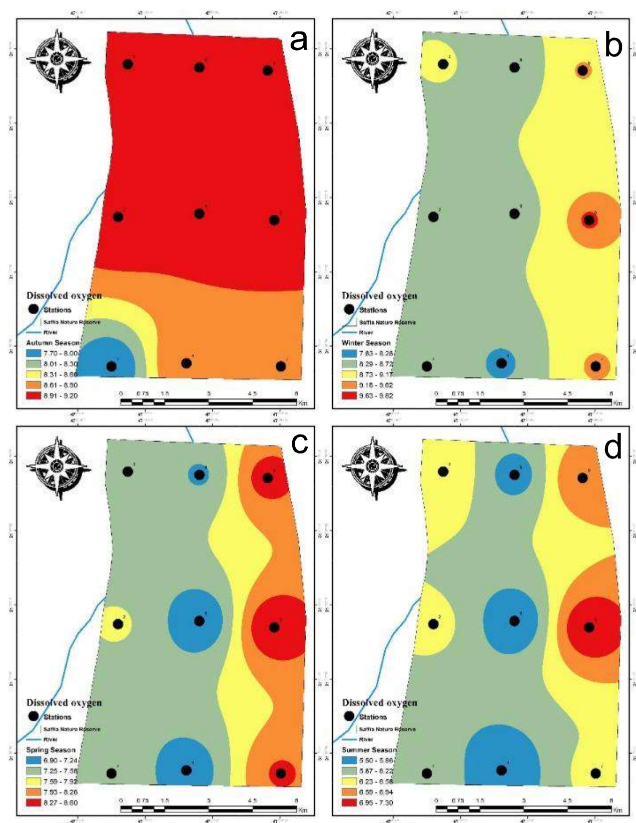


**Fig. 10**. Spatial distributions of DO mg $L^{-1}$ values using IDW interpolation: (a) autumn 2019, (b) winter 2020, (c) spring 2020, and (d) summer 2020

is due to the flow of nitrogen-rich floodwaters that bring in large quantities of contaminated wastewater (Pradeep et al 2012). The nitrate concentration reached the highest value (8.04 mg $L^{-1}$) in station No.1 in the winter season and the lowest was in station No.6 (0.53 mg $L^{-1}$) during the same season (Fig. 11). During the seasons, the sufficient nitrate concentrations were in the winter and spring seasons and the lowest were in the summer and autumn seasons. There was significant difference between the seasons. In contrast, no significant differences were between the stations and there is a significant negative correlation between nitrate concentrations and water temperatures. The reason for the high nitrate concentrations during the winter season may be to the rains, which in turn dissolve the organic compounds and nitrogen fertilizers on the banks of the rivers (Lomoljo et al 2009), as well as the low nitrate consumption by phytoplankton and aquatic plants (Twomey and John 2001, Al-Saadi et al 2008). The increase in oxidation of nitrite to nitrate as a result of the decrease in water temperature, which increases the concentrations of dissolved oxygen (Hussein and Fahad 2008). In the summer season, nitrate concentrations decreased most of the study stations. It may be caused by an increase in temperature and decrease in dissolved oxygen concentrations, which leads to the reduction of nitrates to nitrites (Al-Emara et al 2001). This study is in agreement with previous studies on the marshes in southern Iraq in terms of high active nitrate concentrations in winter and spring seasons and low in summer and autumn seasons (Al-Saboonchi et al 2011, Douabul et al 2013, Al-Thahaibawi et al 2014, Al-Rikabi and Al-Kubaisi 2014). The results of the active nitrate concentrations in the current study did not exceed the World Health Organization, which is 50 mg $l^{-1}$ (Fig. 12 a-d).

**Active phosphate ($PO_4^{3-}$):** Phosphorus is essential for different living organisms, and its increase also leads to an overgrowth of microorganisms in large quantities, which affects other aquatic organisms (Al-Emara et al 2001, Bakan et al 2010). The current study results showed that the highest reactive phosphate concentration was at station No.9 in the spring season (0.133 µg $L^{-1}$). The lowest was at station No. 6 in the winter season was (0.005 µg $l^{-1}$). The study stations' show that the highest value of the reactive phosphate concentration was in the summer and spring seasons during seasons. The lowest concentrations were in the winter and autumn seasons (Fig.13). The statistical analysis showed a significant difference between the seasons as well as the presence of significant differences between the stations at the probability level. There is a significant negative correlation at the between the active phosphate concentrations and water temperatures (Fig. 14 a-d).

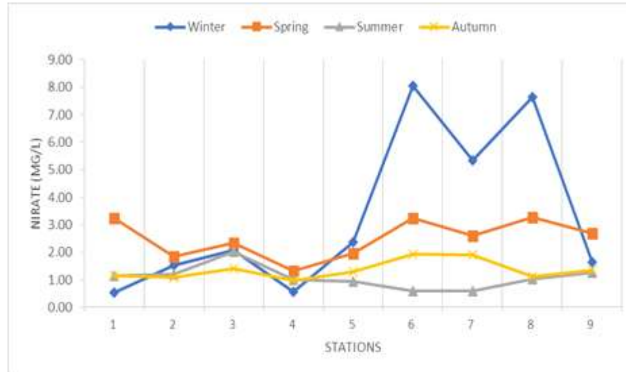


**Fig. 11.** Nitrate concentration ($NO_3^-$) mg $L^{-1}$ in SNR

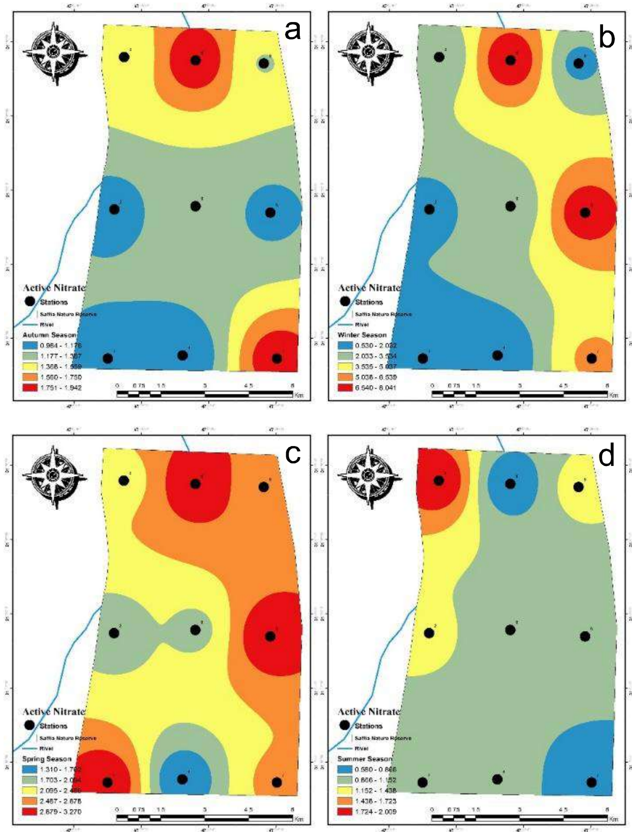


**Fig. 12**. Spatial distributions of $NO_3^-$ mg $L^{-1}$ concentrations using IDW interpolation: (a) autumn 2019, (b) winter 2020, (c) spring 2020, and (d) summer 2020

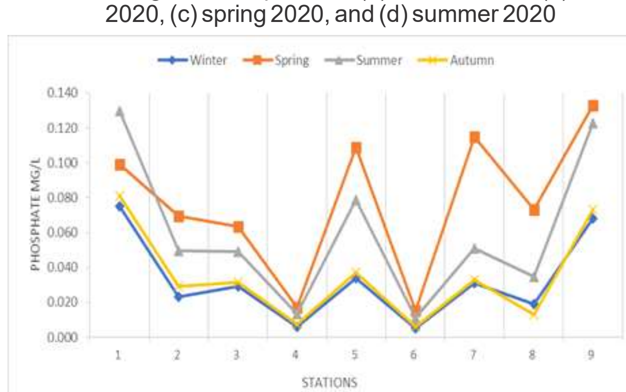


**Fig. 13.** Phosphate concentration ($PO_4^{3-}$) µg $l^{-1}$ in SNR

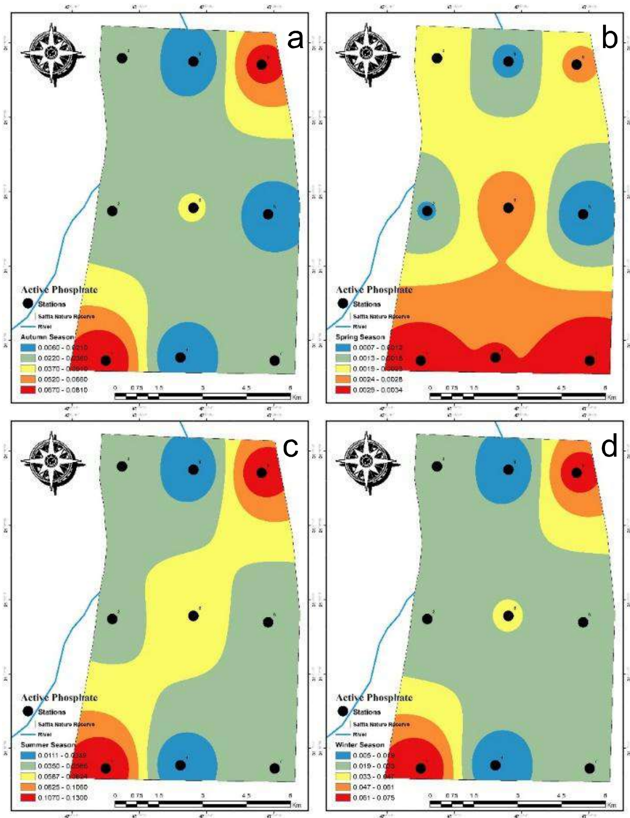


**Fig. 14**. Spatial distributions of $PO_4^{3-}$ concentrations using IDW interpolation: (a) autumn 2019, (b) winter 2020, (c) spring 2020, and (d) summer 2020

## CONCLUSIONS

The results of the study showed deterioration in water quality due to the high electrical conductivity and best properties were in the summer season. There is a negative exponential relationship between water temperatures and pH and dissolved oxygen, and a positive relationship between water temperature and electrical conductivity.

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# Perceptions of Pastoralists about Climate Change in Ethiopia: A Case Study of Saba Boru District

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***Abstract***: This study was conducted in the Saba Boru district of the Guji zone in Ethiopia's Oromia regional state. A long-term alteration in a nation's or region's climatic tendencies is referred to as climate change. Agriculture accounts for roughly 47 percent of Ethiopia's GDP, and more than 85 million people rely on agriculture for a living, either directly or indirectly. This study examined local pastoralists' perceptions of climate change and related problems and is based on primary data collected from 821 households of 12 kebeles of the Saba Boru district. The collected data have been analyzed via descriptive and inferential statistics evaluate the results. There is increased annual temperature from 20.6 °C to 21.28 °C, large variance in annual rainfall from 758.23 to 2.32 mm, and higher change in annual solar radiation from -99 °C to 18.33 °C during 1981 to 2019 are the evidence of climate change. More than 81 percent of respondents agreed that higher rainfall and changes in rainfall patterns were the shreds of evidence of climate change, while 78.1 percent agreed that greater drought was a sign of climate change. Although 79.3 percent of respondents agreed to an increase in temperature and high sunlight intensity as observed evidence of climate change, 15.2 percent disagreed. Similarly, 41.3 percent of respondents disagreed on the low fertility of most soils as observed signals of climate change, while 53.4 percent agreed. The study demonstrates that respondents in the communities examined are aware of climate change, but with variable levels of agreement.

***Keywords:*** Climate Change, Perception, Pastoralists, Variance, and Saba Boru district

Climate change is one of the world's most critical environmental challenges. The Intergovernmental Panel on Climate Change projects a global mean temperature increase of 1.1°C to 6.4°C of 2100, which is likely to cause storms and floods, and as the oceans expand thermally and ice sheets and glaciers melt, sea levels rise (Lemmen et al 2008). Climate change is predicted to have a significant influence on dry and semi-arid rangelands, which comprise approximately two-thirds of the African continent (Galvin et al 2001). Many of the impacts of climate change in these areas are characterized by variability in rainfall patterns and extreme weather events such as recurring droughts, floods and windstorms (IPCC 2013). These places, such as Sub-Saharan Africa, are home to an estimated 386 million people, including pastorals who rely on natural resources for a living (Conway 2009, IPCC 2015, Thornton et al 2007 and Adhikari et al 2015). Agricultural production activities in Africa, on the other hand, are more vulnerable to climate change than any other social-economic activities (Bonatti 2016, Elum et al 2017). It is predicted that agricultural production in African will be decreased by 8 to 22% by 2050 (Schlenkerand and Lobell 2010). The repeated dry seasons have been seen over the last thirty years, as well as the continued consequences of El Nio in East African nations in general, and Ethiopia in particular, has resulted in a huge number of people being food insecure as a result of climate change. Ethiopia's agricultural industry is vulnerable to the effects of climate change because the country's livelihood is mostly built on rain-fed agriculture (Burnett 2013, ISET 2013).

Ethiopia is experiencing an increase in the warming trend of annual temperatures as well as the severity of droughts. The country's annual temperature has risen by 0.37 degrees Celsius every ten years over the last 55 years (Tadege 2007, Mcsweeney et al 2010). Ethiopia is one of Africa's most vulnerable nations to climate change and unpredictability, and it is regularly confronted with climate-related hazards that threaten people's lives and livelihoods (World Bank 2010, Burnett 2013, ISET 2013). Climate change elements such as drought, flood, and soil degradation are among the key contributors to Ethiopia's low agricultural production (Asrat and Simane 2017c, Yirga 2007). These factors, combined with a heavy reliance on traditional farming techniques and improper complementary services (such as extension, credit, marketing, etc.), reduce smallholder pastorals' adaptive capacity or increase their vulnerability to climate change, affecting the already poor agricultural performance (Asrat and Simane 2017d).

The region's ecosystem is fragile, with a growing trend of natural resource degradation, and rainfall patterns and distribution have changed and become unpredictable (Nega et al 2015). One of Ethiopia's pastoral areas is the Saba Boru district, Guji zone, and the Oromia region. The federal and regional governments, as well as humanitarian groups, are concerned about the study area's recurring drought and severe food insecurity. The area's pastoral livelihood system is sensitive to the negative effects of climate change (Fratkin 2014) since their livelihood is reliant on fundamental natural resources such as water and pastures. Pastoralists have continued to struggle for generations to adapt to climate change. However, due to the growing tendencies of recurring droughts and high rainfall variability, as well as the existing weak socioeconomic conditions, pastoralists have become low adaptable to climate change and variability (Ayal and Leal 2017).

Pastoral communities, on the other hand, have indigenous knowledge of their environment and have implemented a variety of adaptation strategies to deal with climate-related risks and environmental stresses (Egeru 2012). Such adaptation strategies have significant cultural and religious dimensions and implications, but their applicability and effectiveness may be limited due to societal values, processes, and power dynamics (Lorenzoni et al 2009). According to studies, understanding local climatic knowledge can be very valuable for major decision-making processes (Beatrice et al 2009). Traditional knowledge may offer new insights for strengthening current scientific understanding as well as a foundation for developing suitable research and development policies. Furthermore, the potential value of local practices, increasing socio-ecological resilience has been underappreciated, notably in Ethiopia's pastoral production system, including the Guji pastoral and agro-pastoral areas. However, in recent years, significant climatic occurrences (e.g., recurring drought and fluctuation in rainfall) have contributed to food insecurity, poverty, and exacerbated the area's existing susceptibility (Abate 2016).

Ethiopia is among the most underprivileged African countries to climate change. Whether directly or indirectly, pastoralists reliant on natural resources face threats from climate change impacts such as water scarcity, changing rainfall and drought patterns, increased desertification and bush encroachment in rangelands, expansions of human and livestock diseases, and exacerbated conflicts due to competition for resources, primarily water. Even though pastoral communities are preserving and surviving their lives through knowledge-based adaptation strategies, most academics do not consider pastoralists' Indigenous Knowledge to be a foundation of scientific knowledge in every aspect. Similarly, in Ethiopia, the government's pastoral area policies are insufficient in light of the regular occurrence of droughts and the broader effects of climate change (Global Assessment Report 2015). As a result, the policies suggested in various countries were mainly ineffective in resolving pastoral communities' challenges, particularly reducing their vulnerability to climate change consequences (Mengistu and Haji 2015).

Southern Ethiopia, where the Guji Zone is located, and other portions of Ethiopia's Somali area depend on IK aimed at mitigating climate change losses or accelerating recovery (Abarufa 2011). The Guji pastoralists, in particular, who dwell in the Sabba Boru district of the Guji zone, bear the brunt of climate change and face a slew of issues as a result. Even so, they had already adapted to the effects of climate change and reduced their vulnerability through IK-based weather forecasting, pond and well construction and management (water-related practices), hay collection and storage for the dry season, seasonal livestock mobility, crop cultivation participation, livestock species diversification and livestock traditional health care systems and are surviving in these extremely difficult environmental conditions in the area. As a result, examining the impact of climate change and pastoral communities' adaptation techniques is critical, and this study is intended to fill some of these gaps and expand its vital role in autonomous adaptation in the local region. The major aim of this study is to assess the perception of local pastoralists' on climate change. The specific objectives are to examine pastoralists' knowledge of climate change and the actions they may take. Investigate the sources of climate change information used by pastoralists and scrutinize pastoralists' perceptions of climate change's effects. Explore the coping strategies used by pastoralists and evaluate the government's efforts to alleviate the effects of climate change.

## MATERIAL AND METHODS

**Study area:** The study was conducted in the Saba Boru district, Guji zone of Ethiopia's Oromia region, which is located between 5°2'47"N-5°46'43"N latitudes and 38°50'2"E-39°15'42"E longitudes, and is 563 kilometers far from the country capital Addis Ababa in the southern part of the Oromia regional state (Fig. 1). The major topography of the Sabba Boru district is rugged and broken, with various hills and ridges varying in elevation from 800 to 1500 meters. The district is divided into two agro-climatic zones: desert (81 Per cent) and semi-arid (19 Per cent). The district's annual temperature ranges from 12.71 °C to 29.6 °C, with an average rainfall of 600 - 1400mm. The rainy season is divided into two parts: March-May (Ganna), which is the long rainy season, and September-October (Hageyya), which is the

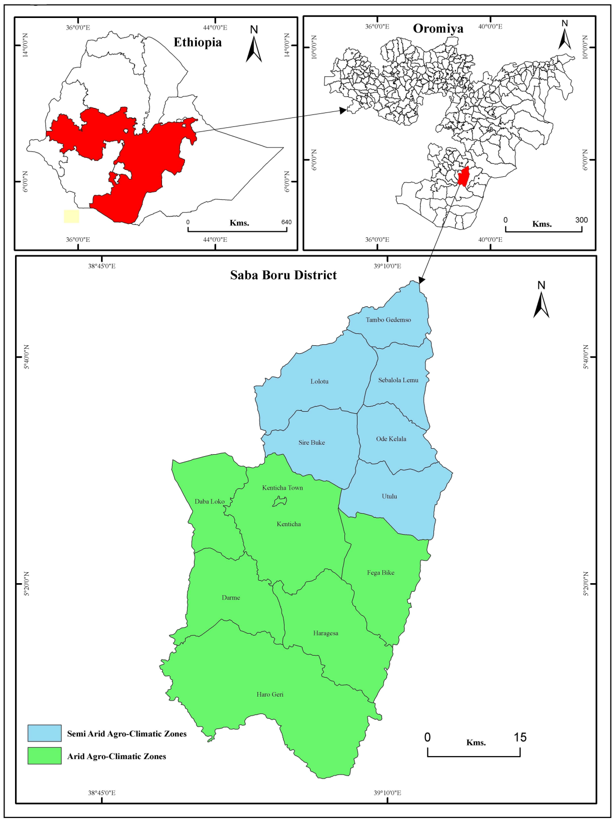


**Fig. 1.** Study area

short rainy season. The regular tendency of the rainfall pattern was changing. The area contains two soil types, 70 percent sandy soil and 30 percent fertile soil, with a mean annual temperature of 20.61°C. Livestock farming employs 75 percent of the district's population, while sedentary farming and non-farm activities employ the other 25 percent. It is distinguished by subsistence livestock and crop cultivation practices. There are 214,456 cattle, 255,899 goats, 16,733 sheep, 14,621 camels, 46,442 donkeys, 8,056 mules, 284 horses, and 360,581 chickens. The most common crop kinds grown in the study area are maize, teff, haricot bean, and wheat. The area was sparsely inhabited and characterized by a moisture deficit, which resulted in water problems, reducing the area's livestock and crop production potential.

**Research Methodology**

**Design:** The district of Saba Boru was selected for this study based on the following criteria (i) pastoral communities' homeland, where livestock is their biggest source of income (ADF 2003) and (ii) comprised primarily of arid/semi-arid lands that have experienced serious climate change variabilities, such as rising drought periods and unpredictable rainfall (Theodory and Malipula 2014). In the Sabba Boru district, there are 12 Kebeles; 6 are categorized as arid agro-climatic zones, while the remaining 6 are categorized as semi-arid agro-climatic zones. Therefore, the major attention was to give equal status to both climatic zones of the district. The district administrators were consulted initially to choose the best representative kebeles based on vulnerability to drought, water scarcity, and representativeness of the livelihood activities. A simple random sampling method was used, as a result, 6 Kebeles were chosen from arid agro-climatic zones and 6 semi-arid agro-climatic zones, and 821 (26.3 percent) households from these kebeles were selected for as a sample size respectively by considering its representativeness in reflecting the realities of pastoralism and agro-pastoralism in the study area. In this study, a mixed research approach was used, with both qualitative and quantitative methods used for primary and secondary data collection. Household surveys, structured questionnaires, Key Informant Interviews (KII), and Focus Group Discussions (FGD) were employed to collect primary data and secondary sources of data were obtained from published and unpublished documents. Preliminary surveys were performed with local enumerators and key informants before the start of the main survey, and the final questionnaire was revised and updated when required. The survey questionnaire was open-ended, dichotomous, and multiple-response in nature, and it was translated into the home's native language. Data on various viewpoints were acquired through household interviews conducted by local field assistants. The collected data were analyzed with descriptive and inferential statistics, and the hypothesis was tested.

**Analytical techniques:** For analyzing the data, a combination of descriptive statistics (sum, averages, percentages, livelihood component framework, and recommendation matrix), mathematical techniques (percentage perception index and agreement index), and statistical techniques (logistic regression model & Logit model) were used to achieve the goal, objectives and produces the meaningful results. To input the primary data, Microsoft Office Excel 2010® was used, and IBM SPSS Statistics Version 27 was used to analyze the primary data and to develop the map of the study area, ArcGIS version 10.8 software was used.

**Livelihood component framework:** The livelihood component framework was constructed to measure the impact of production practices on pastoralists' asset possession, activities and strategies, wellbeing, and external policies and institutions (Ashley and Hussein 2000).

**Percentage perception index:** To quantify pastoralists' perceptions of experiencing climate change, the percentage perception index was used (Dhar and Uddin 2017). Each pastoralist of the research areas was asked to indicate his/her option regarding each level of change on selected opinions. During the pre-testing of the questionnaire, pastoralists identified a large number of statements but for the simplicity of calculation, the first ten of them were selected based on the highest frequencies. Pastoralists had the option to indicate each statement as 'increase', 'decrease', and 'no change'. To see the percentage of each statement, the following simple percentage formula was used:

Percentage perception index = No. of respondents' opinion about statements (increase, decrease or constant) × 100] ÷Total no. of respondents

**Agreement index:** The agreement index was used to quantify pastoralists' perceptions about the impacts of natural calamities on their day-to-day life (adopted from Bernhart et al 2007). The index was composed of two divisions: (1) positive impacts of natural calamities; and (2) negative impacts of natural calamities. Each division of the index included 10 statements based on questionnaire pre-testing and secondary literature (Nyuor et al. 2016; Alam et al. 2017; Zoundji et al. 2017). The authors found plenty of statements in this case also but kept the first ten statements for each division based the on highest frequencies. Each division of the index included 10 statements.

**Logit model:** To identify the factors influencing changing climate change decisions by the pastoralists, the logistic regression model (i.e., Logit model) was used (Gujarati 2003). The model was constructed individually for each study area to get specific and meaningful estimates. The independent variables included in the analysis were not the same in all the models as major determining factors varied in each study area based on pastoralists' socioeconomic characteristics, geographical state, and agricultural systems (Daskalakis et al 2002). The major determining factors in each study area were identified through personal interviews, FGDs and KIIs.

**Assessment of pastoralists' livelihood:** To analyze the livelihood outcome of the pastoralists after changing climate change decisions, a sustainable livelihood framework was approached (DFID 1999). The approach identified and measured five types of livelihood assets or capitals which were: human capital, social capital, financial capital, natural capital, and physical capital.

**Recommendation matrix:** Suggestions and policy recommendations were presented by the researchers in the form of a recommendation matrix (Dhar et al 2018b) for improving pastoralists living standards through adopting the best decision.

**Statistical analysis:** One-way analysis of variance is commonly used to determine the significance of differences between and within variables and, on the other hand, is used to test the statistical significance of the variables.

F=MSTMSE (2)

MST = Σki = 1(ti/nu)-G2/nk-1 (3)

MSE= Σki = 1 Σkj = 1Y2ij- Σki = 1(ti/ni)k-1 (4)

There F is the variance ratio for the overall test, MST is the mean square due to treatments/groups (between groups), MSE is the mean square due to error (within groups, residual mean square), Yij is an observation, Ti is a group total, G is the grand total of all observations, ni is the number in group i and n is the total number of observations. In this research study, One way ANOVA analysis was performed.

## RESULTS AND DISCUSSION

**Climate variations from 1981 to 2019:** Increased annual temperature 20.6°C to 21.28°C, large variance in annual rainfall 758.23 to 2.32 mm, little change in annual relative humidity 60.95 to 60.19 percent, and higher change in annual solar radiation -99°C to 18.33°C are evidence of climate change from 1981 to 2019 (Table 1). P-value is 0.00000 at p≤0.05. As a result of this, the climate change variability hypothesis has acquired significant scientific acceptance.

**Pastoralists' knowledge of climate change:** The 81.2 percent of respondents agreed that higher rainfall and changes in rainfall patterns were evidence of climate change, while 78.1 percent agreed that greater drought was a sign of climate change. Although 79.3 percent of respondents agreed on an increase in temperature and high sunlight intensity as observed evidence of climate change, 41.3 percent disagreed on the low fertility of most soils as observed signals of climate change, while 53.4 percent agreed. It demonstrates that respondents in the communities examined are aware of climate change, but with variable levels of agreement. The P-value is 0.00003 at p≤0.05. As a result, the hypothesis that Pastoralists' awareness of climate change varies significantly in the study area is accepted. The findings demonstrate that individual Pastoralists have various degrees of understanding regarding climate change.

**Source of information about climate change:** Pastoralists in the study area have five major sources of information on climate change as 87.1% of the respondents obtain information through radio, 74.8% through natural experience, and 58.2% through television. However, 33.6% of the respondents were undecided about obtaining information from extension personnel compared to 41.3% who agreed while 51.5% of the respondents were also undecided about obtaining information on climate change from the newspaper as against 15.6% who agreed. It reveals that the major sources of information on climate change available to pastoralists are radio, natural experience, and

**Table 1.** Study area's average annual temperature, precipitation, relative humidity, and solar radiation (1981 to 2019)

| Year | Annual temperature (°c) | Annual perception (mm) | Annual relative humidity (%) | Annual solar radiation (°c) | Variance |
|---|---|---|---|---|---|
| 1981 | 20.06 | 758.23 | 60.95 | -99 | 0.17°c annual temperature |
| 1982 | 19.94 | 824.73 | 63.07 | -99 | |
| 1983 | 20.33 | 690.42 | 59.83 | 19.34 | |
| 1984 | 20.66 | 391.39 | 51.37 | 21.61 | 42031.59 mm annual precipitation |
| 1985 | 19.87 | 645.44 | 59.51 | 20.65 | |
| 1986 | 19.92 | 774.84 | 59.52 | 20.59 | |
| 1987 | 20.41 | 737.18 | 59.64 | 21.05 | |
| 1988 | 20.27 | 855.61 | 60.77 | 19.98 | 9.72 (%) annual relative humidity |
| 1989 | 19.82 | 795.66 | 62.29 | 19.79 | |
| 1990 | 20.3 | 695.86 | 61.01 | 20.01 | |
| 1991 | 20.79 | 559.31 | 56.48 | 20.54 | |
| 1992 | 20.6 | 553.14 | 57.58 | 20.44 | 706.04°c annual solar radiation |
| 1993 | 20.24 | 594.02 | 58.13 | 20.74 | |
| 1994 | 20.67 | 613.84 | 56.39 | 21.15 | |
| 1995 | 20.42 | 702.33 | 60.65 | 20.07 | |
| 1996 | 20.21 | 733.86 | 61.09 | 19.77 | |
| 1997 | 20.25 | 997.68 | 64.12 | 20.43 | |
| 1998 | 20.58 | 649.58 | 61.39 | 19.14 | |
| 1999 | 20.65 | 469.7 | 54.67 | 20.11 | |
| 2000 | 20.96 | 379.19 | 51.65 | 20.64 | |
| 2001 | 20.88 | 523.86 | 56.71 | 20.21 | |
| 2002 | 21.07 | 555.76 | 57.71 | 19.53 | |
| 2003 | 21.13 | 485.41 | 56.21 | 20.26 | |
| 2004 | 21.29 | 401.64 | 55.39 | 20.06 | |
| 2005 | 20.96 | 538.92 | 55.79 | 20.15 | |
| 2006 | 20.57 | 805.12 | 62.23 | 19.49 | |
| 2007 | 20.71 | 681.23 | 59.03 | 20.22 | |
| 2008 | 20.66 | 586.78 | 55.68 | 19.58 | |
| 2009 | 21.21 | 517.86 | 56.44 | 19.62 | |
| 2010 | 20.74 | 675.69 | 60.07 | 18.7 | |
| 2011 | 21.17 | 525.74 | 55.63 | 19.74 | |
| 2012 | 20.53 | 729.14 | 59.64 | 19.75 | |
| 2013 | 20.13 | 927.36 | 64.7 | 18.58 | |
| 2014 | 20.77 | 690.22 | 60.21 | 18.88 | |
| 2015 | 20.95 | 833.83 | 59.65 | 20.22 | |
| 2016 | 20.84 | 721.99 | 59.92 | 19.36 | |
| 2017 | 20.84 | 759.16 | 57.27 | 18.31 | |
| 2018 | 20.21 | 2.54 | 64.04 | 17.52 | |
| 2019 | 21.28 | 2.32 | 60.19 | 18.33 | |

**Source:** https://power.larc.nasa.gov/data-access-viewer/

television. On the other hand, very few respondents obtain information through newspaper and extension personnel which indicates the dearth of training sessions on climate change in the study area. The P-value is 0.03720 at p≤0.05. Therefore, the hypothesis which states that there is a significant variation in pastoralists' sources of information on climate change is accepted. It, therefore, means that pastoralists in the study area do not get information on climate change from a singular source. This is true given that there are various sources of information on a particular issue and most importantly where there are various media and other sources where information can be obtained.

**Pastoralists perception of effects of climate change:** The 75.6 % of the respondents perceived the effects of climate change as an increase in rainfall, 69.6 % as a decrease in agricultural output, 65.1% as an increase in the cost of food crops, 45.5% as a decrease in rainfall. However, 47.6% disagreed with to decline in the availability of forest resources as an effect due to climate change while 32.6% agreed while 19.8 % of the respondents are undecided about the increase in daily temperature as an effect of climate change. 69.6 % of the respondents perceived that climate change has led to a decrease in agricultural output and is a very significant factor that increases the cost of food crops generally as agreed by 65.1% of the respondents. Furthermore, 41.8 and 38.6% of the respondents also agreed that there had been an increase in drought and flood respectively which are serious contributing problems associated with climate change that threatened the livelihood of pastoralists in the study area. P-value is 0.00007 at p≤0.05. Thus, the hypothesis which states that pastoralists' perception of climate change varies significantly in the study area is accepted. The result confirms the fact that individual pastoralists feel the effect of climate change differently hence, the variation in their perception of effects.

**Pastoralists' coping strategies of climate change:** The 78.9% of the respondents used supplementary irrigation, 75.4% adopted planting of different varieties of crops probably because the different varieties of crops have different levels of tolerance for adverse effects of climate change and so would not result in a complete loss on the part of the pastoralists. 73.9% of the respondents adopted the application of fertilizers to improve and enhance crop yield, 71.1% of the respondents engaged in changing cropping patterns because changing crop patterns guides against crop infestation and disease attack. 65.5% of the respondents adopted new farming techniques while 28.2% disagreed with the shading of young plants as a coping

**Table 3.** Pastoralists source of information on climate change

| Source of information | Agree (%) | Disagree (%) | Undecided (%) | P-value p≤0.05 |
|---|---|---|---|---|
| Radio | 87.1 | 7.4 | 5.5 | 0.03720 |
| Newspaper | 15.6 | 32.9 | 51.5 | |
| Television | 58.2 | 26.2 | 15.6 | |
| Extension personnel | 41.3 | 25.1 | 33.6 | |
| Through natural experience | 74.8 | 14.1 | 11.1 | |

**Table 2.** Pastoralists' knowledge about climate change

| Knowledge of climate change | Agree (%) | Disagree (%) | Undecided (%) | P-value p≤0.05 |
|---|---|---|---|---|
| Increase in temperature and high sunshine intensity | 79.3 | 15.2 | 5.5 | 0.00003 |
| Increased rainfall and change in rainfall pattern | 81.2 | 11.7 | 7.1 | |
| Increased drought | 78.1 | 14.4 | 7.5 | |
| Poor fertility of most soils | 53.4 | 41.3 | 5.3 | |

**Table 4.** Pastoralists perception of effects of climate change

| Perception of effects | Agree (%) | Disagree (%) | Undecided (%) |
|---|---|---|---|
| Increase in rainfall | 75.6 | 8.9 | 15.5 |
| Decrease in rainfall | 45.4 | 33.2 | 21.4 |
| Due to climate change, there is increased spread in agricultural pests, diseases, and weeds on farmland | 37.5 | 36.2 | 26.3 |
| Climate change has led to a decline in the availability of forest resources | 32.6 | 47.6 | 19.8 |
| Decrease in agricultural output due to climate change | 69.6 | 24.8 | 5.6 |
| Increase in the cost of food crops due to climate change | 65.1 | 26.4 | 8.5 |
| Climate change has led to an increased rate of erosion and flooding in many places | 38.6 | 39.9 | 21.5 |
| Increased incidences of drought during the dry season due to climate change | 41.8 | 32.4 | 25.8 |
| Increase in daily temperature | 41.2 | 30.5 | 28.3 |

**Table 5.** Pastoralists' coping strategies of climate change

| Coping strategies | Agree (%) | Disagree (%) | Undecided (%) |
|---|---|---|---|
| Planting of different varieties of crops | 75.4 | 9.9 | 14.7 |
| Changing cropping pattern | 71.1 | 13.4 | 15.5 |
| Using supplementary irrigation | 78.9 | 17.6 | 3.5 |
| Application of fertilizers to improve and enhance crop yield | 73.9 | 17.6 | 8.5 |
| Mulching of crop plants | 57.7 | 14.8 | 27.5 |
| Shading of young plants | 43 | 28.2 | 28.8 |
| Adoption of new farming techniques | 65.5 | 21.1 | 13.4 |

**Table 6.** Governmental actions on climate change

| Actions are taken by government | Agree (%) | Disagree (%) | Undecided (%) |
|---|---|---|---|
| Provision of weather alert (Radio and television for daily weather forecast and relevance to agricultural activities) to help for effective adaptation | 65.1 | 23.5 | 11.4 |
| Provision of extension agents to educate more on agriculture and better land management techniques | 39.3 | 43.2 | 17.5 |
| Adequate access to new technologies | 24.8 | 63.7 | 11.5 |
| Provision of sufficient current knowledge to adapting measures | 33.8 | 44.4 | 21.8 |
| Provision of irrigation facilities and investments | 31.7 | 48.6 | 19.7 |

**Table 7**. Things that should be done to mitigate climate change

| Things that should be done to mitigate climate change | Frequency | Percentage |
|---|---|---|
| Early notification | 28 | 15.9 |
| Insurance | 36 | 25.8 |
| Better Awareness | 24 | 18.5 |
| Teaching new techniques | 29 | 17.2 |
| Provision of technology | 24 | 14.4 |
| Extension agents | 18 | 8.3 |
| Total | 159 | 100.0 |

strategy and 28.8% of the respondents were undecided about the shading of young plants as a coping strategy. P-value is 0.00000 at p≤0.05. Thus, the hypothesis which states that climate change coping strategies adopted by pastoralists have a significant variation in the study area is accepted.

**Governmental actions on climate change:** Weather alerts (radio and television for daily weather forecast and relevance to agricultural activities) to help for effective adaptation accounted for 65.1%. Provision of extension agents to educate more on agriculture and better land management techniques accounted for 39.3%, provision of sufficient current knowledge to adapting measures accounted for 33.8% while 63.7% of the respondents disagreed that adequate access to new technologies an action so far taken by the government while 24.8% are agreed. Also, 48.6% of the respondents disagreed on the provision of irrigation facilities and investments as actions taken by the government respectively. 31.7% of the respondents were undecided about the provision of agricultural insurance as governmental action. This indicates that the pastoralists need adequate agricultural insurance and adequate access to new technologies from the government. P-value is 0.00908 at p≤0.05. Thus, the hypothesis which states that governmental Actions on climate change for pastoralists have a significant variation in the study area is accepted.

**Things that should be done to mitigate climate change:** Insurance accounted for 25.8%, better awareness 18.5%, teaching new techniques accounted for 17.2%, early notification accounted for 15.9%, provision of technology 14.4%, and 8.3% provision of extension agents. This indicates that Government should provide adequate insurance schemes for pastoralists, better awareness and teaching new farming techniques should be adopted by these pastoralists by providing extension agents by the Government. P-value is 0.01612 at p≤0.05. As a result, the hypothesis that things that should be done to mitigate climate change vary significantly, and government need to deliver palatable assurances plans for pastoralists, predominant mindfulness, and educating present-day developing procedures in the study area is accepted.

## CONCLUSION

There is a significant statistical variation in respondents' knowledge and sources of information about climate change. The study also through its findings concludes that there is a significant statistical variation in pastoralists' perception of the effects of climate change while there was no statistically significant variation in the coping strategies adopted by pastoralists. There has been not enough action taken in the study area to help pastoralists mitigate the effects of climate change. Pastoralists in the study area need to adjust to the changing climate trend to save their means of livelihood, as addressing the climate change issues observed in the study will significantly help Pastoralists remain in business. Supporting pastoralists to increase their adaptation capacities through the provision of necessary resources such as credit facilities, information and training can significantly help them increase and sustain high levels of productivity even under changing climatic conditions. Government policies need to support the research and development of appropriate technologies to help pastoralists adapt to changes in climatic conditions. Government responsibilities include putting in place policy measures to mitigate the adverse effects of climate change on pastoralists. Examples of these policy measures include the introduction of drought-resistant crop varieties, improving climate information forecasting and dissemination, or promoting farm-level adaptation measures, such as the use of irrigation technologies. Accessibility to key agricultural production information like water and soil conservation techniques as well as the other adaptation options identified will help to boost pastoralists' coping strategies.

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# Contribution of GIS in the Identification and Mapping of Natural Forest Habitats: Case Study of the Forests of El Kala, Wilaya of El Tarf, Algeria

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***Abstract***: The El Kala region, with its different natural forest habitats, represents an important biological heritage at the national and international levels. Today, it is threatened by various dangers, such as overexploitation and fires. It is therefore urgent to preserve these sensitive and fragile habitats and imperative to better identify them to apply adequate preservation and management measures. Current forest inventory data do not allow the identification of these habitats. The quality of these data also limits the relevance of landscape analyses. The current approach is inspired by various European experiences, including the ecological approach of phytosociology for habitat determination. The phytoecological study and the use of a high-resolution satellite image sentinel-2B allowed us to elaborate on a land-use map. Statistical processing using factorial correspondence analysis helped us to identify the habitats. The mapping was facilitated by the use of an open-source geographic information system Qgis 3.4.9. Finally, were able to discriminate two forest habitats with *Quercus suber* L. and one habitat with *Quercus faginea* Lam. The exploitation of Sentinel-2B images is very useful for high-resolution monitoring of land use and the extent of fragmentation of natural forest habitats caused by anthropozoic action.

***Keywords***: GIS, Sentinel-2B image, El Kala forests, Forest management, Natural forest habitats

Mediterranean woodland formations are characterized by a high degree of fragility due to environmental conditions and human action. Throughout its history, Algerian woodlands have been subjected to various forms of aggression: anthropozoic and climatic, leading to a degradation of woodland areas into scrub and grassland. The El Kala region, which is one of the Mediterranean basin's hotspots (Véla and Benhouhou 2007) with high biodiversity, is currently experiencing these dangers. Indeed, the regressive dynamics of the ecosystems have intensified over the last decades and we are witnessing the fragmentation and reduction of forest habitats.

In Algeria, few studies have been conducted to define forest habitats. These studies have mainly focused on the mapping of forest stations (Terras 2011), the mapping of mammal biotope (Zahafi 2017), the mapping of rainforests in the region of El Kala (Kahli et al 2018), the diversity of habitats (Medjahdi and Letreuch belarouci 2017 and Zeraia 2018) and finally, the degradation, reduction and dynamics of habitats under the influence of anthropogenic pressures (Siba et al 2022). All these studies have concerned different aspects of habitats without providing a clear methodology for the identification and mapping of natural habitats. This approach is inspired by various European experiences, namely: the Corine Biotope typology (Bissardon et al 1997), which has now been succeeded by the EUNIS (European Nature Information System) typology by Louvel et al (2013), as well as the habitat notebooks which are the French version of the Natura 2000 nomenclature (Bensettiti et al 2002, Bensettiti et al 2005). The present work concerns the identification and mapping of forest habitats in the El Kala region. The mapping of habitats and species must necessarily be based on field observations and to do this our approach is inspired by the methodological guide for the mapping of natural habitats and plant species applied to terrestrial sites of the natura 2000 network (Clair et al

2006).The objective of our work is to implement, from data collected in the field and by exploiting a satellite image, a map of natural forest habitats that will be useful in the management and monitoring of these ecosystems (Nguyen et al 2021, Khalaf and Younis Al-alaf 2021).

## MATERIAL AND METHODS

**Study area**: The study area is located in the extreme North-East of Algeria, our study area covers an area of more than 30 000 hectares, part of which is included in the El-Kala National Park which is fully included in the Wilaya of El-Tarf, and another part outside the park located in the communes of El-Tarf and Zitouna. It is located between 8°14'29.76" and 8°29'57.48" East longitude and 36°34'51.6" and 36°48'36" North latitude. It is bounded to the north by the East-West motorway, to the south by Jebel El Ghourrah, to the east by Tunisia, and to the west by Zitouna and Bouteldja (Fig. 1).

**Data description:** The mapping of habitats and species must necessarily be based on field observations and to do this present approach is inspired by the methodological guide for the mapping of natural habitats and plant species applied to terrestrial sites of the natura 2000 network (Clair et al 2006, Cajeri et al 2012) as well as the ecological approach of phytosociology for the determination of habitats (Bonhême 2021). The phytoecological study and the use of a satellite image will enable us to draw up a map of the land occupation. The processing of the floristic surveys by correspondence factorial analysis will facilitate the identification of the different habitats. The approach adopted for the identification and mapping of forest habitats in our study area is based on the processing of a 10m sentinel 2B image by the open-source software QGIS 3.4.9 and consists of three phases:- Processing of the satellite image, Mapping of the land use and Statistical processing of the data using factorial correspondence analysis (FCA) for habitat identification and mapping.

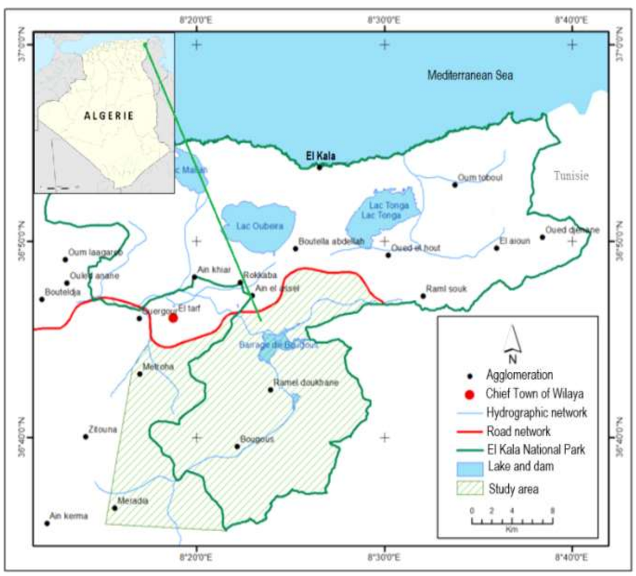


**Fig. 1.** Location of the study area

**Satellite image processing:** In this phase, proceeded to a color composition of the three visible RGB bands of the sentinel image 2B of 6 June 2020 (T32SM_ 20200602T100559, downloaded from the Copernicus platform at https://scihub.copernicus.eu) using QGIS 3.4.9 Madeira software. The three bands are merged into individual files by creating a layer stack. The layer stack allows the bands to be displayed in red, green, or blue depending on the use. Once the colored composition was obtained we highlighted our site of interest using the clipping option which reduces the file size and allows for faster processing of the image and used the boundary of our study area (Fig. 2 and 3) and then proceeded to a supervised classification (Fig. 4) of this area to have more precision (Qadir 2019).

**Land use mapping:** The field study began in April 2021 with a survey of the area, taking into account the results of the classification, which guided us in the choice of the location of

**Fig. 2.** Merge of the RGB bands

**Fig. 3.** Cutting of the study area

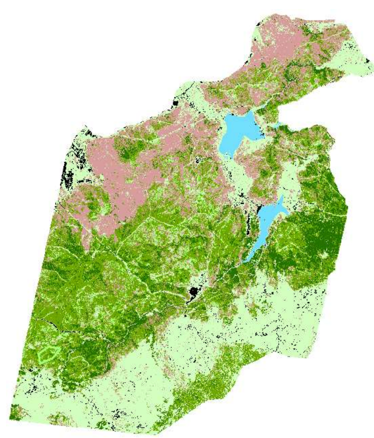

**Fig. 4.** Result of the supervised classification

the sampling plots, taking into account biotic and abiotic factors. Field sampling will allow the identification and characterization of all the facies identified by the supervised classification.

The choice of plot locations calls for various sampling methods specific to the types of problems posed, and considering the objective of the study, we adopted subjective sampling for the installation of the plots. Within each plot, carried out an inventory that took into account two aspects: biotic and abiotic. A complete floristic survey was carried out on each 400 $m^2$ plot with the scoring of the abundance-dominance of the species present (Bert 1992). The ecological data are assessed, or measured directly in the field. The pre-minute land use map obtained by supervised classification and floristic information allows us to establish the land use map. The latter is primarily a map of the present vegetation, understood mainly in terms of its structure and essential floristic composition, plus the other forms of land use (Long 1974).

**Statistical processing of the surveys by correspondence factor analysis (CFA) and identification of forest habitats:** The processing of the phytoecological surveys was carried out using factorial correspondence analysis (FCA). The latter was developed by Benzekri (1964) and Cordier (1965) and was the most suitable method in this field. Since then, this method has been used successfully by many authors (Lacoste and Roux 1971, Romane 1972, Bonin and Roux 1978, Montana and Greig-Smith 1990, Mercier et al 1992). Correspondence factorial analysis makes it possible to highlight the relationships between the various plant groups and ecological factors (climatic, edaphic, etc.). For a forester, especially a manager, this type of computer processing is a crucial phase that facilitates the identification of homogeneous and homo-ecological zones at the level of stations and stands and makes it possible to define forest habitats based on a combination of the most discriminating floristic groups, characterized by a type of soil and placed in a precise climatic context. The factorial correspondence analysis was applied to a presence/absence matrix of 23 surveys and 40 species using the XLSTAT software. The collected data are integrated with a geographical information database. The processing and analysis of the data will allow the identification of habitats.

## RESULTS AND DISCUSSION

The application of GIS allowed to produce the land use map by superimposing the different digitized layers and created a database by bringing together all the layers and their attributes. Land use map database contains all the information about the map units survey number, the vegetation formation, the type of the formation, its floristic composition, its height, and density, as well as the altitude, the exposure, observations. The results obtained are represented in the form of cartographic support identifying the various components of the area studied. Five physiognomic types are highlighted: forests, matorrals, plantations, wadi vegetation (riparian vegetation) as well as grasslands and fallow lands. These vegetation formations occupy a surface area of 33,408.4 ha, i.e., 96.6% of the study area. The remainder is made up of 1,148.62 ha and is occupied by: firebreaks, bare soil, settlements, rocky outcrops, reservoirs and dams as well as road infrastructures (Fig. 5 and 6).

**Forests:** They occupy a large area of 12 826, 8 hectares (37, 1% of the total area) and highlighted several forest facies, pure forests, and mixed forests. Pure forests with *Quercus faginea* Willd. occupying an area of 1335, 4 hectares. Mixed forest with *Quercus faginea* Willd. and *Quercus suber* L. covering an area of 658, 5 hectares. Pure *Quercus suber* L. forests covering 10 832, 4 hectares.

**Matorrals:** These are the result of forest degradation and are characterized by trees not exceeding 6 meters in height. In present study area, they occupy a surface area of 9773 hectares, i.e., 28.28% of the total surface area. These essentially evergreen bushy formations that derive from the forest play a fundamental role in the current Mediterranean landscape (Quezel and Medail 2003).

**Plantations:** These occupy an area of 2 115, 3 hectares, i.e., 6, 12% of the total area. They are essentially made up of pure stands of *Eucalyptus* sp or mixed with *Acacia dealbata* Link.

**Riparian vegetation (wadi vegetation):** These are plant formations found on the banks of the wadis to the north and south of the study area and occupy a surface area of 174 hectares. They are mainly represented by: *Populus alba* L., *Populus nigra* L., *Laurus nobilis* L., *Nerium oleander* L., *Salix alba* L. and *Salix pedicellata* Desf.

**Grasslands and fallow lands:** These formations are mainly found in the southern part of the study area and occupy a

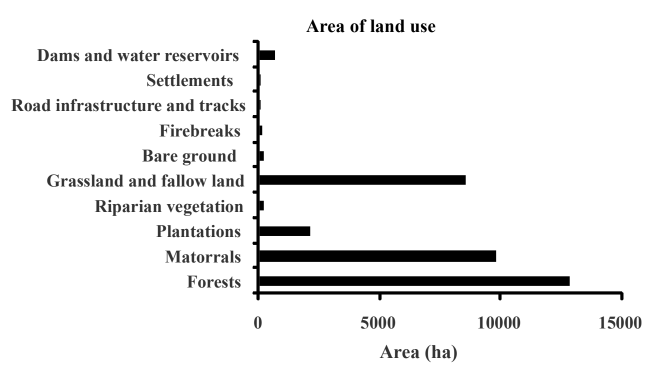


**Fig. 5.** Distribution of area by land-use type

significant area of 8,519 ha or 24.65% of the total area.

**Bare soil:** This covers an area of 197, 1 ha.

**Road infrastructure and tracks:** They occupy 56, 39 hectares. Settlements: These cover 83.53 hectares.

**Firebreaks:** These cover 162, 4 hectares. Dams and water reservoirs: The Mexa and Bougous dams cover an area of 649, 2 hectares.

**Mapping of forest habitats:** The natural forest habitats of the study area were identified by employing factorial correspondence analysis (FCA). The latter is a preferred tool for processing floristic data. It was elaborated based on information from the land use map and data from plant surveys carried out during our field campaigns.

**Correspondence factor analysis**: It distributed the species and records around the first two main axes that express the maximum information. The ½ factorial design absorbs the maximum inertia, 58.69% of the total variation. On the positive side of axis 1, the set I formed by ten surveys (3, 4, 5, 6, 7, 9, 10, 11, 13, and 14) which is opposed to the set II formed by ten surveys (1, 2, 8, 12, 15, 16, 18, 19, 22 and 23). As for axis 2, only three surveys (17, 20, and 21) are found in its positive part forming set III. The cloud of sets in the 1-2 plane (Fig. 7) with its typical parabolic shape seems to show a Guttman effect (Escofier and Pagès 2005).

**Group I:** It includes degraded forest facies, matorrals, and plantations characterized by the following species: *Quercus suber* L., *Calicotome spinosa* (L.) Link, *Erica arborea* L., *Phillyrea angustifolia* L., *Lavandula angustifolia* Mill, *Pistacia lentiscus* L., *Olea europaea* subsp. *Europaea* L., *Cistus monspeliensis* L., *Cistus salviifolius* L., *Chamaerops humilis* L., and *Ampelodesmos mauritanicus* (Poir) T.Durand and Schinz. The presence of *Calicotome spinosa* (L.) Link. is an indicator of the degradation of the cork oak forest, which can lead to the disappearance of the cork oak and its usual cork tree, and the installation of a flora belonging to other degraded facies such as *Ampelodesmos mauritanicus* (Poir) T. durand and Schinz (Dahmani 1984 , Zeraia 1981). *Pistacia lentiscus* L, on the other hand, is a species known for its thermo-xerophilic character and is indicative of the degradation of cork oak forest (Debazac 1959, Aime 1976 and Dahmani 1984). The presence of *Pistacia lentiscus* L. also indicates degradation caused by fires, hence the

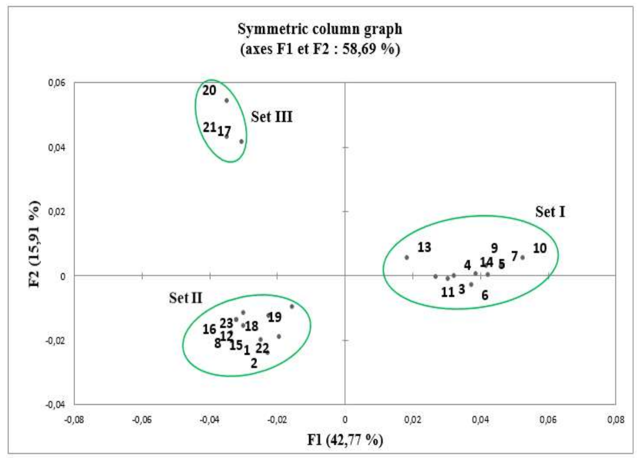


**Fig. 7.** Projection of the 23 floristic statements of the factorial analysis of correspondences on the factorial plan ½

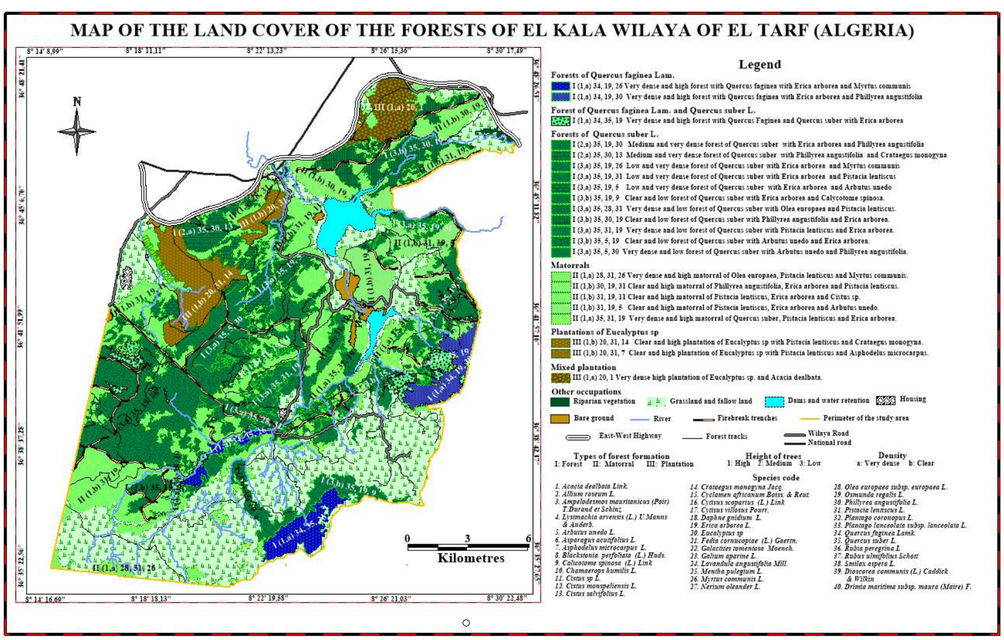


**Fig. 6.** Land use map of the study area (forests of El Kala)

degradation of the vegetation cover, which creates openings for tree and shrub strata and the installation of thermophilic species (Khelifi 1987) such as *Chamaerops humilis* L. and heliophilic species such as *Cistus salviifolius* L. The association of *Pistacia lentiscus* L. and *Ampelodesmos mauritanicus* (Poir) T.Durand and Schinz. bears witness to the degradation of the cork oak forest. This group, which includes degraded facies with cork oak, represents the habitat of *Quercus suber* L. in a thermophilic environment.

**Group II:** This groups together forest facies with *Quercus suber* L. with an undergrowth dominated by the following species: *Quercus suber* L., *Cytisus villosus* Pourr. *Rubus ulmifolius* Schott, *Crataegus monogyna* Jacq, *Daphne gnidium* L., *Myrtus communis* L., *Rubia peregrina* L., *Pistacia lentiscus* L., *Cytisus scoparius* (L.) Link, *Smilax aspera* L., *Daphne gnidium* L. and *Dioscorea communis* (L.) Caddick & Wilkin. The appearance of *Rubia peregrina* L., which is a hygrophilous species (Khelifi 1987), characterizes well-drained humus soils. *Crataegus monogyna* Jacq. and *Rubia peregrina* L. are humicolous species (Bekdouche 2010). This group, which includes the advanced cork oak forests, forms the habitat of *Quercus suber* L. in a humid environment.

**Group III:** It occupies the positive side of axis 2, and includes records of pure Quercus faginea Lamk. forests as well as mixed *Quercus faginea* Willd. and *Quercus suber* L. forests where the atmosphere is forested. The species characterizing this group are: *Quercus faginea* Willd., *Quercus suber* L., *Rubus ulmifolius* Schott, *Viburnum tinus* L., *Crataegus monogyna* Jacq, *Cytisus villosus* Pourr, *Asparagus acutifolius* L., *Rubia peregrina* L., *Dioscorea communis* (L.) Caddick and Wilkin, *Osmunda regalis* L., *Myrtus communis* L. *Arbutus unedo* L., *Cyclamen africanum* Boiss. and Reut, *Smilax aspera* L. and *Blackstonia perfoliata* (L.) Huds. The tree stratum prevents the passage of light to the lower strata, which favors the development of a lianascent flora such as *Smilax aspera* L. (Khelifi 1987). The presence of *Osmunda regalis* L., *Cyclamen africanum* Bois. and Reut. and *Dioscorea communis* (L.) Caddick and Wilkin. This indicates that the environments are shaded. Group III groups together the facies of the Zeen oak with its floral procession representing the habitats of *Quercus faginea* Willd in a cool environment.

**Map of natural forest habitats:** In present study were able to delineate three natural forest habitats in our study area, two with *Quercus suber* L and one with *Quercus faginea* Willd covering an area of 24 715,4 ha (Fig. 8).

**Thermophilous habitat with *Quercus suber* L.:** It is dominated by a degraded undergrowth of thermophilous character and covers an area of 14 766, 6 ha or 59.77% of the total forest area. This area shows the extent of degradation in our study area. This habitat, which is normally found only in the thermo-Mediterranean zone at an altitude of no more than 400 m, is found in the Meso-Mediterranean zone at an altitude of more than 800 m, colonizing the *Quercus faginea* Willd. habitat, thus forming fragments of thermophilous habitats with *Quercus suber* L. This dynamic transformation of the most humid and evolved habitats into thermophilic and degraded habitats is the consequence of anthropic actions,

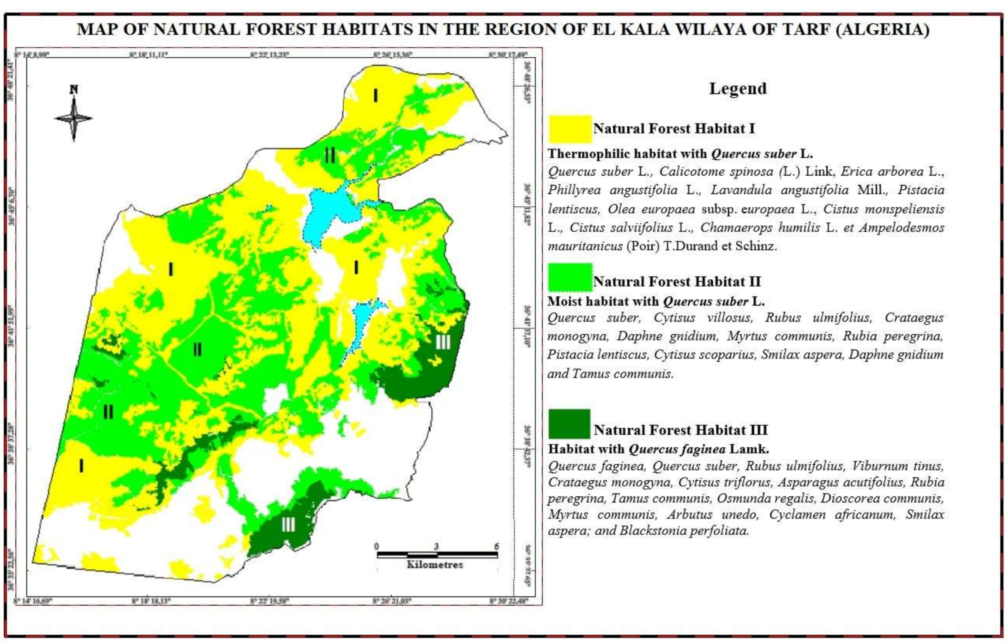


**Fig. 8.** Map of natural forest habitats

primarily fires, combined with climate change. The opening of the shrub layer after fire favors the installation of thermophilic species (Khelifi 1987) such as *Pistacia lentiscus* L., *Cistus monspeliensis* L., and *Cistus salviifolius* L. (Dahmani 1984).

**Moist habitat with *Quercus suber* L.:** This habitat includes the most advanced facies of *Quercus suber* L. and is found in almost the entire study area between 150 m and 950 m altitude, covering an area of 7 944,2 ha, i.e., 32.15% of the total forest area in our study area. It is characterized by a cover of more than 90% and an undergrowth with a humid atmosphere. However, its extent is limited by the thermophilic cork oak facies, which reduces its area to the detriment of the thermophilic habitat. The presence of certain species such as *Pistacia lentiscus* in its floristic procession shows the frequency of fires, which favors the fragmentation of this habitat. Habitat fragmentation leads to both quantitative and qualitative habitat loss for species that originally depended on the ecosystem (Faboorg et al 1993). And finally, habitat destruction leads to the loss of rare and endemic species at the expense of ubiquitous ones (Jeph and Khan 2019). At altitude, the presence of *Quercus suber* in this habitat and always associated with *Cytisus villosus* Pourr. which characterizes humid and shady environments, and its appearance indicates that these subterranean forests are gradually giving way to the zenaia (Zeraia 1981) in a logic of progressive dynamics.

**Habitat with *Quercus faginea* Willd. :** It is located between 300 m and 1200 m in both vegetation levels, but its surface area is very limited, covering only 1 993,9 ha. In the thermo-Mediterranean vegetation level, it is found along watercourses where the atmosphere is more or less humid in the southern part. The largest area of this habitat is located in the south-eastern part of the study area between 450 m and 1200 m altitude. In these conditions, the trees of Oak zeen reach average heights of 19 m, the global cover of the vegetation in these conditions is 100% and the undergrowth is essentially made up of species indicative of shady environments such as the species *Osmunda regalis* L. (Belouahem-Abed 2009). The presence of *Cyclamen africanum* Bois. and Reut. which is a mesophilic species indicative of humus soils indicating a humid and cool forest environment. These conditions allow the good development of *Quercus faginea* Willd. which is a deciduous tree, endemic to the Mediterranean, and prefers brown, leached, deep, permeable, and slightly acid soils.

## CONCLUSION

The present approach allowed us to identify and map the natural forest habitats of our study area. The contribution of the high-resolution satellite image sentinel 2B seems to be relevant for the identification of the different sylvofacies and the estimation of the land cover areas. GIS seems to be the right tool for monitoring the natural dynamics of ecosystems and the biotic disturbances, natural or anthropogenic, that the ecosystem is undergoing. The results showed that this ecological approach of phytosociology for habitat determination seems to be a suitable methodology for the identification and mapping of habitats and can be generalized for the whole forest territory, for better management and monitoring of these ecosystems.

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# Floristic Diversity and Species Composition in Urban Areas at Sub-Himalayan Region of West Bengal, India

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***Abstract*:** Urban green landscapes are crucial in the period of drastic population increase, climate change concerns and pollution. Urban forestry conserves biodiversity and provides ecosystem services, thereby increasing the aesthetic value of cities. However, studies on the urban vegetation cover and their quantification are rare in India. Hence, the present analysis focused on the vegetation composition, quantitative characters and diversity indices in urban areas. The study was carried out through stratified random quadrat sampling and line transect method in urban green areas (three parks and one institutional area) of Cooch Behar city, West Bengal, India. Around 76 plant species, which belong to 67 genera and 39 families, were documented in the studied areas. The highest species richness was reported in Nripendra Narayan Park, followed by Royal Eco Heritage Park. Royal Eco Heritage Park is highly diverse according to the species diversity index. The species *Codiaeum variegatum, Polyalthia longifolia* and *Neolamarckia cadamba* are reported from all the urban forestry landscapes. The study serves as a managerial planning tool for the proper maintenance and management of urban green spaces.

***Keywords*:** Vegetation diversity, Urban green sites, Species composition, Himalayas

Dramatic urbanization is happening unevenly worldwide (Sun et al 2020). According to the UN (2018) report, the urban population will increase up to 68% of the world population (6.6 billion) by 2050. This population trend develops concern in developing countries where urban environmental problems and lack of food security hinder sustainability (Sun et al 2020, Kuddus et al 2020). Moreover, the city transport sector, industrialization and reduction in green space are leading more to climate change. Urban areas that presently contribute less than three per cent of the global terrestrial surface; account for 78 % of carbon emissions, 60 % of residential water use and 76 % of wood used for industrial purposes (Pandey and Chaudhry 2010). If the current urban growth rate continues, the global urban land cover will increase by 1.2 million $km^2$ by 2030, with considerable loss of habitats in critical biodiversity hotspots (Seto et al 2013). Therefore, urban forestry practices are significant and are of immediate need of the hour. Urban forestry practices mitigate sound and air pollution, provides ecosystem services (Wirtz et al 2021) and conserve biodiversity (Giuliano et al 2004, Khera et al 2009). Tree components in urban forestry practices sequester carbon which mitigates climate change.

In India, urban forestry-related works are scanty (Nagendra and Gopal 2010a, Chaudhry and Tewari 2011) compared to the forest vegetation studies. Even though few studies mention the environmental implications of urbanization, analysis and documentation of urban park-oriented biodiversity are less. Urban forestry vegetation, distribution and utilization need more scientific explorations to reveal the conservation roles of such urban landscapes. Hence, the present study documented vegetation quantitatively and the composition of urban green space in sub-humid climatic conditions of West Bengal, India. This study and its information are helpful to plan the strategies for urban landscape vegetation management and conservation.

## MATERIAL AND METHODS

**Site description:** Cooch Behar is a historical town established by the erstwhile Koch dynasty and comes under the Terai zone of West Bengal (sub-Himalayan foothill region). The Cooch Behar district is located in West Bengal, India with $26^0$ 23' 45.8" N latitude and $89^0$ 23' 16.7" E Longitude and at 43 m above mean sea level. The present study was carried out at three parks with a total area of 5, 10 & 15 ha (Nripendra Narayan Park (N. N. Park), Royal Eco Heritage Park, Rajbari Heritage Site) and one institutional area (Border Security Force-BSF-50 ha) in the town of Cooch Behar, West Bengal, India. There is a considerable variation in seasonal and diurnal temperature of the study sites, mostly moist tropical in nature. The total annual rainfall received was about 2305.91 mm of which about 80 % was recorded from April to September and relative humidity ranged from about

49 to 94 %. The summer and winter temperatures are mild with the highest of 33$^0$C during August and the lowest of 9$^0$C during January.

**Field survey, sampling and inventory:** All the areas of parks and institutions were physically visited for documentation purposes. The identification was done mostly at the location except for a few species that were not identified easily were mounted on the herbarium sheets following the standard method of herbarium for further identification. The mounted specimens were cross-checked with the available herbarium in the Department of forestry UBKV, Pundibari, West Bengal, India. Trees or shrubs along the boundary or paths of the sites were sampled through line transects of size 2 m × 10 m long and for others through stratified random nested quadrat (20 x 20) sampling method. Standard procedures were adapted to calculate density, relative frequency, relative abundance, relative density and importance value index (Raunkiaer 1934, Cintron and Novelli 1984). Some of the frequently used diversity indices like species richness, species diversity index (Menhinick 1964), concentration of dominance (Simpson 1949), Shannon-Wiener diversity index (Shannon and Weiner 1963) and species evenness index (Pielou 1975) were used to analyze the vegetation diversity of the urban green areas.

## RESULTS AND DISCUSSION

**Diversity indices and species composition:** Overall, 76 plant species were documented from the parks and institutional area, which belong to 67 genera and 39 families (Table 1, 2; Fig. 1). Among the parks and institutional areas, N. N. Park was dominated by other sites with 42 species (25 families and 40 genera), followed by Royal Eco Heritage Park with 41 (24 families and 39 genera). The species diversity index or Menhinick's index was 4.58 for Royal Eco Heritage Park followed by N. N. Park, Rajbari Heritage and the lowest 1.09 for the BSF campus of the Cooch Behar Town. The Shannon and Weiner index of species was 6.00 for N. N. Park, followed by Royal Eco Heritage Park, BSF area and Rajbari. The evenness index was 0.05 for Royal Eco

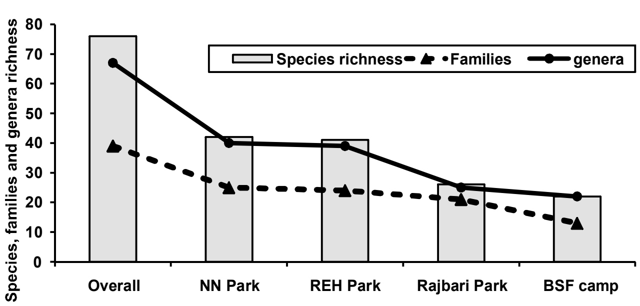


**Fig. 1.** Species, family and genera richness in the green sites

Heritage Park and N. N. Park. The highest index value estimated for Royal Eco Heritage Park indicates the diversity and highest species richness. However, the diversity of the sites was neither too high nor too less as the presence of species was more or less frequent. The concentration of dominance value of overall species was 5.75 for Royal Eco Heritage Park and 5.65 for N. N. Park. This reflects the number of chances the species encountered during sampling was low and a lower value means the chances of encountering being high, indicates an abundance of occurrence.

**Vegetation analysis of urban parks:** The degree of dispersion of the species in the N. N. Park ranged from 16.7 to 83.3 %. The chance of occurrence of *Callistemon lanceolatus, Elaeocarpus ganitrus* and *Mimusops elengi* each was lowest while *Jatropha curcas* was the most frequent species. The chance of occurrence of trees and shrubs ranged from 16.7 to 66.7 % and 16.7 to 83.3 % respectively, while for herbs it was 33.3 %. The relative frequency ranged from 1.2 to 5.9. The highest relative frequency was estimated for *Jatropha curcas* and the lowest for *Mimusops elengi, Neolamarckia cadamba* and *Syzygium cumini* each. Similarly, the value of relative frequency showed that the chance of occurrence of *J. curcas* was highest concerning all other species while the chance of occurrence was least for species like *M. elengi, N. cadamba and S. cumini*. Herb species with a relative frequency of 2.4 had the lowest chance of occurrence with other life forms *i.e*., shrubs (2.4-5.9) and trees (1.2-4.7). The density of species was in the range of 0.2-10.0 % indicating the highest numerical strength for *Dalbergia sissoo* and lowest for *M. elengi, N. cadamba* and *S. cumini*. The numerical strength of the herbs was 0.7 %, while it ranged from 0.8-8.2 % for shrubs and 0.2-10.0 % for trees. Numerical strength values indicate that the trees were the dominating species in N. N. Park. Similarly, the relative density was in the range of 0.2 (*M. elengi, N. cadamba* and *S. cumini*)- 16.5 (*D. Sissoo*). Relative density estimated for herbs (1.1), shrubs (1.1-13.5), and trees (0.3-16.5) indicate that herbs were low in numerical strength population density relative to shrubs and trees. The abundance of documented species was in the range of 1.0-16.3 %. In N. N. Park *Hibiscus rosa-sinensis* was the most abundant species, while the least abundant species were *M. elengi, N. cadamba and S. cumini*. Similarly, relative abundance estimated was in the range of 0.7-10.9 i.e., *H. rosa-sinensis* was the most abundant species relative to all other documented species and *M. elengi, N. cadamba* and *S. cumini* were the least abundant species relative to all other species. A similar trend was observed for herbs, shrubs, and trees as was estimated for relative density. IVI reflect the

**Table 1.** Vegetation diversity in parks

| Scientific name | D | RD | RF | RA | IVI | D | RD | RF | RA | IVI | D | RD | RF | RA | IVI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N. N. Park | | | | | R. E. H. Park | | | | | R. H. Site Park | | | | |
| *Araucaria araucana* K. Koch | 0.3 | 0.6 | 2.4 | 0.7 | 3.6 | | | | | | | | | | |
| *Areca catechu* (L. f.) | 0.7 | 1.1 | 2.4 | 1.3 | 4.8 | | | | | | 0.3 | 0.7 | 2.0 | 1.5 | 4.2 |
| *Artocarpus Heterophyllus* Lam. | 0.7 | 1.1 | 1.2 | 2.7 | 5.0 | 0.5 | 0.8 | 2.8 | 0.7 | 4.3 | 1.0 | 2.0 | 5.9 | 1.5 | 9.4 |
| *Azadirachta indica* A. Juss | | | | | | 0.5 | 0.8 | 1.4 | 1.4 | 3.6 | | | | | |
| *A. integrifolia* | | | | | | 1.8 | 2.7 | 2.8 | 2.5 | 8.0 | | | | | |
| *Albizia lebbeck* Benth. | 0.5 | 0.8 | 3.5 | 0.7 | 5.0 | 1.0 | 1.6 | 4.2 | 1.0 | 6.7 | | | | | |
| *Anacardium occidentale* L | | | | | | 0.3 | 0.4 | 1.4 | 0.7 | 2.5 | | | | | |
| *Albizia procera* (Roxb.) Benth. | | | | | | 1.0 | 1.6 | 4.2 | 1.0 | 6.7 | | | | | |
| *Alstonia scholaris* (L) R. Br | 0.3 | 0.6 | 1.2 | 1.3 | 3.1 | | | | | | | | | | |
| *Bombax ceiba* L. | 0.5 | 0.8 | 1.2 | 2.0 | 4.0 | | | | | | 0.5 | 1.0 | 2.0 | 2.2 | 5.2 |
| *Borassus flabellifer* L. | 0.3 | 0.6 | 2.4 | 0.7 | 3.6 | | | | | | | | | | |
| *Bischofia javanica* Blume | | | | | | 1.0 | 1.6 | 1.4 | 2.9 | 5.8 | | | | | |
| *Butea monosperma* | 0.3 | 0.6 | 1.2 | 1.3 | 3.1 | | | | | | | | | | |
| *Bambusa ventricosa* McClure | 0.2 | 0.3 | 1.2 | 0.7 | 2.1 | 0.3 | 0.4 | 1.4 | 0.7 | 2.5 | | | | | |
| *B.vulgaris* Schrad. Ex J. C. Wendl | | | | | | 0.3 | 0.4 | 1.4 | 0.7 | 2.5 | 0.3 | 0.3 | 2.0 | 0.7 | 3.0 |
| *Cassia fistula* L. | 0.2 | 0.3 | 1.2 | 0.7 | 2.1 | 1.5 | 2.3 | 2.8 | 2.2 | 7.3 | | | | | |
| *Calophyllum inophyllum* L. | | | | | | | | | | | 0.5 | 1.0 | 5.9 | 0.7 | 7.6 |
| *Callistemon lanceolatus* (Sm.) | 1.7 | 2.8 | 1.2 | 6.7 | 10.6 | 0.5 | 0.8 | 1.4 | 1.44 | 3.6 | | | | | |
| *Cocos nucifera* L. | 1.8 | 3.0 | 3.5 | 2.5 | 9.01 | 0.5 | 0.8 | 2.8 | 0.7 | 4.3 | 0.7 | 1.3 | 3.9 | 1.5 | 6.7 |
| *Cinnamomum tamala*T. Nees& C.H. Eberm | | | | | | 0.5 | 0.8 | 1.4 | 1.4 | 3.6 | | | | | |
| *Caryota urens* L. | | | | | | 1.0 | 1.6 | 1.4 | 2.9 | 5.8 | | | | | |
| *Delonix regia* (Hook) Raf | 0.2 | 0.3 | 1.2 | 0.7 | 2.1 | 2.0 | 3.1 | 1.4 | 5.8 | 10.3 | 0.5 | 1.0 | 3.9 | 1.1 | 6.0 |
| *Dalbergia sissoo* Roxb. ex DC | 10.0 | 16.5 | 4.7 | 10.1 | 31.2 | 0.3 | 0.4 | 1.4 | 0.7 | 2.5 | | | | | |
| *Elaeocarpus ganitrus* Roxb./Sphaericus | 0.3 | 0.6 | 1.2 | 1.3 | 3.1 | | | | | | | | | | |
| *Ehretia acuminata* (D. C) R. Br. | | | | | | 2.8 | 4.3 | 4.2 | 2.6 | 11.1 | | | | | |
| *Eucalyptus globulus* Labill | 0.3 | 0.6 | 2.4 | 0.7 | 3.6 | | | | | | | | | | |
| *Ficus benghalensis* Linn | 0.5 | 0.8 | 3.5 | 0.7 | 5.0 | | | | | | | | | | |
| *F. elastica* Roxb. ex Hornem | | | | | | | | | | | 0.7 | 1.3 | 3.9 | 1.5 | 6.7 |
| *F. glomerata* Roxb. | | | | | | 0.5 | 0.8 | 2.8 | 0.7 | 4.3 | | | | | |
| *F. religiosa* L. | | | | | | 1.0 | 1.6 | 4.2 | 1.0 | 6.7 | | | | | |
| *F. roxburghii* Lour. | | | | | | | | | | | 0.2 | 0.3 | 2.0 | 0.7 | 3.0 |
| *Gmelina arborea* Roxb. | | | | | | | | | | | 0.2 | 0.3 | 2.0 | 0.7 | 3.0 |
| *Grevillea robusta* Cunn. ex R. Br. | 1.8 | 3.0 | 3.5 | 2.5 | 9.0 | | | | | | | | | | |
| *Litsea monopetella* (Roxb.) | | | | | | 2.0 | 3.1 | 4.2 | 1.9 | 9.2 | | | | | |
| *Lagerstroemia parviflora* (L) Pers | 1.3 | 2.2 | 3.5 | 1.8 | 7.5 | | | | | | | | | | |
| *L. speciosa* (L) Pers | 1.0 | 1.7 | 4.7 | 1.0 | 7.4 | 5.5 | 8.5 | 2.8 | 7.9 | 19.2 | | | | | |
| *Michelia champaca* L. | 0.3 | 0.6 | 1.2 | 1.3 | 3.1 | 0.3 | 0.4 | 1.4 | 0.7 | 2.5 | | | | | |
| *Mimusops elengi* L. | 0.2 | 0.3 | 1.2 | 0.7 | 2.1 | 6.5 | 10.1 | 2.8 | 9.4 | 22.2 | 1.0 | 2.0 | 0.7 | 3.0 | 3.0 |
| *Mangifera indica* L. | 2.3 | 3.9 | 3.5 | 3.1 | 10.5 | 1.3 | 1.9 | 2.8 | 1.8 | 6.5 | 0.3 | 0.7 | 2.0 | 1.5 | 4.2 |

**Cont...**

**Table 1.** Vegetation diversity in parks

| Scientific name | D | RD | RF | RA | IVI | D | RD | RF | RA | IVI | D | RD | RF | RA | IVI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N. N. Park | | | | | R. E. H. Park | | | | | R. H. Site Park | | | | |
| *Mallotus tetracoccus* (Roxb.) Kurz. | | | | | 25 | 3.0 | 1.4 | 2.2 | 4.7 | | | | | | |
| *Neolamarckia cadamba* (Roxb.) | 0.2 | 0.3 | 1.2 | 0.7 | 2.0 | 5.5 | 8.5 | 5.6 | 4.0 | 18.1 | 7.3 | 14.4 | 7.8 | 8.2 | 30.4 |
| *Oncoba spinosa* Forssk | | | | | | | | | | | 0.2 | 0.3 | 2.0 | 0.7 | 3.0 |
| *Psidium guajava* L. | | | | | | 0.8 | 1.2 | 1.4 | 2.2 | 4.7 | 0.8 | 1.2 | 1.4 | 2.2 | 4.7 |
| *Polyalthia longifolia* (Soon) | 0.7 | 1.1 | 1.2 | 2.7 | 5.0 | 8.5 | 13.2 | 2.5 | 12.3 | 28.2 | 8.5 | 13.2 | 2.8 | 12.3 | 28.2 |
| *Pongamia pinnata* (L.) Pierre | 2.7 | 4.4 | 3.5 | 3.6 | 11.5 | 0.3 | 0.4 | 1.4 | 0.7 | 2.5 | | | | | |
| *Plumaria rubra* Linn | 0.3 | 0.6 | 2.4 | 0.7 | 3.6 | 1.3 | 1.9 | 4.2 | 1.2 | 7.3 | | | | | |
| *Pinus wallichiana* A.B. Jacks | 0.7 | 1.1 | 2.4 | 1.3 | 4.8 | | | | | | | | | | |
| *Roystonea regia* O. F. Cook | 0.7 | 1.1 | 2.4 | 1.3 | 4.8 | 4.5 | 7.0 | 2.8 | 6.5 | 16.2 | | | | | |
| *Saraca asoca* (Roxb.) Willd. | | | | | | | | | | | 1.0 | 1.6 | 4.2 | 1.0 | 6.7 |
| *Syzygium cumini* (L) Skeeks | 0.2 | 0.3 | 1.2 | 0.7 | 2.1 | | | | | | 0.2 | 0.4 | 1.8 | 0.7 | 2.9 |
| *Swietenia mahagoni* | 0.2 | 0.3 | 1.2 | 0.7 | 2.1 | 1.8 | 2.7 | 2.8 | 2.5 | 8.0 | | | | | |
| *Shorea robusta* Roth | | | | | | 0.3 | 0.4 | 1.4 | 0.7 | 2.5 | | | | | |
| *Samanea saman* F. Muell | 0.5 | 0.8 | 2.4 | 1.0 | 4.2 | | | | | | | | | | |
| *Terminalia arjuna* (Roxb.) Weight & Arn | 0.3 | 0.6 | 2.4 | 0.7 | 3.6 | | | | | | 0.7 | 1.3 | 3.9 | 1.5 | 6.7 |
| *Toona ciliate* M. Roem | | | | | | 1.0 | 1.6 | 2.8 | 1.4 | 5.8 | | | | | |
| *Terminalia elliptica* Wild | 1.5 | 2.5 | 2.4 | 3.0 | 7.8 | 2.0 | 3.1 | 1.4 | 5.8 | 10.3 | | | | | |
| *Tectona grandis* L. f | | | | | | 0.3 | 0.4 | 1.4 | 0.7 | 2.5 | | | | | |
| *Tabernaemontana divaricata* R. Br. Ex Roem. & Schult | | | | | | | | | | | 1.3 | 2.7 | 5.9 | 2.0 | 10.6 |
| *Thuja orientalis* L. | | | | | | 1.0 | 1.6 | 2.8 | 1.4 | 5.8 | | | | | |
| *Citrus limetta* L. | 0.7 | 1.1 | 1.2 | 2.7 | 5.0 | 1.0 | 1.6 | 2.8 | 1.4 | 5.8 | 0.2 | 0.3 | 2.0 | 0.7 | 3.0 |
| *Codiaeum variegatum* (L) A. Juss. | | | | | | | | | | | 1.3 | 2.6 | 7.8 | 1.5 | 11.9 |
| *Duranta plumieri* | 5.2 | 8.5 | 2.4 | 10.4 | 21.3 | 0.3 | 0.4 | 1.4 | 0.7 | 2.5 | | | | | |
| *Hibiscus rosa sinensis* L. | 8.2 | 13.5 | 3.5 | 10.9 | 27.9 | 0.3 | 0.4 | 1.4 | 0.7 | 2.5 | 7.8 | 15.4 | 3.9 | 17.5 | 36.7 |
| *Jatropha curcas* L. | 6.7 | 11.0 | 5.9 | 5.4 | 22.2 | | | | | | | | | | |
| *Murraya exotica* (L.) Jack | 4.2 | 6.9 | 4.7 | 4.2 | 15.8 | | | | | | | | | | |
| *Rosa rubiginosa* L. | | | | | | | | | | | 14.7 | 28.9 | 3.9 | 32.7 | 65.5 |
| *Celosia argentea* | | | | | | | | | | | 2.5 | 4.9 | 5.9 | 3.7 | 14.5 |
| *Canna indica* L. | 0.7 | 1.1 | 2.4 | 1.3 | 4.8 | | | | | | | | | | |
| *Musa paradisica* | | | | | | | | | | | 0.2 | 0.3 | 2.0 | 0.7 | 3.0 |

RF-Relative frequency; D-Density (individuals/ha); RD-Relative density; RA-Relative abundance; IVI-Importance value index importance of a particular species in its habitat IVI estimated for the documented species in N. N. Park was in the range of 2.1- 31.2. The most important species in the park were *D. sissoo* and the least *M. elengi, N. cadamba* and *S. cumini*. In herbs, IVI was 4.8 for *Canna indica* and in shrubs, it was *H. rosa-sinensis* with an IVI of 27.9. The next valuable trees after *D. sissoo* were *Pongamia pinnata* (11.5), degree of dispersion of the plant species in Royal Eco Heritage Park was in the range of 25-100 % i.e., the most frequent species in the park was *Neolamarckia cadamba*, while the least frequent species were *Syzygium jambos, Mallotus tetracoccus* and *Bischofia javanica*. The degree of dispersion of shrubs was 25-50 % and trees 25-100 %. Relative frequency estimated for the documented species was 1.4-5.6, i.e., *N. cadamba* was the most frequent species relative to all other documented species, while the least frequent species in relative terms were *Tectona grandis and Bambusa vulgaris*.

The density was in the range of 0.3- 8.5%. *Polyalthia longifolia* was the most numerically dominant species in the park due to its conical canopy which enhanced the aesthetic beauty of the park. The numerical strength of shrubs was 0.3-1.0 % and trees 0.3- 6.5 %. The relative density of all the documented species was in the range of 0.4-13.2. Relative density for the shrubs was in the range of 0.4-1.6 and for trees 0.4-10.1. The abundance of the entire documented species was in the range of 1.0-17.0 %. The most abundant species documented in the park was *Polyalthia longifolia* and the least abundant species were *Syzygium jambos, Tectona grandis* and *Bambusa vulgaris*. The relative abundance ranged between 0.7 and 12.3. The most abundant was *P. longifolia* relative to all other documented species in the park. IVI values estimated for the documented species of the park were 2.5-28.2. Thus, the most important species in this park was *P. longifolia* for its avenue and aesthetic values due to its dark green foliage, drooping branches and conical canopy. The other important species in this park were *Mimusops elengi* (22.2) and *Lagerstroemia Speciosa* (19.24). These species are also preferred avenue and aesthetic plants. The least important plant in the park was *S. jambos, T. grandis*

**Table 2.** Vegetation analysis of B. S. F. campus, Cooch Behar town

| SN | F | D' | A' | RD | RF | RA | IVI |
|---|---|---|---|---|---|---|---|
| *Areca catechu* | 66.7 | 8.3 | 12.5 | 13.0 | 5.2 | 12.9 | 31.0 |
| *Artocarpus hetrophyllus* | 66.7 | 3.3 | 5.0 | 5.2 | 5.2 | 5.2 | 15.5 |
| *Azadirachta indica* | 50.0 | 1.2 | 2.3 | 1.8 | 3.9 | 2.4 | 8.1 |
| *Albizia procera* | 100.0 | 6.2 | 6.2 | 9.6 | 7.8 | 6.4 | 23.7 |
| *Bombax ceiba* | 33.3 | 0.8 | 2.5 | 1.3 | 2.6 | 2.6 | 6.5 |
| *Butea monosperma* | 83.3 | 2.0 | 2.4 | 3.1 | 6.5 | 2.5 | 12.1 |
| *Cassia fistula* | 33.3 | 0.8 | 2.5 | 1.3 | 2.6 | 2.6 | 6.5 |
| *Delonix regia* | 50.0 | 1.0 | 2.0 | 1.6 | 3.9 | 2.1 | 7.5 |
| *Dalbergia sissoo* | 50.0 | 1.2 | 2.3 | 1.8 | 3.9 | 2.4 | 8.1 |
| *Eucalyptus globulus* | 33.3 | 0.3 | 1.0 | 0.5 | 2.6 | 1.0 | 4.2 |
| *Ficus religiosa* | 33.3 | 0.8 | 2.5 | 1.3 | 2.6 | 2.6 | 6.5 |
| *Gmelina arborea* | 50.0 | 2.2 | 4.3 | 3.4 | 3.9 | 4.5 | 11.7 |
| *Lagerstroemia speciosa* | 83.3 | 6.8 | 8.2 | 10.6 | 6.5 | 8.5 | 25.6 |
| *Melia azedarach* | 50.0 | 2.0 | 4.0 | 3.1 | 3.9 | 4.1 | 11.1 |
| *Michelia champaca* | 33.3 | 0.7 | 2.0 | 1.0 | 2.6 | 2.1 | 5.7 |
| *Mangifera indica* | 100.0 | 4.5 | 4.5 | 7.0 | 7.8 | 4.6 | 19.4 |
| *Psidium guajava* | 33.3 | 2.0 | 6.0 | 3.1 | 2.6 | 6.2 | 11.9 |
| *Polyalthia longifolia* | 83.3 | 13.7 | 16.4 | 21.2 | 6.5 | 16.9 | 44.7 |
| *Syzygium cuminii* | 66.7 | 2.7 | 4.0 | 4.2 | 5.2 | 4.1 | 13.5 |
| *Shorea robusta* | 50.0 | 1.0 | 2.0 | 1.6 | 3.9 | 2.1 | 7.5 |
| *Tectona grandis* | 83.3 | 1.7 | 2.0 | 2.6 | 6.5 | 2.1 | 11.2 |
| *Duranta plunnmieri* | 50.0 | 1.2 | 2.3 | 1.8 | 3.9 | 2.4 | 8.1 |

SN- scientific name; F-frequency, D'- density; A': abundance; RD-relative density; RF-relative frequency; RA- relative abundance; IVI-important value index *and B. Vulgaris* with an IVI value of 2.5 each. They were just scattered and casually planted trees in the interior of the park.

The frequency of the documented species was estimated in the range of 25-100 % i.e., *Codiaeum variegatum*, *Polyalthia longifolia* and *Neolamarckia cadamba* were documented from all the sampled plots of the site, while *Mimusops elengi, Oncoba spinosa and Syzygium cumini* were observed from the quarter of the sampled plots. Trees and shrubs occurred on all sampled plots and herbs on a quarter of the sampled plots. Similarly, the relative frequency was in the range of 1.4-5.6. The density of documented species in the site ranged between 0.2 and 14.7 %. *Rosa rubiginosa* was observed with the highest density in the site, while *M. elengi, O. spinosa and S. Cumini* were observed with the lowest density. The relative density ranged between 0.3 (*Mimusops elengi, Oncoba spinosa* and *Syzygium cumini*) and 28.9 (*Rosa rubiginosa*). Species abundance estimated in the Rajbari Heritage site was 1.0-44.0 % and the most abundant species found in the site was *R. rubiginosa* and the least abundant species were *M. elengi, O. spinosa*, *and S. cumini* and six other species. Similarly, relative abundance estimated was in the range of 0.7-32.7 and *R. rubiginosa* was most abundant relative to all documented species from the site, while *M. elengi, O. spinosa and S. cumini* were least abundant relative to all other documented species. The IVI was in the range of 3.0-65.5 and the most important species at the site was *R. rubiginosa* followed by *H. rosa-sinensis* (36.8), *and Polyalthia longifolia* (30.4) and the least was *M. elengi, Neolamarckia cadamba* and *S. cumini* with IVI value of 3.03 each. Rajbari Heritage site, Cooch Behar town is a heritage archaeologically protected site and popular among visitors. The species selected in its garden and along the path add to the aesthetic beauty of the heritage building.

**Institutional area (BSF campus):** BSF campus was abundant with open space with fewer scattered trees kept aside for their security operations, drilling and parking, thus the site was observed with the least species richness of all study sites (Table 2). Most of the species found on the campus were either planted along the paths and roads or surrounding the building infrastructures meant for providing shade and seasonal fruits with avenue purpose. The frequency or the degree of dispersion of the documented plant species on the BSF campus ranged between 33.3 and 100 %. The most frequent species were *Albizia procera* and *Mangifera indica* and the least frequent species were *Eucalyptus globulus, Michelia champaca and Ficus religiosa*. *Duranta plumieri* was the only shrub species found on the BSF campus. The relative frequency ranged between 2.6 and 7.8. *Albizia procera* and *Mangifera indica* were the most abundant species relative to all other documented species.

The density of the documented species was estimated in the range of 0.3-13.7 %. The species with maximum numerical strength on the campus was *Polyalthia longifolia* while *Eucalyptus globulus* was with minimum numerical strength. The other numerically stronger species on the campus were *Acacia catechu* (8.3) and *Lagerstroemia speciosa* (6.8). Similarly, the relative density estimated was in the range of 0.5 (*E. globulus*)-21.2 (*Polyalthia longifolia*). The abundance of the documented species on the campus ranged between 1.0 to 16.4 %. The abundance of the species in the campus in descending order was *P. longifolia* (16.4 %), *A. catechu* (12.5 %), *L. speciosa* (8.2 %), *Michelia champaca, Shorea robusta* (2.0 % each) and *E. globules* (1.0 %). A similar order of the species was also observed for relatives and the range estimated was 1.0-16.9. The estimated IVI for the documented species on the campus was in the range of 4.1-44.6. In this site also the most important species was *P. longifolia* followed by *A. catechu* (31.0), *L. speciosa* (25.6) and the lesser important species were *E. globulus* (4.1), *M. champaca* (5.7)*, Shorea robusta* (7.5) and *Dalbergia sissoo* (7.5). The species with high IVI were planted all along the paths and roads as avenue plantations, while the lower IVI species were scattered trees providing shade. *Duranta plumieri* the only shrub species on the campus with an IVI of 8.1 was a hedgerow planted all along the paths and in front of the buildings. The land for the campus was acquired by the BSF from the residents and the scattered trees were the actual plantation of the homegardens of the residents which were retained by the BSF.

The other species which were estimated with higher IVI were planted in a planned manner for campus beautification as avenues and aesthetics. It was observed that in the studied urban sites especially the parks, preference for species with large canopies that bears an enormous amount of flowers and fruits was more as compared to small and narrow canopy trees. Contrast species preferences were also reported from urban sites in Bengaluru (Nagendra and Gopal 2010a, b) and Guangzhou, China (Jim and Liu 2001). Large trees were reported as a better habitat for avian and small mammal species, accumulate more biomass, stock more carbon; remove more air particulate pollutants, greater shade and more effective cooling (Mcpherson and Simpson 2003, Pauleit 2003). This is a welcome trend at a time when initial impacts of climate change are being experienced globally (Nagendra and Gopal 2010a, Nowak 2010). A similar study estimating biodiversity indices of different urban green sites of Bangaluru, India (Nagendra and Gopal 2010a) and Nairobi, Kenya (Nyambane et al 2016) concluded that the

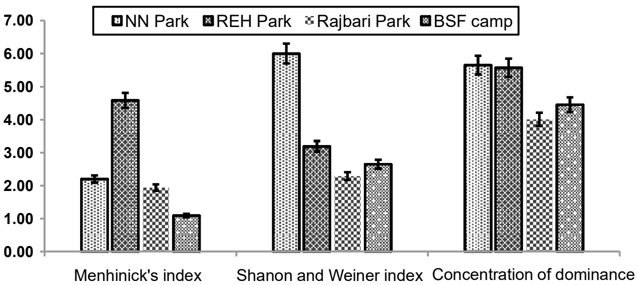


**Fig. 2.** Diversity indices of the study area

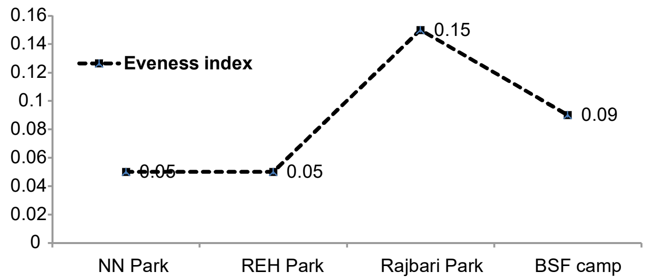


**Fig. 3.** Evenness index of the study area

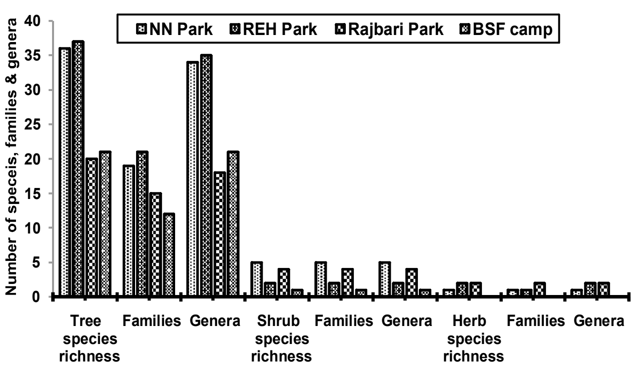


**Fig. 4.** Life form diversity in study areas

sites were quite phyto-diverse with the dominance of few tree species with significant variation of diversity among the studied sites. It was reported that the common biodiversity indices like those estimated in this study vary among and within the cities or urban landscape through time (Barbour et al 1980, Iverson and Prasad 2001, Nowak et al 2008).

Urban green spaces or the extent of vegetation cover in urban landscapes is influenced by several species and the number of individuals planted which in turn is influenced by the combination of natural and anthropogenic factors (Nowak 2010). Natural factors include native vegetation and its abundance, natural biotic interactions (seed dispersers, pollinators, and plant consumers), and climatic factors. The dominance of native species in the present study sites is clearly because the region is classified under Indo Malayan Biodiversity Hotspot (Myers et al 2000) and park managers had the choice of species from the wide range available best suited for the park. Conditioned on these natural influences is the anthropogenic system which includes people, urban infrastructure, land use and management decisions (Rathore and Jasrai 2013, Widyatmoko et al 2013, Edmondson et al 2014, Mitra and Zaman 2014, Churkina et al 2015, Livesley et al 2016, Mandari and Gunawan 2016).

BSF campus with more than 50 ha was documented with the lowest of 22 species richness, while N. N. Park with about 10 ha area with 42 species, Rajbari Heritage site with about 15 ha area with 26 species and Royal Eco Heritage Park with about 5 ha area harboured 41 species. This is contrary to the ecological concept of the species-area relationship and supported by studies reporting larger park areas with higher species richness due to greater habitat diversity and microhabitat heterogeneity than smaller ones (Cornelis and Henry 2004, Khera et al 2009, Carbó-Ramírez and Zuria 2011) the present study documented lesser species richness in larger areas. This is a clear instance of natural systems superimposed by an anthropogenic system. The species documented in the studied sites was the result of the creator's or developer's choice. The BSF campus has more open areas left for Border Security Force's operational purpose and trees are planted only along the roads and paths, residences and other buildings and rarely with scattered trees. Rajbari Heritage site conserves the Royal palace of the erstwhile Royal family of Cooch Behar in the heart of the town so dominated by lawns with occasional scattered trees and trees planted along the boundaries. The site was in dilapidated conditions and neglected till the Archaeological Survey of India took over in 2000 AD. The other two sites were the historical parks established by the Royal Family of Cooch Behar within the town area, thus with smaller area coverage but with more species. The studied parks were located within the Cooch Behar town and were comparatively species-rich as compared to the BSF campus which is located at the periphery of the town. It was reported that the species richness and diversity of plants located inside the cities were more as compared to their surrounding locations (Nowak 2010). Some non-native plant species were also documented from the study sites which might have invaded through transportation corridors or escaped from cultivation.

## CONCLUSION

The present study was an initiation to understand the urban vegetation in the sub-humid climatic conditions of

West Bengal, India in terms of its species richness, composition and conservation. These urban green sites of Cooch Behar City are a fairly diverse community in which the species are moderately even distributed with higher chances of encountering a species and dominance distributed among the species. Thus, urban green sites can also be managed for *ex-situ* conservation of species and also as a repository of plant species. Further research in parks is required to understand the Cooch Behar or regional specific characteristics and consequently, the implications for planning policies in the urban context. This study has policy implications for planners and urban designers, as well as for environmental organizations.

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# Documentation of Invasive Alien Plant Species in Anaikatty Hills, Coimbatore, Western Ghats

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***Abstract*:** In this paper presented a comprehensive inventory of the non-native vascular flora of Anaikatty hills. The survey was undertaken to document the invasive alien plant species in different ecosystems during September 2017 to October 2019 in Anaikatty hills, Coimbatore forest division, Western Ghats. A total of 98 invasive alien species under 81 genera and 40 families were recorded. Asteraceae is the most dominant family with 16 species followed by Amaranthaceae and Solanaceae (6 species each). *Cassia* and *Ipomoea* are the dominant genera (4 species each) followed by *Indigofera* and *Solanum* (3 species each). The life form analysis of the invasive alien flora showed that herbaceous species constitute the major life form (73.47%) followed by shrubs (9.18 %), climbers (8.16 %), trees (5.10 %) and grasses (4.08 %). Phytogeographical regions analysis revealed that tropical American elements (57.14 %) are the most dominant. It is an immense need to control the infestations of such alien and naturalised weeds in the natural ecosystem. This can be eliminated by better planning, periodic monitoring and adopt suitable controlling measures.

***Keywords***: Non-native, Asteraceae, Plant invasions, Western Ghats, Tropical America

Invasive alien plants are introduced deliberately or unintentionally outside their natural habitats into new areas where they express the capability to establish, invade and outcompete native species (Sujay et al 2010, Pant and Sharma 2010, McGeoch et al 2010). Most of the introduced herbaceous and shrubby taxa multiply in a limited period of time and destroy the endemic and native vegetation (Nagi and Hajra 2007). Humans are main vector for both intentional and accidental introduction of alien plant and animal species and they reach high densities and biomass (Hurka et al 2003, Parthasarathy et al 2012). Invasion by exotic species is one the major causes for loss of biodiversity (Richardson et al 2000). Thus, invasive plants are a serious impediment for conservation and sustainable use of biodiversity.

International Union for Conservation of Nature and Natural Resources (IUCN) defines alien invasive species as a non-indigenous species which get established in natural or semi-natural ecosystem or habitat, changes the quality of the habitat, alters the functioning of natural ecosystem and ultimately threatens to the biological diversity. Investigation of alien invasive species has become an imperative issue as invasion is considered a serious ecological and socio-economic problem in India and also at global level. Invasive plant species in a forest landscape displaces the native species by out competing the seeds of native species to germinate and by suppressing the growth of native saplings. Considering the negative impacts of invasive alien species invasion in the Indian forest ecosystems, the present study was carried out to enumerate the invasive alien species in Anaikatty hills, Coimbatore forest division, Western Ghats.

## MATERIAL AND METHODS

**Study area:** The study was carried out in Anaikatty hills, Coimbatore forest Division, Southern Western Ghats during September 2017 to October 2019. Anaikatty hills is situated in the part of Nilgiri Biosphere Reserve and falls between the latitudes 11º 01'N to 11º 09'N and longitudes is 76º 44'E to 76º 55'E, covering 180 sq km. The reserve forest is represented by several forest types such as west coast semi evergreen, southern moist mixed deciduous, southern dry mixed deciduous, southern dry deciduous forest and grassland. The study area is very rich in wildlife harbouring a good population of Asian elephants, Indian Gaur and numerous other wild fauna and flora. The climate of the area is semi-arid as it is located in the rain shadow part of the Western Ghats. Maximum temperature varied between 28ºC and 36º C during 1998-2001 (Nirmala 2002). The average rainfall of Anaikatty is about 670 mm, and majority of it is from the south-west monsoon.

**Field survey**: Intensive field studies were carried out to

**Table 1.** List of invasive alien plant species in Anaikatty hills, Coimbatore, Western Ghats

| Species name | Family | Life-form | Forest type in which occur | Origin country | Uses |
|---|---|---|---|---|---|
| *Acacia auriculiformis* L. | Mimosaceae | Tree | DMDF, MDF | Australia | Fuel wood, Timber |
| *A. farnesiana* (L.) Willd | Mimosaceae | Tree | DDF, DMDF | South America | Fuel wood |
| *Acanthospermum hispidum* DC. | Asteraceae | Herb | DDF, DMDF, MDF | Brazil | Medicinal |
| *Aerva javanica* (Burm. f.) Juss. ex Schult. | Amaranthaceae | Herb | DDF, DMDF | Tropical America | Medicinal |
| *Agave americana* L. | Agavaceae | Shrub | DDF, DMDF, MDF | America | Fibre, Ornamental |
| *Ageratina adenophora* (Spreng.) King & Robinson | Asteraceae | Herb | MDF, SEF | Mexico | Fodder |
| *Ageratum conyzoides* L. | Asteraceae | Herb | DDF, DMDF, MDF | Tropical America | Medicinal |
| *Alternanthera philoxeroides* (Mart.) Griseb. | Amaranthaceae | Herb | DDF, DMDF | Tropical America | None |
| *Alternanthera pungens* Humb. | Amaranthaceae | Herb | DDF, DMDF | Tropical America | Fodder |
| *Amaranthus spinosus* L. | Amaranthaceae | Herb | DMDF, MDF | Tropical America | Vegetable, Medicinal |
| *Antigonon leptopus* Hook. & Arn. | Polygonaceae | Climber | DDF, DMDF, MDF | Tropical America | Ornamental |
| *Argemone mexicana* L. | Papaveraceae | Herb | DDF, DMDF, MDF | South America | Medicinal |
| *Asclepias curassavica* L. | Asclepiadaceae | Herb | DMDF, MDF | Tropical America | Medicinal |
| *Bidens pilosa* L. | Asteraceae | Herb | MDF, SEF | Tropical America | Fodder |
| *Blainvillea acmella* (L.) Philipson | Asteraceae | Herb | DMDF, MDF | Tropical America | None |
| *Boerhavia erecta* L. | Nyctaginaceae | Herb | DDF, DMDF | Tropical America | Medicinal |
| *Calotropis gigantea* (L.) R. Br. | Asclepiadaceae | Shrub | DDF, DMDF | Tropical Africa | Medicinal, Ornamental |
| *Cassia hirsuta* L. | Caesalpinaceae | Herb | DDF, DMDF, MDF | Tropical America | Medicinal |
| *Cassia occidentalis* L. | Caesalpinaceae | Herb | DDF, DMDF, MDF | South America | Medicinal |
| *Cassia tora* L. | Caesalpinaceae | Herb | DDF, DMDF | South America | Medicinal |
| *Cassia uniflora* Miller | Caesalpinaceae | Herb | DMDF, MDF | Tropical America | Medicinal |
| *Catharanthus roseus* L. | Apocynaceae | Herb | DDF, DMDF, MDF | Tropical America | Medicinal, Ornamental |
| *Chloris barbata* (L.) Sw. | Poaceae | Grass | DDF, DMDF, MDF | Tropical America | Fodder, Medicinal |
| *Chromolaena odorata* L. | Asteraceae | Shrub | DDF, DMDF, MDF, | Tropical America | Fuel wood |
| *Cleome gynandra* L. | Cleomaceae | Herb | DDF | Tropical America | Medicinal |
| *Cleome monophylla* L. | Cleomaceae | Herb | DMDF | Tropical Africa | Vegetable |
| *Cleome viscosa* L. | Cleomaceae | Herb | DDF, DMDF | Tropical America | Medicinal |
| *Crotalaria pallida* Dryand | Fabaceae | Herb | DDF, DMDF, MDF | Tropical America | Fodder |
| *Croton bonplandianum* Baill. | Euphorbiaceae | Herb | DDF, DMDF, MDF | South America | Fodder, Medicinal |
| *Cuscuta reflexa* Roxb. | Cuscutaceae | Twiner | DDF, DMDF, MDF | Mediterranean | None |
| *Cyperus iria* L. | Cyperaceae | Herb | DDF, DMDF, MDF | Tropical America | Fibre |
| *Datura innoxia* Mill. | Solanaceae | Herb | DMDF, MDF | Tropical America | Medicinal |
| *Datura metel* L. | Solanaceae | Shrub | DMDF, MDF | Tropical America | Medicinal |
| *Delonix regia* (Bojer) Raf. | Caesalpinaceae | Tree | DDF, DMDF, MDF | Madagascar | Ornamental |
| *Digera muricata* (L.) Mart. | Amaranthaceae | Herb | DMDF, MDF | South West Asia | Medicinal, Vegetable |
| *Echinochloa colona* (L.) Link. | Poaceae | Grass | DMDF, MDF | South America | Fodder |
| *Eclipta prostrata* (L.) Mant. | Asteraceae | Herb | DMDF, MDF | Tropical America | Medicinal |
| *Emilia sonchifolia* (L.) DC. | Asteraceae | Herb | DMDF | Tropical America | Medicinal |
| *Euphorbia heterophylla* L. | Euphorbiaceae | Herb | DMDF | Tropical America | Ornamental |
| *Euphorbia hirta* L. | Euphorbiaceae | Herb | DDF, DMDF, MDF | Tropical America | Medicinal |

**Cont...**

**Table 1.** List of invasive alien plant species in Anaikatty hills, Coimbatore, Western Ghats

| Species name | Family | Life-form | Forest type in which occur | Origin country | Uses |
|---|---|---|---|---|---|
| *Galinsoga parviflora* Cav. | Asteraceae | Herb | DMDF, MDF | Tropical America | None |
| *Gnaphalium polycaulon* Pers. | Asteraceae | Herb | DDF, DMDF | Tropical America | Fodder |
| *Gomphrena serrata* L. | Amaranthaceae | Herb | DDF, DMDF | Tropical America | Fodder |
| *Hyptis suaveolens* (L.) Poit. | Lamiaceae | Herb | DDF, DMDF, MDF | Tropical America | Medicinal |
| *Imperata cylindrica* (L.) Raensch | Poaceae | Grass | DDF, DMDF, MDF | Southeast Asia | Fodder |
| *Indigofera astragalina* DC. | Fabaceae | Herb | MDF | Tropical America | None |
| *Indigofera linifolia* (L.f.) Retz. | Fabaceae | Herb | DDF | Tropical South America | Fodder |
| *Indigofera linnaei* Ali. | Fabaceae | Herb | DMDF | Tropical Africa | Fodder |
| *Ipomoea carnea* Jacq. | Convolvulaceae | Shrub | DDF, DMDF, MDF | South America | Manure |
| *Ipomoea hederifolia* L. | Convolvulaceae | Twiner | MDF | Tropical America | Medicinal |
| *Ipomoea pes-tigridis* L. | Convolvulaceae | Twiner | DMDF, MDF | Tropical east Africa | Medicinal |
| *Ipomoea staphylina* Roem. and Schult. | Convolvulaceae | Climber | DDF, DMDF, MDF | Tropical Africa | Fodder |
| *Jatropha gossypifolia* L. | Euphorbiaceae | Shrub | DDF, DMDF | Tropical America | None |
| *Lagascea mollis* Cav. | Asteraceae | Herb | DMDF | Tropical central America | Medicinal |
| *Lantana camara* L. | Verbenaceae | Shrub | DDF, DMDF, MDF, SEF | Tropical America | Ornamental |
| *Leonotis nepetiifolia* (L.) R.Br. | Lamiaceae | Herb | DMDF, MDF | Tropical Africa | Medicinal |
| *Leucaena leucocephala* (L.) de Wit | Mimosaceae | Tree | DDF, DMDF | Mexico | Fodder, Fuel wood |
| *Ludwigia adscendens* (L.) Hara. | Onagraceae | Herb | DDF, DMDF, MDF | Tropical Africa | Medicinal |
| *Malvastrum coromandelianum* (L.) Garcke | Malvaceae | Herb | DDF, DMDF, MDF | Tropical America | Fibre |
| *Martynia annua* L. | Pedaliaceae | Herb | DDF, DMDF | Tropical America | Medicinal |
| *Merremia aegyptia* (L.) Urb. | Convolvulaceae | Climber | DDF | Tropical America | None |
| *Mimosa pudica* L. | Mimosaceae | Herb | DDF, DMDF, MDF | Brazil | Medicinal |
| *Ocimum americanum* L. | Lamiaceae | Herb | DDF, DMDF | Tropical America | Medicinal |
| *Opuntia stricta* Haw. | Cactaceae | Shrub | DDF, DMDF, MDF | Tropical America | Fruit edible |
| *Oxalis corniculata* L. | Oxalidaceae | Herb | DDF, DMDF, MDF | Europe | Vegetable |
| *Parthenium hysterophorus* L. | Asteraceae | Herb | DDF, DMDF, MDF | South America | Fodder |
| *Passiflora foetida* L. | Passifloraceae | Climber | DDF, DMDF | South America | Medicinal |
| *Pedalium murex* L. | Pedaliaceae | Herb | DDF, DMDF | Tropical America | Medicinal |
| *Peperomia pellucida* (L.) Kunth | Piperaceae | Herb | MDF, SEF | Tropical South America | None |
| *Peristrophe paniculata* (Forssk.) Brummit | Acanthaceae | Herb | DDF, DMDF | Tropical America | Fodder |
| *Physalis minima* L. | Solanaceae | Herb | MDF | Tropical America | Medicinal |
| *Pilea microphylla* (L.) Liebm. | Urticaceae | Herb | MDF, SEF | South America | Medicinal |
| *Pistia stratiotes* L. | Araceae | Herb | DDF, DMDF | Tropical America | Medicinal |
| *Polygonum chinense* L. | Polygalaceae | Herb | DDF, DMDF | South Asia | None |
| *Portulaca oleracea* L. | Portulacaceae | Herb | DMDF, MDF | South America | Vegetable |
| *Portulaca quadrifida* L. | Pourtulacaceae | Herb | DMDF, MDF | Tropical America | Medicinal |
| *Prosopis juliflora* (Sw.) DC. | Mimosaceae | Tree | DDF, DMDF | Mexico | Fuel wood |
| *Richardia scabra* L. | Rubiaceae | Herb | DDF, DMDF, MDF | South America | None |
| *Rorippa dubia* (Pers.) H. Hara | Brassicaceae | Herb | DMDF, MDF | Tropical America | None |
| *Ruellia tuberosa* L. | Acanthaceae | Herb | DDF, DMDF | Tropical America | Ornamental |
| *Saccharum spontaneum* L. | Poaceae | Grass | DDF, DMDF | West Asia | Fodder |
| *Scoparia dulcis* L. | Scrophulariaceae | Herb | DDF, DMDF | Tropical America | Medicinal |

**Cont...**

**Table 1.** List of invasive alien plant species in Anaikatty hills, Coimbatore, Western Ghats

| Species name | Family | Life-form | Forest type in which occur | Origin country | Uses |
|---|---|---|---|---|---|
| *Sida acuta* Burm. f. | Malvaceae | Herb | DDF, DMDF, MDF | Tropical America | Medicinal |
| *Solanum diphyllum* L. | Solanaceae | Herb | MDF | West Indies and South America | None |
| *Solanum nigrum* L. | Solanaceae | Herb | DMDF, MDF | Tropical America | Vegetable |
| *Solanum seaforthianum* Andrews | Solanaceae | Climber | DDF, DMDF | Brazil | Medicinal, Ornamental |
| *Sonchus oleraceus* L. | Asteraceae | Herb | DDF, DMDF | Meditarrian region | None |
| *Spermacoce hispida* L. | Rubiaceae | Herb | DMDF, MDF | Tropical America | Medicinal |
| *Stachytarpheta jamaicensis* (L.) Vahl | Verbenaceae | Herb | MDF | Tropical America | Ornamental |
| *Synadenium grantii* Hook. f. | Euphorbiaceae | Shrub | DMDF, MDF | Tropical America | Ornamental |
| *Synedrella nodiflora* (L.) Gaertn. | Asteraceae | Herb | DMDF, MDF | West Indies | None |
| *Tribulus terrestris* L. | Zygophyllaceae | Herb | DDF, DMDF | Tropical America | Medicinal |
| *Tridax procumbens* L. | Asteraceae | Herb | DDF, DMDF | Central America | Medicinal |
| *Triumfetta rhomboidea* Jacq. | Tiliaceae | Herb | DMDF, MDF | Tropical America | Medicinal |
| *Typha angustata* Bory and Chaup. | Typhaceae | Aquatic Herb | DDF, DMDF, MDF | Tropical America | None |
| *Urena lobata* L. | Malvaceae | Herb | DDF, DMDF | Africa | Medicinal |
| *Waltheria indica* L. | Sterculiaceae | Herb | DDF, DMDF, MDF | Tropical America | Medicinal |
| *Xanthium strumarium* L. | Asteraceae | Herb | DDF, DMDF, MDF | North America | Medicinal |

DMDF-Dry Mixed deciduous Forest, DDF-Dry Deciduous Forest; MDF-Moist Deciduous Forest; SEF-Semi-Evergreen Forest

record the invasive alien plant species from September 2017 to October 2019. Plant specimens were collected and preserved as voucher specimens following standard procedures. The identification of plants was done with the help of Flora publications (Hooker 1872-1897, Gamble 1915-1936, Henry et al 1987, Matthew 1983, Nair and Henry 1983, Chandrabose and Nair 1988). The nativity of the invasive species was determined based on theinformation available in the published literatures (Maheswari 1960, Sekar 2012, Singh et al 2013, Divakara et al 2013, Sekar et al 2015, Reshi et al 2017). The invasive alien species are listed alphabeticallyfollowed by family, life-form, forest types, origin country and use valuesin which it occurs.

## RESULTS AND DISCUSSION

A total of 98 species of invasive alien plant species belonging to 81 genera and 40 families were recorded in the Anaikatty hills, Coimbatore (Table 1). Herbs (73.47%) formed the predominant life-form followed by shrubs (9.18%), climbers (8.16%), trees (5.10%) and grasses (4.08%). The predominance of herbaceous life form in the invasive alien flora of the study area is in conformity with findings of Naidu et al (2015) reported for the tropical forests of Northern Andhra Pradesh and Sekar et al (2015) for Himachal Pradesh. A total of 40 families of invasive alien flora recorded, among this Asteraceae constituted the predominant family with 16 species, followed by Solanaceae and Amaranthaceae (8 species each). The comprehensive list of invasive alien flora for India (Rao and Murugan 2006) and China (Haung et al 2009) reported Asteraceae as the most dominant family. The dominance sequence of invasive alien genera of the study area comprised *Ipomea* and *Cassia* (4 species each) and *Cleome* (3 species). The invasive alien species in this study are categorized based on their Geographic origin. A total of 18 geographical origins/regions are considered for the analysis. Tropical American elements contributed 57.14% of invasive alien species followed by South America (12.24%) and Tropical Africa (8.16%). The invasive alien flora of India was also found to dominated (58%) by Tropical American elements (Reddy 2008, Singh et al 2010).Five invasive alien tree species are reported in the present study. Among this *Acacia auriculiformis*, *Leucaena leucocephala*, *Delonix regia* and *Prosopis juliflora* are planted in social forest or commercial forestry and agroforestry. These species are cause major problems as invaders of natural and seminatural ecosystems (Richardson 1998). *Leucaena leucocephala* and *Prosopis juliflora* are small fast-growing trees native to Mexico. *Prosopis juliflora* was introduced to India around 1870 (Raizda and Chatterji 1954) and *Leucaena leucocephala* around 1950 (ILDIS 2007). Of the 98 invasive alien species found in Anaikatty hills, highest number in the dry mixed deciduous forest (85 species) followed by moist deciduous and dry deciduous (62species each) and semi evergreen forest (6 species). The obnoxious invasive species, *Lantana camara* and *Chromolaena odorata* (*Eupatorium odoratum*) was in all the four forest typessurveyed. *Prosopis juliflora* has extensively invaded thedry deciduous forest. *Pistia stratiotes, Typha angustata* and *Ludwigia adscendens* were abundantly found in rivers and other water bodies. *Hyptis suaveolens* has dominant in along the waysides of the most of the areas. Majority of the invasive alien species recorded in the Anaikatty hills, have use values for humans. Plant parts use values reported included medicinal, fodder, ornamental, vegetable, fuel wood, fibre, edible, timber and manure. (Table 1). Prakash and Balasubramanian (2018) also reported that most of the invasive alien species are used in various purposes in the nearest area. About 50% of the invasive alien species of the present study area havemedicinal uses.

## CONCLUSION

Anaikatty hills, Southern Western Ghats is invaded by a set of invasive alien species including such as *Lantana camara*, *Hyptis suaveolens* and *Chromalaena odorata*. Particularly the dry deciduous forests are infested by diverse number of invasive weeds which require management intervention for the weed control.

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# Flower-Pollinator Interactions in Liana (*Caesalpinia cucullata* Roxb.) in a Tropical Rain Forest of Mizoram

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***Abstract*:** Lianas (woody climbers) are relatively underexplored life forms of many forests, which predominantly forms tropical forests and provide food and shelter to a variety of animals. A study on flower-pollinator interactions in *Caesalpinia cucullata* Roxb. was conducted in the tropical rain forest of Indo-Burma hot spot at Tanhril area of Aizawl district of Mizoram. Floral visitors of *C. cucullata* were monitored and recorded during 24 field days, four to six hour per day with a total of about one hundred hours during the flowering season of November–December, 2016. The flowers of *C. cucullata* were found to be visited by three insect species belonging three families; nine passeriformes birds belonging eight families and one Hoary-bellied Himalayan squirrel (Irrawaddy squirrel) belonging family Scuiridae. Birds and squirrel mainly visited the flowers in morning hours while butterflies and bees exhibited diurnal pattern of foraging. The results revealed that the bird pollination is supported by butterflies in *C. cucullata*. The flowers of *C. cucullata* would be excellent food resource to the dependent animal species during dry cold period in the extreme tropical sloppy mountain forest site when availability of floral resource is very scarce. Therefore, *C. cucullata* could be a valuable liana species for the conservation of valuable species of insects, birds and squirrels.

***Keywords*:** Liana, Birds, Insects, Pollination, Tropical forest and conservation

Tropical forest community contains enormous diversity of flora and fauna with their ecological interactions. One of the peculiar and mesmerizing life forms found in tropical rain forest is woody climbers, i.e., liana, which remained a relatively underexplored plant life forms compared to that of tree species (Rice et al 2004). In the last two decades there is a pulsating trend in liana research owing to their growing significance in tropical forest dynamics due to global change (Ledo and Schnitzer 2014). Liana competes with trees for above and belowground resources, leading to decrease in recruitment, regeneration, growth, fecundity and survival of trees especially in disturbed forest sites (Phillips et al 2002, Schnitzer and Bongers 2011). Conversely, lianas act as an important resource to the forest functioning like stabilizing microclimatic conditions of under canopy, trail for arboreal animals to crossways the tree tops, acts as foliar, floral, fruit and nesting resources to a diverse group of vertebrate and invertebrate fauna (Emmons and Gentry 1983, Yanoviak and Schnitzer 2013). Birds are reported to depend on lianas for a variety of direct resources such as fruit (many lianas produce fleshy fruits which are frequently consumed by birds) and nectar. -Indirect resources like sheltering, nesting sites, perching space, insects and their larvae for feeding (Kominami et al 2003, Sankamethawee et al 2011). Nectar of lianas act as floral rewards to the diverse array of birds such as humming birds, honeyeaters, warblers, parrots, blackbirds, cardinals and orioles (Stein 1992, Peres 2000, Fleming et al 2005). Many liana-harboring insects (mainly Hymenopterans, Dipterans and Hemipterans) extract floral nectar as their feed, such insects turn act as a food resource to insectivorous birds (Gryj et al 1990). Lianas are also reported to be harbouring large number of endophytic fungi (Biplab 2018). Lianas and their tangles offer either obligate and facultative nesting and/or roosting niche for a spectrum of bird species (Mack and Wright 1996, Michel et al 2015). Intense liana entangles offer excellent habitat for birds to hide and protect from predators (Boinski et al 2003), song and display perches (Durães 2009). In turn, lianas get benefited from a range of services by birds in pollination, seed dispersal and protection from insects in herbivory (Gryj et al 1990, Stein 1992, Lenz et al 2011, Michel et al 2015), while some birds used to rob nectar and predate seeds of liana, thus affecting it negatively (Lara and Ornelas 2001).

The trend of bird population and their species diversity are declining globally (Sekercioˇglu et al 2004) and presently, 21% of bird species are measured to be extinction-prone and 13-39% of bird species are speculated to be extinct by 2100 (Sekercioˇglu et al 2004). Specialized fruit and nectar eating bird species are more vulnerable to extinction than other functional groups. Therefore, the decline in population of specialist bird species involved in pollination and seed dispersal of liana are going to impact the liana and other key plant groups (Ansell et al 2011). Contrary to this, the generalist bird species are reported to increase with increasing liana abundance and diversity in logged rain forest site (Biamonte et al 2011). Therefore, it is utmost important to understand the nature and degree of liana-animal interaction for the sustainable conservation of lianas, mammals, birds, insects and tropical forest communities.

*Caesalpinia cucullata* Roxb. (Syn. *Mezoneuron cucullatum* (Roxb.) Wight and Arn.) commonly known as hooded-flowered brasiletto, Sahyadri thorn, (Locally known as Hling-Khang in Mizo) is a large climbing shrub with thorns and is reported to be an armed straggler (Muthumperumal and Parthasarathy 2009). It bears fragrant flowers in terminal and axillary racemes of 20-40cm in length. Yellow flowers appeared like hoods with long stamen filament and protruding red anthers. *C. cucullata* is distributed throughout the north eastern hilly states of India (Barik et al 2015), and sparsely found in evergreen forests of Sahyadri hills and its presence is also recorded from North Andaman in Semi evergreen and littoral forests (Ghosh 2013). It is closely related to *Caesalpinia decapetala* (Deshmukh et al 2013). Its beans are locally consumed by the tribals of Koraput, Orissa (Mishra and Padhan 2011) and roots are used in curing sprains (Bandopadhya and Mukherjee 2010). In Chinese traditional medicines it is reported to be an effective anti-abortion agent (Xiaoping and Shaanxi, 2003). A variety of active phytochemicals was isolated and characterized from the different parts of *C. cucullata* (Cheng-yu et al 2013). There is no scientific report on flower-animal interaction (floral visitors) of *C. cucullata* so far and this study is the first report on the flower visitors and their role in pollination and resource utilization for sustainability and conservation of dependent pollinators as well as the liana species.

## MATERIAL AND METHODS

Five individuals of *C. cucullata* were identified along deep mountain slopes inside the Mizoram University campus, Tanhril, Aizawl (latitude 23°.43'53. 19'' N to 24°.35' N and longitude 92°.39'44.21'' E to 93°.29' E and altitude 832 m). A reconnaissance survey was also made all across the campus to locate other individuals of *C. cucullata* but other individuals were not found which might be due to highly dense and close forest canopy cover, inaccessible steep forest mountain slopes in the study area. Hence, recording of phenological events (for two seasonal calendars i.e., 2016-17 and 2017-18) and pollinator floral visitors (in 2016) were done on five individuals located nearby to each other with the help of binocular and camera. Floral visitors of *C. cucullata* were monitored and recorded during 24 field days, four to six hours per day with a total of about one hundred hours during the flowering season of November-December 2016. Five branches per individuals were chosen randomly and the observations were recorded over the course of whole day length between 0600 h morning to the 1700 h dusk in five blocks (0601-0800; 0801-1000; 1001-1200; 1201-1400 and 1401-1700). The visitation rate of the floral visitors was assessed in terms of visits per branch per day (visits/branch/day) and the pollinators were classified as regular and occasional visitors on the basis of their frequency. Floral visitors included insects, birds and squirrels. Floral visitors were monitored with the help of binocular, camera, and also directly when they visited the flower. Bird's mode of approach, landing, probing behaviour with bill while perched, floral resource used by the flower visitors, contact with reproductive organs which can potentially promote pollination were recorded. The allocation of each monitoring time block was done in such a way that all the selected individuals of lianas in a group was monitored in each observation block during field visit. Floral visitors were identified with the help of standard handbooks and manuals (Ali 1943, Richard et al 2011). The structure and brief tree floristic diversity of the forest and climatic features of the study site were described by Kumar and Khanduri (2016).

## RESULTS AND DISCUSSION

*Caesalpinia cucullata* flowered during cool dry period from mid of November to first week of January with peak flowering (i.e. blooming) recorded during second to third week of December in 2016 (Fig. 1A-B). Early fruiting started in first week of January which coincided with late flowering phase. Both fruits and flowers can be observed simultaneously in the same branch of *C. Cucullata* (Fig. 1C). Fruiting phase was extended from first week of January-2017 to last week of April-2017. Fruit maturity took place in February-2017 and dispersal was recorded in March and April-2017 (Fig. 1D and Fig. 4). In 2017, floral budding was initiated in the third week of November-2017 and just before the anthesis and blooming phase a brief period of atypical intense rainfall occurred during 9-11 December-2017 (Fig. 3) which disrupted the whole flowering phase, pollination and fertilization and all unopened floral buds from the branches fell down within a week (Fig. 1E). Consequently, no animal foraging and fruit set were recorded during the season 2017-2018 (Fig. 4).

Three insect's species belonging to three families; nine passeriformes birds belonging to eight families and one Hoary-bellied Himalayan squirrel (Irrawaddy squirrel) belonging to family Scuiridae were found visiting the flowers of *C. cucullata* during the flowering phase of December-2016. *Vindula erota erota* (butterfly) is one of most prolific floral visitor recorded exhibiting peculiar sexual dimorphism in morphology (colour) between male and female individuals (Fig. 1 H-I). Diurnal foraging activity for *V. erota erota* was

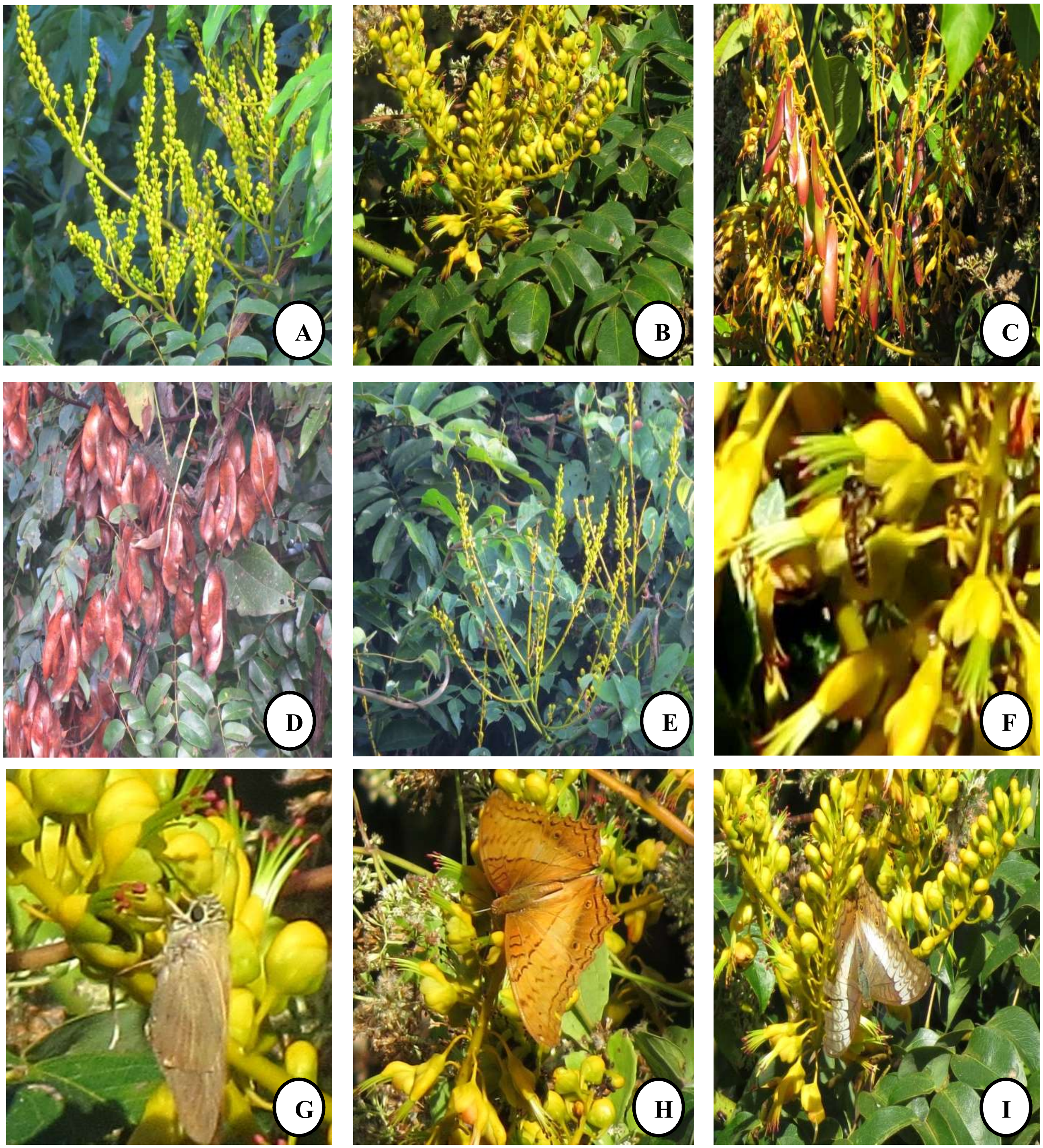


**Fig. 1.** Phenological phases and insects floral visitors of *C. cucullata* : (A) Early unopened floral bud-2016 (B) Flower in blooming phase-2016 (C) Early fruiting phase coincide late flowering phase-2016 (D) Mature fruiting stage-2016 (E) Detrimental impact of unusual out of season rainfall on flowering phase (all floral buds before anthesis fell down)-December 2017 (F) *Apis cerena* (G) *Badamia exclamationis* (H) *Vindula erota erota* (male) (I) *Vindula erota erota* (female)

observed with the peak foraging activity during morning and afternoon hours, however, inter flower movement was slow (Table 1). *Badamia exclamationis* (butterfly) occasionally visited the flower with peak visitation during 0801-1000 hours. Both species of butterfly exhibited hovering and sitting activity on flowers. During foraging, they make definite contact with stamens and stigma of *C. cucullata* and the nectar and pollen were harvested as their food resource (Fig. 1G-I). *Apis cerena* (bee) was recorded foraging the flowers of *C. cucullata* diurnally with peak visits during morning and afternoon. *A. cerena* makes inter flower movement and in one bout it visited 2-6 flowers in a branch. *A. cerena* extracts floral nectar without making regular contacts with protruding red-coloured stamens (Fig. 1F). While foraging, *A. cerena* very occasionally contacted the stamen of the flower for pollen resource and therefore they mainly visited for nectar of the flower.

*C. cucullata* offered some of distinguishing features for bird pollination (ornithophily) such as; (i) upright branches facilitating bird perching, (ii) large number of red colour protruding stamens in flowers can be easily sighted from distance, (iii) production of nectar in protected cup like yellow flower, (iv) corolla colors range from yellow to yellowish orange and (v) prolonged anthers seems to be important feature for pollen transfer. As bird forages for deep seated nectar, a definite contact with anthers to beak, head and neck region of birds was observed (Fig. 2 A-H).

**Table 1.** Butterflies, bee, passerine birds and squirrel visitors to the flowers of *C. cucullata*

| Animal species | Common name | No. of visits/ branch/day (n=10 d) (Mean ±SD) | Frequency | Peak time of visitation | Floral resource sought | IUCN Status |
|---|---|---|---|---|---|---|
| *Insects (Lepidoptera & Hymenoptera)*<br>Family : Nymphalidae<br>*Vindula erota erota* Fabricius | Common cruiser | 30.9±10.72 | Regular | 0801-1200; 1401-1700 | Nectar, Pollen | NA |
| Family: Hesperiidae<br>*Badamia exclamationis* Fabricius | Brown awl | 3.5±1.77 | Occasional | 0801-1000 | Nectar, Pollen | NA |
| Family: Apidae<br>*Apis cerena* Fabricius | Asiatic honey bee | 55.2±12.7 | Regular | 0801-1200;1401-1700 | Nectar Pollen | NA |
| *Birds (Passeriformes)*<br>Family: Chloropsidae<br>*Chloropsis aurifrons* Temminck | Golden-fronted leaf bird | 8.3±2.86 | Regular | 0601-1000 | Nectar | LC,⇌ |
| *Chloropsis cochinchinensis* Gmelin | Blue winged leaf bird | 3.3±2.62 | Occasional | 0601-0800 | Nectar | NT, ↓ |
| Family: Pycnonotidae<br>*Pycnonotus cafer* Linnaeus | Red vented bulbul | 5.6±2.59 | Regular | 0801-1000 | Nectar | LC, ↑ |
| Family: Nectariniidae<br>*Arachnothera longirostra* Latham | Little spider hunter | 2.6±1.77 | Occasional | 0801-1000 | Nectar | LC,⇌ |
| Family: Cisticolidae<br>*Orthotomus sutorius* Pennant | Common tailor bird | 3.1±2.18 | Occasional | 0801-1000 | Nectar | LC,⇌ |
| Family: Zosteropidae<br>*Zosterops palpebrosus* Temminck | Oriental white eye | 5.3±2.35 | Regular | 0601-1000 | Nectar | LC, ↓ |
| Family: Tamaliidae<br>*Mixornis gularis* Horsfield | Pin-striped tit-babbler | 1.8±1.75 | Occasional | 0801-1000 | Nectar | LC,⇌ |
| Family: Phylloscopidae<br>*Phylloscopus* sp. | Leaf warbler | 1.4±1.5 | Occasional | 0801-1100 | Nectar | |
| Family: Dicruridae<br>*Dicrurus macrocercus* Vieillot | Black drongo | 0.9±0.73 | Occasional | 0801-1000 | Nectar | LC,? |
| *Squirrel (Rodentia)*<br>Family: Sciuridae<br>*Callosciurus pygerthus* I. Geoffroy Saint Hilaire | Hoary-bellied Himalayan squirrel | 2.1±1.28 | Occasional | 0801-1000 | Flower, Nectar | LC,⇌ |

NA (Not Available); LC (Least Concern); NT (Near Threatened); ⇌ (Stable); ↑ (Increasing); ↓ (Decreasing) ;?( Unknown)

*Chloropsis aurifrons* was recorded to be the regular visitor to the flower of *C. cucullata* during early morning hours (0601-1000; Table 1); it first perched on the branch of liana then try extracting nectar from more than one flowers in one sitting and spared about 15-35 seconds in a branch and 4-6 seconds per flower. On an average it pokes and extracts nectar from 5-15 flowers in one bout and makes definite contact with stamens through its neck, head and beak (Fig. 2D). *Chloropsis cochinchinensis* was foraging mostly during early morning hours and its behaviour was almost similar with

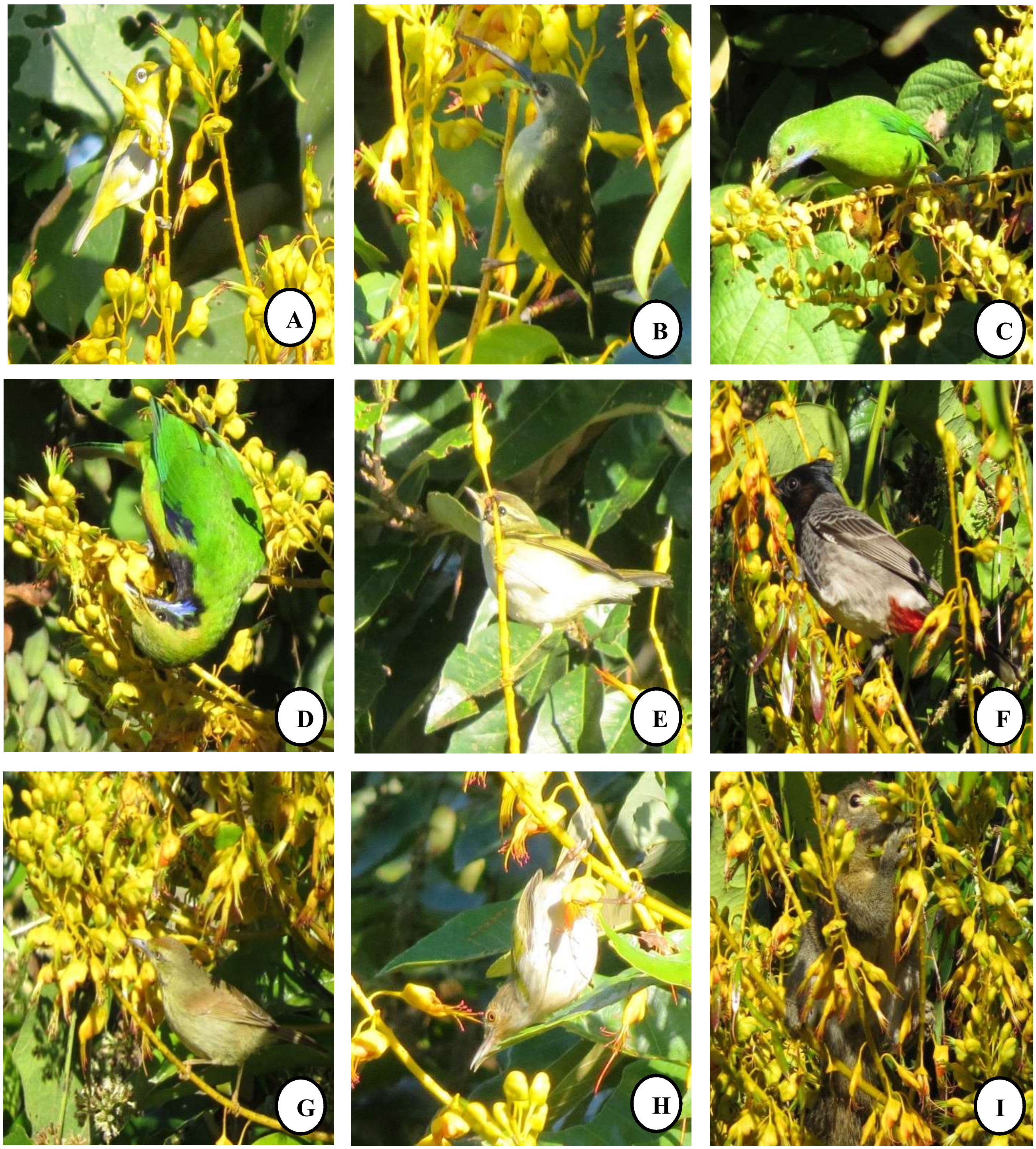


**Fig. 2.** Floral visitors (birds & squirrel) showing interactions with reproductive floral parts of *C. cucullata* (A) *Zosterops palpebrosus* (B) *Arachnothora longirostra* (C) *Chloropsis cochinchinensis* (D) *Chloropsis aurifrons* (E) *Phylloscopus* sp. (F) *Pycnonotus cafer* (G) *Mixornis gularis* (H) *Orthotomus sutorius* (I) *Callosciurus pygerthus*

*C. aurifrons* but it occasionally visited the flower for nectars (Fig. 2C, Table 1).

*Pycnonotus cafer* was observed as a regular visitor to flower with the average visit of 1-3 flowers per visit and was found to be very alert while foraging. It sensed small movement and fly away from the source. It extracted nectar during foraging and spared about 10-15 seconds per flower and simultaneously made precise contact with reproductive parts of flower (Fig. 2F). Oriental white eye (*Zosterops palpebrosus*) visited the flower both singly and in small flocks (Fig. 2A). The peak visitation was recorded during 0600-1000 h. The flower handling time was very less (~3-5 seconds). After harvesting nectar, it rubbed its beak on branches after nectar drinking. Little spider hunter (*Arachnothera longirostra*) occasionally visited the flower. It produced typical noise before and after foraging the flower and rubbed its beak on branches after nectar harvest. It legitimately foraged the flower with long curved beak. The beak and head of *A. longirostra* make precise contact with reproductive parts of flower (Fig 2B) . It spent around 3-5 seconds per flower. *Orthotomus sutorius*, *Mixornis gularis* and *Phylloscopus* sp. were found occasional visitors to flowers of *C. cucullata* and were observed visiting during morning hours (0800-1000) (Fig. 2F, G and H). They make firm perched on the branch and then precisely foraged flower for nectar. At one perch they poked 1-3 flowers. *Dicrurus macrocercus* was found to be very occasional visitor to flower, it perched on branch and try to harvest nectar from flower; while foraging it damages the flowers too. *Callosciurus pygerthus* (Irrawaddy squirrel) to the visited singly flowers of *C. cucullata*, during visits it makes extensive noise, while harvesting nectar, damaged the flower and also did florivory. The prehensile tail of *C. pygerthus* acts as balancer while moving from flower to flower, it spent good amount of time per visit.

Insects mostly exhibited bimodal pattern of regular foraging visit while bird visited mostly in the morning hours with unimodal pattern. *C. aurifrons, P. cafer* and *Z. palpebrosus* were recorded most regular visitors to the flowers of *C. cucullata* while others foraged occasionally for nectar. After web search on IUCN red list to assess the conservation status of floral visitor species, except blue winged leaf bird (*C. cochinchinensis*) which is found to be near threatened (NT), all other birds were found to be in least concern (LC) category. Population trend found be variable with stable population trend for *C. aurifrons, A. longirostra, O. sutorius, Mixornis gularis,* increasing trend for *P. cafer* while decreasing trend for *C. cochinchinensis* and *Z. palpebrosus. Callosciurus pygerthus* was enlisted in LC with stable population trend.

The majority of perennial plant species found in tropics exhibit some degree of seasonality in growth and reproduction to climatic factors (van Schaik et al 1993, Aide 1993). Such a periodicity in tropical long-lived plants is tightly coupled with activities of dependant animal species for plant resources such as emerging leaves, nectar, pollen, fruits and seeds. In turn, animals render their valuable services as pollinators, seed dispersers and protecting from herbivory from other animals. Thus, uneven patterns of climatic factors may have profound impact on such plant-animal interactions which may lead loss of biodiversity and associated ecological functions (Butt et al 2015). In present study erratic intense brief rainfall during 9-11 December, 2017 (Fig. 3) leads reproductive failure of *C. cucullata* in the season. The month of December in general considered as a dry month in present study site, as there were only two episodes of rainfall i.e. 56 mm and 37.6 mm in December-2010 and December-2017, respectively has been recorded during the past decade since 2005. Such atypical climatic events not only affected the liana flowering and reproduction but also influenced the dependent animal species (recorded three species of insects; nine species of birds and one squirrel in the study) for their food resources. Changes in temperature and intense erratic rainfall are reported to be most important factors affecting phenology (flowering and fruit drop) in tropics (Wright and Calderón 2006, Gunarathne and Perera 2014) and in turn has cascading effects on dependent vertebrate fauna.

*C. cucullata* might be a critical food resource during dry cold period, when moisture availability for plant growth and development is limited for deciduous trees and annual herbaceous community in the present tropical sloppy

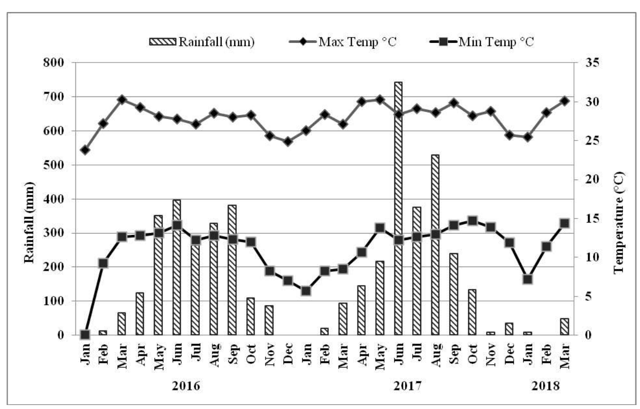


**Fig. 3.** Mean monthly rainfall, minimum and maximum temperature distribution in study area during study period 2016-18 (Source: ENVIS Centre, Mizoram). Atypical rainfall (35.6 mm) in the month of December-2017 on dated 9, December (5mm), 10 December (19mm) & 11 December (11.6 mm)

| | 2016 | | | | | | 2017 | | | | | | | | | | | 2018 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun |
| Flowering phase | | | | | ** | **** | ** | | | | | | | | | * | ** | | | | | | |
| Fruiting phase | | | | | | | ψψψψ | **ψψψψ** | **ψψψψ** | **ψψψψ** | | | | | | | | | | | | | |

**Fig. 4.** Phenogram of *C. cucullata* for reproductive stages (*-Flowering; **ψ**-early fruiting; ψ-mature fruits) in two annual seasons (i.e. 2016-17 & 2017-2018); atypical rainfall during second week of December, 2017 negatively affected flowering phase, pollination and fruiting, hence no fruit set was recorded in 2017-18

mountain forest site. The floral resource availability to the dependent animals is very scarce in the months of November and December as compared to spring and rainy seasons. Other tree species which were overlapping with *C. cucullata* flowerings in December in the study site were *Bombax insigne*, *Parkia roxburghii*, *Neolamarckia cadamba* and *Prunus cerasoides* (Khanduri and Kumar 2017). Floral nectars are rich source of sugars, amino and organic acids which are a suitable source of food to a broad spectrum of animals (Koptur 1992). Floral nectars of liana were reported to serve as an important food resource to birds and around 94 bird species belonging 22 families mainly humming birds, honey eaters and warblers were reported so far (Michel et al 2015). Passerine birds have been recorded as major floral nectar feeders in tropical dry deciduous forest during low food availability in other species of liana *e.g., Combretum fruticosum* (Gryj et al 1990). The bird's acoustic activity and patterns were more complex in liana rich forest site as compared to low liana abundance site in tropical deciduous forests of Costa Rica, thus, indicating importance of liana as direct and indirect resource to floral bird communities (Hilje et al 2017).

## CONCLUSIONS

On the basis of visitation frequency, time, and behaviour of observed animal visitors in *C. cucullata*, it is ample clear that the birds are main potential pollinators in *C. cucullata* duly assisted by butterflies (*Vindula erota erota* and *Badamia exclamationis*). However, diversity of floral visitors reveals that *C. cucullata* is a valuable liana species in the moist tropical forest for conservation of animal visitors, as it flowers during low resource availability. Moreover, the impact of atypical climatic rain exposed its vulnerability to reproductive success that also may influence the dependent animal species for food resources. *C. cucullata* could be a valuable liana species in green urban landscaping for their aesthetic as well conservation value for the dependent animal community.

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# Productivity and Profitability of Sweet corn (*Zea mays* L. *saccharata* Sturt)-Based Intercropping Systems

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***Abstract***: The experiment was conducted during *Kharif* season of 2017-18 at Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Wadura to evaluate the productivity and profitability of intercropping of sweet corn (*Zea mays* L. *saccharata* Sturt) with *Rajmash* (*Vigna vulgaris* L.) and soybean (*Glycine max* L. Merril). The intercrops were grown in additive series with sweet corn as regular rows of 1:1 and paired rows of 2:1 and 2:2. The experiment was laid out in randomized block design having three replications. The intercropping resulted decrease in yield and yield attributes of sweet corn comparing with sole cropping system. Among intercropping systems, sweet corn + soybean (1:1) was better than other treatments of intercropping in terms of the highest net returns of ₹ 505874/ha and benefit cost ratio of 9.00. The intercropping of sweet corn with soybean in regular rows of 1:1 ratio could achieve higher productivity and profitability among different intercropping systems.

***Keywords***: Intercropping, Net returns, Productivity, Soybean and Sweet corn

World population is growing exponentially and there was limited scope for horizontal expansion to augment food production, the alternative is to move on with vertical growth by increasing the productivity of the available land area. The cropping system is a design representing combination of crops either in sequence or in combination grown on an area within a year in a given agro-ecological situation. An attractive strategy for increasing productivity of a cropping system per unit available land is to intensify land use by growing several annual crops simultaneously, known as intercropping system. Intercropping may prove to address some of the major problems associated with modern agriculture, thereby helping to deliver sustainable and productive agriculture. The main purpose of intercropping is to produce a greater yield on a given piece of land by making use of resources that would otherwise not be utilized by a single crop efficiently. Normally, the system involves simultaneous cultivation of a cereal and a legume with adoptable row combination on the same piece of land. Inclusion of grain legume in an intercropping system has assumed added significance in recent past particularly in India since it provides the way to sustainable crop production. Corn (*Zea mays* L.) is a multipurpose crop being consumed in the human diet, animal feed and also used in starch industry (Bibi et al 2010). It is a versatile crop, globally grown under a wide range of agro-ecological situations of tropical, sub-tropical and temperate regions over an area of 193.7 million hectare (m ha) with production of 1147.7 million metric tonnes (m Mt) and average productivity of 5.75 t/ha (FAOSTAT 2020). In India as a third most important cereal crop, maize contributed about 8% to the national food basket being grown over an area of 9.2 m ha with grain production of 27.8 million metric tonnes (m Mt) and average productivity of 2.96 t/ha during 2018-19 (Dacent 2020). The speciality corn like sweet corn *(Zea mays* L. *saccharata* Sturt.) has emerged as an alternative food source. The higher content of water soluble polysaccharide in the kernel of sweet corn adds sweetness in addition to texture and quality (Venkatesh et al 2003). Corn provides sufficient inter-row space, which can be profitably utilized for raising an intercrop like beans and soybean. Both, *rajmash* and soybean build up the soil fertility by fixing large amount of atmospheric nitrogen through the root nodules, and contribute organic matter through leaf fall on soil surface at maturity. Intercropping of these legumes helps in soil conservation and improvement of soil fertility and weed control (Belel et al 2014). The intercropping systems are being mostly adopted by small holding farmers with limited resources. Sweet corn is an input intensive and high value crop, therefore study was undertaken to find out the most compatible legume under row regular rows of 1:1 and paired rows of 2:1 and 2:2.

## MATERIAL AND METHODS

The trial was conducted under irrigated conditions during *Kharif* season of 2017-18 in the experimental area at SKUAST-Kashmir, Wadura, J&K. The experimental site was located at 34˚17' N latitude and 74˚33' E longitude with an altitude of 1524 meters above mean sea level. The soil was well drained silty- clay loam, non-saline (0.37 dS/m) with neutral in reaction (pH 7.2) and contained 6.8 g/kg organic carbon, 224.5 kg/ha available nitrogen, 19.28 kg/ha available phosphorus and 163.6 kg/ha available potassium. The experiment consisted of ten treatments (Table 1). These treatments were replicated thrice and arranged in a randomized complete block design having each plot size of 4.5 m × 3.0 m. The sweet corn variety 'Mithas', bean 'French Yellow' and soybean 'Shalimar Soybean-1' were used. The different row arrangements of sole as well as intercropping systems of sweet corn and intercrops depicted in Fig. 1. Full dose of phosphorus (60 kg $P_2O_5$/ha) and potassium (30 kg $K_2O$/ha) and half dose of nitrogen (60 kg N/ha) were applied as basal dose before the sowing of sweet corn seeds while the remaining half dose of nitrogen (60 kg N/ha) was top dressed at respective critical stages i.e. first at 35 DAS and 65 DAS. In case of sole bean and soybean, 30:60:30 and 30:90:60 kg N, $P_2O_5$, $K_2O$ per hectare was applied as basal dose through urea, diammonium phosphate (DAP) and murate of potash (MOP) respectively.

## RESULTS AND DISCUSSION

### Productivity of Sweet Corn and Intercrops (Bean and soybean)

**Yield attributes of sweet corn and intercrops:** Cropping system had non-significant effect on yield attributes *viz.* number of cobs/m$^2$, number of rows/cob, number of kernels/row, test weight, cob length and girth (with and without husk) of sweet corn (Tables 1 and 2). Since the number of cobs/plant is the genetic make-up, it could not easily be altered by the agronomic management practices. However, single green cob weight with and without husk varied markedly with significantly highest green cob weight (with and without husk) was recorded with sole sweet corn. The parameter obtained in intercropping system with bean or soybean having row ratio of 1:1 and 2:1 were at par to the sole system. The weight of single green cob decreased significantly with 2:2 row ratios (Table 2). Yield attributing characters of intercrops (bean and soybean) *viz*. number of pods/plant, number of seeds/pod and test weight were reduced due to intercropping (Table 1). Decreasing trend of these attributes with the intercropping systems to the sole cropping system could be attributed to rise in interspecific competition with sweet corn. This might be owing to increase for the competition for light and minerals and more shading in intercropping lead to decrease in photosynthesis. These results confirm the findings of Carruthers et al (2000) and Getachew et al (2006).

**Table 1.** Yield attributes of sweet corn and intercrops as influenced by cropping system

| Treatment | Yield attributes of sweet corn | | | | Yield attributes of intercrops | | |
|---|---|---|---|---|---|---|---|
| | No. of cobs/m$^2$ | No. of rows/cob | No. of kernels/row | Test weight (g) | Number of pods/plant | Number of seeds/pod | Test weight (g) |
| Sole cropping system | | | | | | | |
| Sweet corn sole (75 cm) | 6.09 | 14.3 | 41.7 | 154.0 | - | - | - |
| Sweet corn paired sole (50/100 cm) | 6.06 | 13.9 | 44.4 | 151.1 | - | - | - |
| Bean sole | - | - | - | - | 16.6 | 5.92 | 299.8 |
| Soybean sole | - | - | - | - | 56.3 | 2.28 | 269.1 |
| Intercropping system | | | | | | | |
| Sweet corn + Bean (1:1) | 5.57 | 13.7 | 41.9 | 148.9 | 15.4 | 4.56 | 298.5 |
| Sweet corn + Soybean (1:1) | 6.04 | 13.8 | 42.5 | 149.3 | 52.0 | 2.14 | 269.1 |
| Sweet corn paired + Bean (2:1) | 5.51 | 13.4 | 41.5 | 145.7 | 16.0 | 5.60 | 296.5 |
| Sweet corn paired + Soybean (2:1) | 5.52 | 13.5 | 42.6 | 147.8 | 49.2 | 2.04 | 267.8 |
| Sweet corn paired + Bean (2:2) | 5.00 | 13.2 | 39.8 | 139.2 | 15.4 | 5.21 | 296.2 |
| Sweet corn paired + Soybean (2:2) | 5.42 | 13.3 | 41.5 | 143.0 | 44.9 | 1.91 | 264.8 |
| CD (p=0.05) | NS | NS | NS | NS | - | - | - |

**Yields of sweet corn and intercrops:** There was significantly higher green cob yield with the sole system of sweet corn both in regular and paired rows. Among intercropping system, the green cob yield obtained with sweet corn + soybean (1:1) and sweet corn + bean (1:1) were at par to the sole system. The significantly lowest green cob yield was with intercropping of paired rows of sweet corn + bean (2:2) (Table 3). The pure stand of crops maintained supremacy over the intercropping

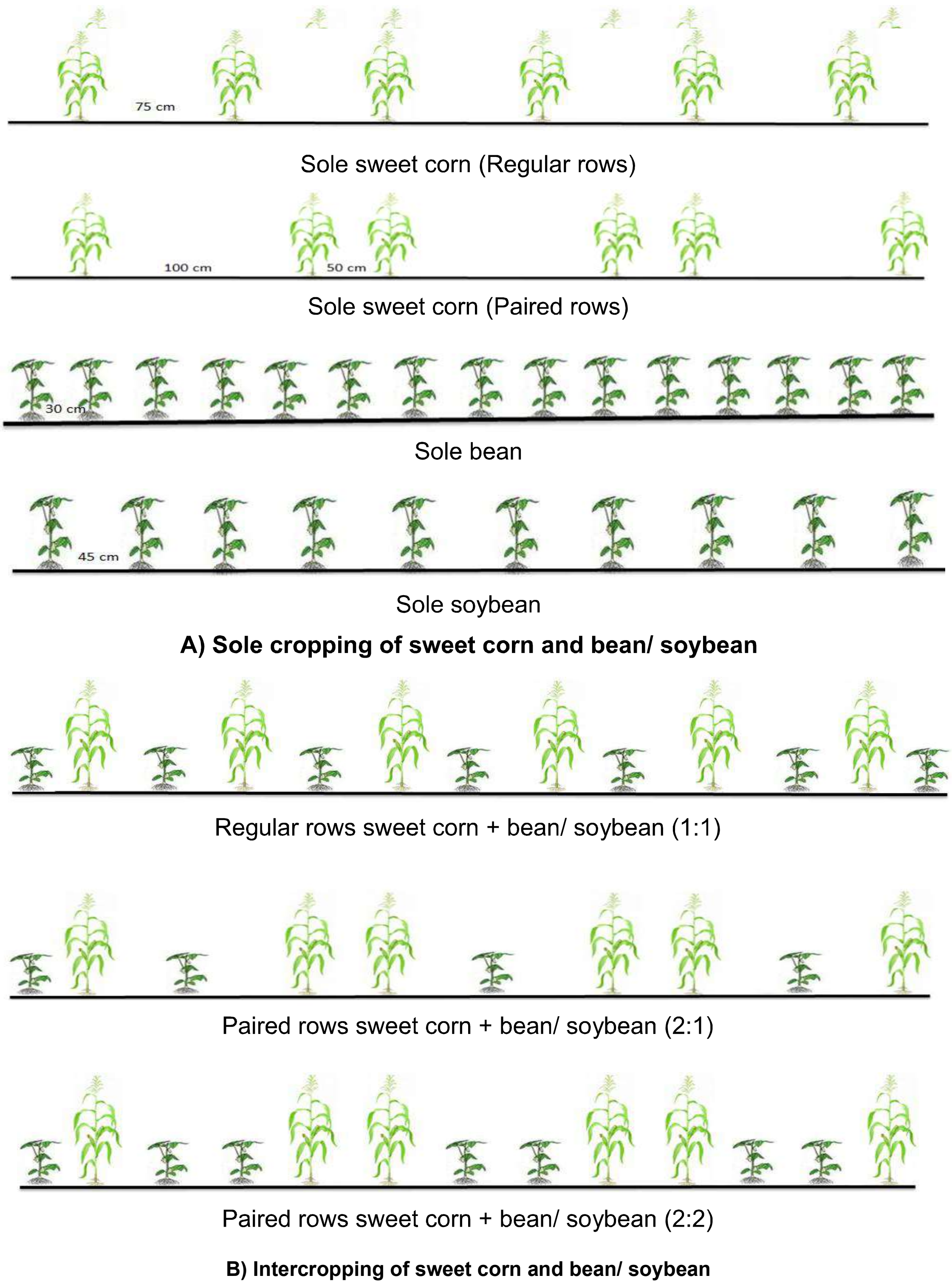


**Fig. 1.** Different row arrangements of sole as well as intercropping systems of sweet corn and intercrop (bean and soybean)

system with respect to economic yield, which might be attributed to limited disturbance of the habitat and interspecific competition in the sole cropping environment (Aynehband and Behrooz 2011 and Takim 2012). The trend of green fodder yield followed the green cob yield. Yield of intercrops (bean and soybean) were reduced due to intercropping with sweet corn (Table 3). Maximum seed yield of bean and soybean (1.14 and 2.30 t/ha, respectively) were recorded with the sole systems of bean and soybean followed by intercropping systems having 1:1 and 2:2 row ratios. Yield was mostly affected in the short statured under sown leguminous crops. Tall growing sweet corn plants shaded the leguminous crops and the main reason for reduction in yield was probably due to the receipt of lower amount of incoming solar radiation which affected the rate of photosynthesis and thereby translocation of photosynthates from source to sink. Relatively tall growing crop like soybean was less affected with respect to receipt of incoming solar flux. The results were also in consistent with the findings of Patra *et al* (2000). The shading effect of sweet corn plants (taller) on intercrops may also cause to decline in photosynthetic rate of lower plants ( bean and soybean) and thereby yield of intercrop reduced in intercropping arrangements. Metwally *et al* (2012) reported that the reduction of light intensity caused by the corn plant reduces the photosynthetic capacity of a second crop in an intercrop pattern.

**Table 2.** Cob length, cob girth and green cob weight of sweet corn as influenced by cropping system

| Treatment | Cob length (cm) | | Cob girth (cm) | | Weight of single green cob (g) | |
|---|---|---|---|---|---|---|
| | With husk | Without husk | With husk | Without husk | With husk | Without husk |
| Sole cropping system | | | | | | |
| Sweet corn sole (75 cm) | 24.3 | 22.4 | 6.30 | 5.70 | 0.58 | 0.41 |
| Sweet corn paired sole (50/100 cm) | 24.0 | 22.2 | 6.27 | 5.61 | 0.57 | 0.40 |
| Intercropping system | | | | | | |
| Sweet corn + Bean (1:1) | 23.6 | 21.8 | 6.22 | 5.53 | 0.54 | 0.37 |
| Sweet corn + Soybean (1:1) | 23.8 | 21.9 | 6.24 | 5.56 | 0.55 | 0.39 |
| Sweet corn paired + Bean (2:1) | 23.5 | 21.2 | 6.13 | 5.51 | 0.52 | 0.36 |
| Sweet corn paired + Soybean (2:1) | 23.6 | 21.7 | 6.20 | 5.51 | 0.53 | 0.37 |
| Sweet corn paired + Bean (2:2) | 23.4 | 20.7 | 6.01 | 5.41 | 0.43 | 0.33 |
| Sweet corn paired + Soybean (2:2) | 23.4 | 21.1 | 6.03 | 5.45 | 0.51 | 0.34 |
| CD (p=0.05) | NS | NS | NS | NS | 0.08 | 0.04 |

**Table 3.** Yield of sweet corn and intercrops as influenced by cropping system

| Treatment | Yield of sweet corn | | | Yield of intercrops | |
|---|---|---|---|---|---|
| | Green cob yield (t/ha) | | Green fodder yield (t/ha) | Seed yield (t/ha) | Straw yield (t/ha) |
| | With husk | Without husk | | | |
| Sole cropping system | | | | | |
| Sweet corn sole (75 cm) | 32.7 | 23.1 | 32.4 | - | - |
| Sweet corn paired sole (50/100 cm) | 32.2 | 22.7 | 31.7 | - | - |
| Bean sole | - | - | - | 1.14 | 2.79 |
| Soybean sole | - | - | - | 2.30 | 5.91 |
| Intercropping system | | | | | |
| Sweet corn + Bean (1:1) | 30.6 | 22.6 | 30.7 | 0.46 | 1.38 |
| Sweet corn + Soybean (1:1) | 31.4 | 23.0 | 31.6 | 1.41 | 4.02 |
| Sweet corn paired + Bean (2:1) | 27.3 | 20.1 | 27.5 | 0.25 | 0.68 |
| Sweet corn paired + Soybean (2:1) | 30.3 | 20.1 | 30.0 | 0.76 | 2.07 |
| Sweet corn paired + Bean (2:2) | 24.2 | 18.2 | 22.0 | 0.42 | 1.20 |
| Sweet corn paired + Soybean (2:2) | 27.2 | 18.5 | 23.0 | 1.28 | 3.62 |
| CD (p=0.05) | 4.4 | 3.1 | 4.2 | - | - |

**Table 4.** Economics as influenced by cropping systems of sweet corn, bean and soybean

| Treatment | Total cost of cultivation (₹/ha) | Gross return (₹/ha) | Net return (₹/ha) | B: C ratio |
|---|---|---|---|---|
| Sole cropping system | | | | |
| Sweet corn sole (75 cm) | 52475 | 523344 | 470869 | 8.97 |
| Sweet corn paired sole (50/100 cm) | 52475 | 516318 | 463843 | 8.84 |
| Bean sole | 34375 | 92582 | 58207 | 1.69 |
| Soybean sole | 34135 | 73239 | 39104 | 1.15 |
| Intercropping system | | | | |
| Sweet corn + Bean (1:1) | 57225 | 551109 | 493884 | 8.63 |
| Sweet corn + Soybean (1:1) | 56225 | 562099 | 505874 | 9.00 |
| Sweet corn paired + Bean (2:1) | 56025 | 476462 | 420437 | 7.50 |
| Sweet corn paired + Soybean (2:1) | 55025 | 481401 | 426376 | 7.75 |
| Sweet corn paired + Bean (2:2) | 57825 | 444912 | 387087 | 6.69 |
| Sweet corn paired + Soybean(2:2) | 55825 | 463995 | 408170 | 7.31 |

**Economics:** The maximum gross return, net return and B:C ratio was obtained with sweet corn + soybean (1:1) followed by sole systems of sweet corn (Table 4). In agreement with these results, higher net monetary return was also reported by Meena et al (2006) and Sonam et al (2014).

## CONCLUSION

Cereal-legume intercropping systems have higher productivity than sole cropping systems. The soybean was more suitable for intercropping with sweet corn compare to bean. Among intercropping system, green cob and green fodder yields showed significantly higher with sweet corn + soybean (1:1) which was closely followed by sweet corn + bean (1:1). Seed yield of intercrops under sole cropping were higher when compared with their intercropping yields. Among different cropping system, intercropping of sweet corn with soybean in regular rows of 1:1 ratio was more biologically and economically viable intercropping system for irrigated silty clay loam soil of Kashmir valley.

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# Efficacy of Isoproturon and Pendimethalin against Resistant Biotypes of *Rumex* spp. in Wheat (*Triticum aestivum* L.)

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***Abstract***: Persistence of weeds under irrigation conditions is inevitable and manual management practices are labour intensive and cumbersome. As far as wheat is concerned huge losses in yield, are incurred due to *Rumex* spp. Therefore, the present study was carried out to evaluate the efficacy of herbicides against *Rumex* spp. during the *Rabi,* 2017-18 at Department of Agronomy, Chaudhary Charan Singh Haryana Agricultural University, Hisar (Haryana). Isoproturon as post- emergence and pendimethalin as pre-emergence were taken as treatments and applied at three doses (0.5X, 1.0X and 2.0X) under pot study 'X' is the recommended dose of herbicide@ 1000g/ha for isoproturon and 1500g/ha for pendimethalin .Four populations of *Rumex* spp. named as HHH (HAU Hisar), UPH (Ujha, Panipat), JHH (Jind) and JJR (Jhajjar) collected from putative resistance affected farmer's field.UPH and JHH populations are highly resistant whereas JJR population is moderately resistant to sulphonylureas herbicides. HHH population is sensitive so used as standard check for comparison. Majority of biotypes showed sensitivity against isoproturon at recommended dose except UPH biotype. It provided 70-90 per cent control to all biotypes at double of recommended doses. Lower values of plant height, chlorophyll fluorescence, fresh and dry weight were observed in isoproturon treated plants. *Rumex* biotypes were highly sensitive to pendimethalin when applied as pre emergence. It provided complete control to all biotypes. The information collected from this study will facilitate proactive management of *Rumex* spp. through sequential application of pre and post emergence herbicides.

***Keywords***: Biotype, chlorophyll fluorescence, isoproturon, pendimethalin, *Rumex* spp.

Wheat (*Triticum aestivum*) is world's most widely cultivated and leading staple food crop with an area, production and productivity of 214.3 mha, 734.1 mt and 3425.5 kg/ha, respectively (FAO STAT 2018). In India, it is the second most important food crop after rice cultivated in 30.6 mha with 99.8 mt production and 3220 kg/ha productivity (Anonymous 2018). Haryana is the major wheat growing state of India with an area of about 2.53 m ha with 11.7 mt production and 4.62 t/ha productivity (Anonymous 2018a). Weeds are a major impediment to crop production through their ability to compete for light, moisture, nutrients and space (Singh et al 2007). Weeds are a serious cause of concern for wheat productivity loss to the tune of 15-40 per cent or even higher besides lowering down the quality of produce (Chopra et al 2001). Extent of yield loss depends upon type and density of weed, soil characteristics and environmental conditions (Chhokar and Malik 2002). Weed stage, herbicide rates and fertilizers application impact weed control and crop-weed competition. Wheat is infested with diverse weed flora because it is grown in diverse agro-climatic conditions, under different cropping sequences, tillage and irrigation regimes . *Rumex dentatus, Chenopodium album, Medicago sativa, Melilotus alba* and *Fumaria parviflora* are major broad leaf weeds in rice-wheat cropping system (Chhokar et al 2006). Reduced tillage or no till wheat with higher moisture in rice–wheat system favours the infestation of broad leaf weeds like *Malwa parviflora* and *R. dentatus.* Worldwide herbicide is a key tool of weed management in wheat due to its cost and time effectiveness. *R. dentatus* is a major broadleaf weed of *rabi* season and is a serious problem of irrigated wheat particularly in rice-wheat cropping system in north-western Indo-Gangetic alluvial plains of India (Sandhu and Dhaliwal 2016). This weed is highly competitive and yield losses up to 55 per cent have been reported (Heap 2014). Metsulfuron, a sulfonylurea herbicide was recommended for its control in wheat during 1998. But recently, poor efficacy of metsulfuron against the toothed dock (*R. dentatus* L.) was observed under field conditions and the subsequent studies confirmed the instances of herbicide resistance in this weed (Singh et al 2017). Herbicide resistant weeds in wheat crop were susceptible to pre emergence (PRE) herbicides such as pendimethalin, and metribuzin (Chhokar and Sharma 2008). But alone pre-emergence herbicides are not effective against *Rumex* spp.So there is need to evaluate the alternate pre and post emergence herbicides for effective management of *Rumex* spp.

## MATERIAL AND METHODS

The experiment was conducted during *rabi* season of 2017-18 in screen house, Chaudhary Charan Singh Haryana Agricultural University, Hisar with latitude and longitude of 29°9”14' and 75°43”22', respectively. The maximum and minimum weekly mean temperatures of 35.7°C and, 2.6°C were recorded during 2nd, 13th and 14th standard meteorological week. The total rainfall during the crop season was 15.9 mm. The average annual rainfall ranged between 500-750 mm. Isoproturon and pendimethalin were applied at three doses (0.5X, 1.0X and 2.0X) named as in pot experiment under completely randomized design with three replications. Here 'X' is recommended dose of herbicides whose value is 1500 g/ha for pendimethalin and 1000g/ha for isoproturon. Seeds of four populations of *Rumex* spp. named as HHH (HAU Hisar), UPH (Ujha, Panipat), JHH (Jind), and JJR (Jhajjar) were collected from putative resistance affected farmer's fields. HAU population was a standard sensitive population for comparison. Soil was taken from Agronomy Research Farm area for filling the pots, which was free from seeds of *Rumex* spp. and not exposed to herbicides from the last two years. The soil was air-dried, well crushed in fine particles to pass through a sieve of 2 mm pore size. Plastic pots (6″ diameter) were filled with 2 kg material comprising sand and vermi-compost was mixed with field soil in such a way that sand, field soil and vermi-compost are in ratio of (2:3:1). Plant height, chlorophyll fluorescence, mortality percentage, electrical conductivity, fresh weight and dry weight were recorded as parameters. All the observations were statistically analyzed by using software OP STAT.

## RESULTS AND DISCUSSION

**Plant height:** Significant variation in plant height of *Rumex* biotypes was observed at 2 and 4 weeks after treatment (WAT) with application of isoproturon (Table 1). The isoproturon doses, significantly affected plant height. The higher plant height (cm) was recorded in UPH and JHH (22.8) followed by HHH and JJH at 2 WAT. The significantly higher plant height was observed in UPH (22.2) which was statistically similar with JHH (21.6) but significantly higher than other biotypes at 4 WAT. Isoproturon @ 500 and 1000 g/ha resulted statistically similar plant height among all biotypes except HHH at 2 and 4 WAT. Half dose of isoproturon resulted in 5.3 per cent and 8 per cent higher plant height over recommended dose, whereas double dose resulted in 5.3 per cent and 8.6 per cent lower plant height than recommended dose, respectively at 2 and 4 WAT. Non-significant variation in plant height of *Rumex* biotypes was observed at spraying, 2 and 4 WAT with the application of pendimethalin. It is due to zero emergence of *Rumex* spp. plants caused by pre-emergence spray of pendimethalin.

**Plant chlorophyll:** *Rumex* biotypes as affected by the application of isoproturon at 1, 2 and 7 days after treatment (DAT) (Table 2). The significantly higher plant chlorophyll fluorescence (Fv/Fm) was observed in UPH (0.42-0.41-0.37) followed by JHH, HHH and JJH respectively at 1, 2 and 7 DAT. Half dose of isoproturon resulted in 142.0, 180.0 and 360.0 per cent higher plant chlorophyll fluorescence over recommended dose, whereas double dose resulted in 16.7, 20 and 40 per cent lower plant chlorophyll fluorescence than recommended dose, respectively at 1, 2 and 7 DAT, when data was averaged over all biotypes.Non-significant variation in plant chlorophyll fluorescence of *Rumex* biotypes was observed by the application of pendimethalin at 1 and 2 DAT. It is due to zero emergence of *Rumex* plants caused by pendimethalin spray.

**Table 1.** Plant height of *Rumex* biotypes as influenced by isoproturon (g/ha)

| Populations | Plant height week after treatment (cm) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Before spraying | | | | | 2 | | | | | 4 | | | | |
| | 0 | 500 | 1000 | 2000 | Mean | 0 | 500 | 1000 | 2000 | Mean | 0 | 500 | 1000 | 2000 | Mean |
| HHH | 18.3 | 17.3 | 17.0 | 17.3 | 17.5 | 25.7 | 19.3 | 18.0 | 16.7 | 19.9 | 26.3 | 18.7 | 17.0 | 15.7 | 19.4 |
| UPH | 19.0 | 18.3 | 18.3 | 18.0 | 18.4 | 26.7 | 23.7 | 21.7 | 19.3 | 22.8 | 27.3 | 22.7 | 20.3 | 18.3 | 22.2 |
| JHH | 18.0 | 17.0 | 17.0 | 17.0 | 17.3 | 27.0 | 22.0 | 21.0 | 21.0 | 22.8 | 27.7 | 21.0 | 20.0 | 17.7 | 21.6 |
| JJH | 17.0 | 16.3 | 16.3 | 16.0 | 16.4 | 21.0 | 14.3 | 14.3 | 14.3 | 16.0 | 21.7 | 12.7 | 12.3 | 12.0 | 14.7 |
| Mean | 18.1 | 17.3 | 17.2 | 17.1 | | 25.1 | 19.8 | 18.8 | 17.8 | | 25.8 | 18.8 | 17.4 | 15.9 | |
| | CD (P=0.05) | | | | | CD (P=0.05) | | | | | CD (P=0.05) | | | | |
| Population | 0.9 | | | | | 0.7 | | | | | 0.8 | | | | |
| IPU | NS | | | | | 0.7 | | | | | 0.8 | | | | |
| Population x IPU | NS | | | | | 1.4 | | | | | 1.5 | | | | |

IPU, isoproturon; WAT, weeks after treatment

**Weed control:** The control of *Rumex* biotypes significantly varied with the application of isoproturon at 1, 2 and 4 WAT (Table 3). Significantly lower mortality (%) was recorded in UPH (35-42-45) followed by JHH,HHH and JJH at 1, 2 and 4 WATduring. The per cent mortality of HHH was f statistically similar with JHH at 1, 2 and 4 WAT. Half dose of isoproturon resulted in 13.1-15.7-10.4 per cent lower mortality over recommended dose, whereas double dose resulted in 11.5-8.6-10.4 per cent higher mortality than recommended dose, respectively at 1, 2 and 4 WAT.Per cent control of *Rumex* biotypes was non-significant with the application of pendimethalin at 1, 2 and 4 WAT as there is no emergence of *Rumex* plants due to pendimethalin effect.

**Electrical conductivity (EC):** Isoproturon had significant effect on EC of *Rumex* biotypes, before and after boiling the plant solution at 1 WAT (Table 4). Significantly lower EC (ds/m) was in UPH (0.13-0.25) followed by JHH , HHH and JJH t before and after boiling at 1 WAT. Half dose of isoproturon resulted in 13.6-13.6 per cent lower EC over recommended dose, whereas double dose resulted in 13.6-11.4 per cent higher EC than recommended dose, respectively before and after boiling at 1 WAT. Pendimethalin had non-significant effect on EC of *Rumex* biotypes, before and after boiling at 1 WAT as there is no emergence of *Rumex* plants due to pendimethalin action.

**Fresh and dry weight:** The isoproturon doses, significantly higher fresh weight (g/pot) was recorded in UPH (4.01) followed by JHH, HHH and JJH whereas significantly higher dry weight (g/pot) was recorded in UPH (1.49) followed by JHH , HHH and JJH at harvesting (120 DAS) (Table 5). Mean fresh and dry weight in JHH was statistically similar with HHH. Isoproturon @ 1000 and 2000 g/ha resulted in statistically similar fresh and dry weight among all biotypes except UPH at harvesting (120 DAS). Half dose of isoproturon resulted in 45.3 per cent and 51.2 per cent higher fresh and dry weight, respectively over recommended dose,

**Table 2.** Plant chlorophyll fluorescence (Fv/Fm) of *Rumex* biotypes as influenced by isoproturon (g/ha)

| Populations | Chlorophyll fluorescence days after treatment (Fv/Fm) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | | | | | 2 | | | | | 7 | | | | |
| | 0 | 500 | 1000 | 2000 | Mean | 0 | 500 | 1000 | 2000 | Mean | 0 | 500 | 1000 | 2000 | Mean |
| HHH | 0.85 | 0.13 | 0.11 | 0.09 | 0.30 | 0.85 | 0.11 | 0.09 | 0.07 | 0.28 | 0.85 | 0.06 | 0.04 | 0.02 | 0.25 |
| UPH | 0.91 | 0.53 | 0.13 | 0.12 | 0.42 | 0.91 | 0.51 | 0.11 | 0.10 | 0.41 | 0.91 | 0.46 | 0.06 | 0.04 | 0.37 |
| JHH | 0.91 | 0.39 | 0.13 | 0.10 | 0.38 | 0.91 | 0.38 | 0.11 | 0.08 | 0.37 | 0.91 | 0.33 | 0.06 | 0.04 | 0.33 |
| JJH | 0.84 | 0.12 | 0.10 | 0.08 | 0.29 | 0.84 | 0.10 | 0.08 | 0.06 | 0.27 | 0.84 | 0.05 | 0.03 | 0.01 | 0.23 |
| Mean | 0.88 | 0.29 | 0.12 | 0.1 | | 0.88 | 0.28 | 0.10 | 0.08 | | 0.88 | 0.23 | 0.05 | 0.03 | |
| | CD (P=0.05) | | | | | CD (P=0.05) | | | | | CD (P=0.05) | | | | |
| Population | 0.2 | | | | | 0.2 | | | | | 0.2 | | | | |
| IPU | 0.2 | | | | | 0.2 | | | | | 0.2 | | | | |
| Population x IPU | 0.4 | | | | | 0.4 | | | | | 0.4 | | | | |

IPU, isoproturon; DAT, days after treatment

**Table 3.** Per cent control of *Rumex* biotypes as influenced by isoproturon (g/ha)

| Populations | Mortality week after treatment (%) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | | | | | 2 | | | | | 4 | | | | |
| | 0 | 500 | 1000 | 2000 | Mean | 0 | 500 | 1000 | 2000 | Mean | 0 | 500 | 1000 | 2000 | Mean |
| HHH | 0 | 48 | 56 | 67 | 43 | 0 | 53 | 67 | 73 | 48 | 0 | 69 | 81 | 89 | 60 |
| UPH | 0 | 43 | 49 | 50 | 35 | 0 | 45 | 56 | 65 | 42 | 0 | 51 | 58 | 70 | 45 |
| JHH | 0 | 47 | 52 | 64 | 41 | 0 | 50 | 66 | 75 | 48 | 0 | 67 | 79 | 89 | 59 |
| JJH | 0 | 75 | 89 | 89 | 64 | 0 | 89 | 89 | 89 | 67 | 0 | 89 | 89 | 89 | 67 |
| Mean | 0 | 53 | 61 | 68 | | 0 | 59 | 70 | 76 | | 0 | 69 | 77 | 85 | |
| | CD (P=0.05) | | | | | CD (P=0.05) | | | | | CD (P=0.05) | | | | |
| Population | 2.5 | | | | | 4.5 | | | | | 3.0 | | | | |
| IPU | 2.5 | | | | | 4.5 | | | | | 3.0 | | | | |
| Population x IPU | 5.0 | | | | | 9.0 | | | | | 6.0 | | | | |

IPU,isoproturon; WAT, weeks after treatment whereas double dose resulted in 53 per cent and 46.5 per cent lower fresh and dry weight, respectively than recommended dose at harvesting (120 DAS), over all biotypes.Non-significant variation in fresh and dry weight of *Rumex* biotypes was observed by the application of pendimethalin at harvesting time as there is no emergence of *Rumex* plants.

Majority of biotypes showed sensitivity against application of isoproturon at recommended dose and double of recommended dose except UPH biotype at 4 WAT. It provided 70-90 per cent control to all biotypes at double of recommended doses. Lack of mortality in *Rumex* biotypes at half of recommended dose and recommended dose could be due to lower availability of lethal dose of herbicide to translate in satisfactory control. These results are in the conformity with the findings earlier researchers (Sinha and Singh 2005, Khokhar and Charak 2011, Chhokar et al 2017). Low value of chlorophyll fluorescence was observed in all biotypes with the application of isoproturon is due to inhibition of photosystem II. These observations are supported by the findings of Varshney et al (2012). Kumar et al (2008) observed a significant decrease in Fv /Fm at 1 and 2 days after treatment (DAT) in herbicide treated plants. Kirkwood et al (2000) also reported similar findings and found that herbicide application caused large changes in Fv / Fm values after 1 day of application. *Rumex* biotypes were highly sensitive to pendimethalin, when applied as pre emergence. It provided complete control in all biotypes. No emergence was found in pots treated with pendimethalin even at half of the recommended dose of herbicide. It is due to mitotic disruption through inhibition of microtubule protein tubulin. These results are in conformity with findings of Patil and Dhonde (2009). Kaur et al (2017) also observed the good efficacy of pendimethalin against *Rumex* spp.

**Table 4.** EC of *Rumex* biotypes before and after boiling as influenced by isoproturon (g/ha) at 4weeks after treatment

| Populations | EC (ds/m) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Before boiling the plant solution | | | | | After boiling the plant solution | | | | |
| | 0 | 500 | 1000 | 2000 | Mean | 0 | 500 | 1000 | 2000 | Mean |
| HHH | 0.01 | 0.17 | 0.21 | 0.26 | 0.17 | 0.02 | 0.34 | 0.43 | 0.53 | 0.33 |
| UPH | 0.02 | 0.14 | 0.17 | 0.18 | 0.13 | 0.03 | 0.28 | 0.34 | 0.36 | 0.25 |
| JHH | 0.02 | 0.16 | 0.19 | 0.24 | 0.15 | 0.03 | 0.33 | 0.39 | 0.49 | 0.31 |
| JJH | 0.01 | 0.28 | 0.30 | 0.30 | 0.22 | 0.03 | 0.57 | 0.60 | 0.6 | 0.45 |
| Mean | 0.02 | 0.19 | 0.22 | 0.25 | | 0.03 | 0.38 | 0.44 | 0.49 | |
| | CD (P=0.05) | | | | | CD (P=0.05) | | | | |
| Population | 0.01 | | | | | 0.02 | | | | |
| IPU | 0.01 | | | | | 0.02 | | | | |
| Population x IPU | 0.01 | | | | | 0.03 | | | | |

EC, electrical conductivity; IPU, isoproturon; WAT, weeks after treatment

**Table 5.** Fresh and dry weight of *Rumex* biotypes as influenced by isoproturon at harvesting (120 DAS)

| Populations | EC (ds/m) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Before boiling the plant solution | | | | | After boiling the plant solution | | | | |
| | 0 | 500 | 1000 | 2000 | Mean | 0 | 500 | 1000 | 2000 | Mean |
| HHH | 6.97 | 1.40 | 0.60 | 0.33 | 2.33 | 2.47 | 0.53 | 0.23 | 0.13 | 0.84 |
| UPH | 8.57 | 3.50 | 2.87 | 1.10 | 4.01 | 3.23 | 1.27 | 1.03 | 0.43 | 1.49 |
| JHH | 7.63 | 1.43 | 0.77 | 0.37 | 2.55 | 2.83 | 0.53 | 0.23 | 0.13 | 0.93 |
| JJH | 3.23 | 0.47 | 0.43 | 0.40 | 1.13 | 2.40 | 0.27 | 0.23 | 0.23 | 0.78 |
| Mean | 6.60 | 1.70 | 1.17 | 0.55 | | 2.73 | 0.65 | 0.43 | 0.23 | |
| | CD (P=0.05) | | | | | CD (P=0.05) | | | | |
| Population | 0.24 | | | | | 0.12 | | | | |
| IPU | 0.24 | | | | | 0.12 | | | | |
| Population x IPU | 0.49 | | | | | 0.25 | | | | |

IPU, isoproturon; DAS, days after showing

## CONCLUSION

Majority of *Rumex* biotypes showed sensitivity against isoproturon at recommended dose except UPH biotype. It provided 70-90 per cent control to all biotypes at double of recommended doses. *Rumex* biotypes were highly sensitive to pendimethalin when applied as pre emergence. It provided complete control in all biotypes. No emergence was found in pots sprayed with pendimethalin even at half of the recommended dose of herbicide. This is the key finding of this study because pre-emergence intervention with pendimethalin could resolve the problem of resistant *Rumex* biotypes being faced by the farmers without incurring extra cost of post-emergence herbicides.

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# Development and Evaluation of Irrigation Management Strategies for Higher Yield and Water Productivity of Wheat: A Simulation Modelling Approach

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***Abstract***: In the present study, CERES-wheat model was calibrated and validated for predicting growth and yield of wheat by using three years of experimental data (2016-17, 2017-18 and 2019-20) under different irrigation treatments. Further the model was run with twenty years of weather data (2000-01 to 2019-20) with optimum management practices under different irrigation scenarios for developing the irrigation management strategies for obtaining higher grain yield and irrigation water productivity (IWP) under dry, wet and normal rainfall conditions. The results indicated that the model slightly overestimated the maximum leaf area index (LAI) and consequently the grain yield in water stress condition; however, overall, model could excellently simulate anthesis and maturity with RMSE<4 days, RMSEn<10% and d>0.90, as well as grain yield (RMSE= 163-204 kg/ha, RMSEn =3-6%, d = 0.93-0.98) for three, four and five irrigations from CRI to jointing, CRI to anthesis and CRI to dough stage, respectively. The IWP was increased with the decrease in number of irrigations. The maximum yield was obtained when the four irrigations applied from CRI to Anthesis under all-weather years (Dry, wet and normal), but it was as par with the three irrigations applied at CRI, Tillering and Jointing or CRI, Tillering and Anthesis stage for wet years. Under three irrigations scenario the maximum yield of 5050-5302 kg/ha and irrigation water productivity (IWP) of 33.7-35.3 kg/ha-mm was noticed when three irrigations applied at CRI, Tillering and Jointing followed by at CRI, Tillering, Anthesis stage and CRI, Jointing and Anthesis stage and under wet year no difference was noticed in yield and IWP whether three irrigations were applied at CRI, Tillering and Jointing or CRI, Tillering and Anthesis stage and under two irrigations scenario, the maximum grain yield as well as IWP was obtained when applied at CRI and Tillering followed by CRI and Jointing stage.

***Keywords***: Wheat, CERES-wheat, Irrigations, Grain yield, Irrigation water productivity (IWP)

Wheat is one of the major cereal crops in India which plays a very important role for national and global food security. In semi-arid and arid regions where water is the main constraint for the growth and yield of wheat, deficit irrigation at certain specific growth stages can reduce the adverse effects of water stress without compromising the yield (Sun et al 2006). This will also improve the irrigation water productivity (WP) as well as the overall productivity of crop (Attia et al 2016). Deficit irrigation is defined as the application of irrigation water less than the full ET requirement of the crop. Therefore, determining the critical growth stages based on climatic conditions for applying the limited water available for irrigation is important to reduce the impact of water stress on growth and yield of wheat crop. In the fields, however, conducting long term experiments and testing different management scenarios is difficult because it is time consuming and also labour intensive process. CERES-wheat model is very robust in simulating the critical phenological growth stages and yield of different cultivars of wheat under different crop management and environmental conditions (Mahdi and Mizanul 2018, Koushik and Mahdi 2019). The irrigation management strategies (such as amount, depth and frequency) under different soils, climates and management conditions can be developed by using the well calibrated and validated crop model (Chen et al 2018) to obtain higher irrigation water productivity (IWP) and optimum grain yield (Abd El Baki et al 2018).

The objectives of the current research were to: calibrate and validate a CERES-Wheat model for simulating grain yield and phenology of wheat under different levels of irrigation and sowing date and evaluate irrigation management strategies for obtaining higher yield and water productivity.

## MATERIAL AND METHODS

**Experimental details and data collection*:*** Field experiments were conducted during *Rabi* season of 2016-17 and 2017-18, 2019-20 on a sandy loam soil at the research farm of Water Technology Centre, ICAR-Indian Agricultural Research Institute (IARI), New Delhi (28°38'23" N, 77°09'27" E). Wheat cultivar HD-2967 was sown on a split plot design under three sowing dates as the main plot treatments and 5 irrigation regimes levels as subplot treatments within each main plot. The dates of sowing were: $D_1$-15th November, $D_2$ –30th November and $D_3$ –15th December. The irrigation regimes were: $I_1$ –CRI, $I_2$ –CRI and TL, $I_3$ –CRI, TL and JO, $I_4$–CRI, TL, JO and FL, $I_5$– CRI, TL, JO, FL and DS (CRI=Crown Root Initiation, TL- Tillering, JO-Jointing, FL-Flowering and DS- Dough Stage). The recommended dose of Nitrogen (N), phosphorus (P) and potassium (K) were applied at the rate of 120, 60 and 40 kg ha$^{-1}$. Total dose of P and K and half dose of N were applied as basal doses and remaining N doses were top dressed at tillering and booting stages in equal amounts.

Crop growth and yield attributes such as phenological stages, tillers/m$^2$, plant population, dry matter partitioning, biomass, grain yield etc. were collected following the standard procedures and methods. Leaf area index (LAI) at different growth stages were measured by using Canopy Analyser (LP-80). The profile wise data of soil parameters required for the model were taken from Ajdary et al (2007). The weather parameters *viz.* daily solar radiation, maximum and minimum air temperature, and rainfall during the growing seasons were taken from the agro meteorological observatory of ICAR-IARI, New Delhi.

**DSSAT CERES-Wheat:** The DSSAT CERES-Wheat model (Jones et al 2003) is radiation use efficiency (RUE) based model which simulates growth, development and yield of the crop; based on light interception and environmental stresses; soil water balance; and soil N balance. The model describes the progress through the crop life cycle using degree-day accumulation. Input requirements for CERES-Wheat include site information (e.g. latitude, longitude, elevation etc), daily weather (e.g. solar radiation, maximum and minimum air temperature and rainfall), soil conditions (physical and chemical characteristics of soil profile), plant characteristics, and crop management (e.g. sowing date, depth and method; plant population; irrigation and fertilizer management, dates, method, depth and amount; tillage; harvest schedule etc.).

**Calibration and validation of model:** The growth and yield data of wheat crop collected during *Rabi* season of the year 2016-17 from the treatment combination of 15th November sowing date and full irrigation (5 irrigations) were used for model calibration. Treatment with full irrigation and optimum sowing time could meet the ET demand throughout the growing season without any shortage of water. Other information used for calibration were daily weather parameters, soil and crop management data. From model calibration process, the genetic coefficients of the wheat cultivar HD 2967 were derived using the Generalised Likelihood Uncertainty Estimator (GLUE) coefficients estimator module of DSSAT 4.6. An iterative approach was used to obtain reasonable genetic coefficients through trial-and-error procedure until the simulated and measured values matched or was within predefined error limits. The calibrated model was validated by using the independent data set of remaining treatments of *Rabi* season of the year 2016-17 and all treatments data of *Rabi* season of the year 2017-18. Thereafter the model performance was also evaluated using independent data set of 2019-20. The model performance was assessed by using normalised root mean square error (RMSEn) and index of agreement (d) (Wilmot 1982) between the observed and simulated values of growth and yield parameters by using the following equation:

$$RMSE_n = \frac{RMSE \times 100}{\overline{O}}$$

$$d = 1 - \left[ \frac{\sum_{i=1}^{n} (S_i - O_i)^2}{\sum_{i=1}^{n} (|S_i'| + O_i')^2} \right], 0 \le d \le 1$$

Where, *n*= number of observations, *Si*= simulated value for the ith measurement, *Oi*=observed value for the *i*th measurement, O= the overall mean of observed values, $S_i' = S_i - \overline{O}, O_i' = O_i - \overline{O}$ and RMSE=root mean square error which is calculated using the following equation:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (S_i - O_i)^2}{n}}$$

A high value for the Wilmot's *d*-index approaching one and a low value for RMSEn approaching zero indicate a good fit between the simulated and observed values. According to Liu et al (2013), d values < 0.70, 0.71 – 0.80, 0.81 – 0.90 and > 0.91 indicated poor, moderate, good, and excellent agreements, respectively. According to Soler et al (2007), RMSEn values < 10%, 10 – 20%, 20 – 30%, and > 30% indicate good, moderate, fair, and poor performance, respectively.

**Model simulation setup and irrigation scenarios*:*** Simulations were carried out using 20 years (2000/2001–2019/2020) of historical weather data from ICAR-IARI, New Delhi with 15th November sowing date, which is the optimum sowing date for the variety HD-2967 (Bisht et al 2019). Three irrigation scenarios were generated for development of irrigation strategies based on the availability of irrigation water or number of irrigations at different stages (Table 1). It includes four irrigations applied at [CRI (C)+Tillering (T) +Jointing (J) +Anthesis (A)]; three irrigations applied at [CRI (C)+Tillering (T) +Jointing (J), CRI (C)+Tillering (T) +Anthesis (A) and CRI (C)+ Jointing (J) +Anthesis (A)] and two irrigations at [CRI (C)+Tillering (T), CRI (C)+Jointing (J) and CRI (C)+Anthesis (A)}. The yield and water productivity were compared under three irrigation scenarios and based on the analysis the best irrigation management strategies were developed for wheat. The irrigation water productivity (IWP) was calculated by using the following formula:

$$IWP\ (kg/ha\text{-}mm) = \frac{Grain\ Yield\ (GY)\ (kg/ha)}{Total\ Irrigation\ applied\ (I)\ (mm)}$$

## RESULTS AND DISCUSSION

**Calibration of CERES-Wheat model:** The seven genetic coefficients *viz.* P1V, PID, P5, G1, G2, G3 and PHINT of wheat cultivar HD 2967 were derived by GLUE estimator (Table 2). The models provided very satisfactory estimates for the germination, anthesis, physiological maturing date, yield and biomass and LAI. Calibrated results are presented in Table 3.

**Validation of CERES-Wheat Model**

**Anthesis date and physiological maturity:** Statistical indices derived for evaluating the performance of CERES-Wheat model in simulating the days to anthesis (DAS), days to physiological maturity (DAS), maximum leaf area index (LAI) and grain yield (kg/ha) are presented in Table 4. The maximum number of days to anthesis as well as physiological maturity were observed with five irrigations ($I_5$) and the minimum number of days were observed for reduced irrigation frequency as it was found in $I_1$ (when irrigation was applied at CRI stage only). CERES-wheat model also showed an overestimation in respect of phenology of wheat. The statistical results for evaluation of anthesis and physiological maturity dates were excellent with a RMSE less than 4 days for $I_3$, $I_4$ and $I_5$ with d value >0.90. Dar et al (2017). Malik and Dechmi (2019) reported RMSE values lower than 4 days in terms of the time to anthesis and physiological maturity. However moderate agreements were observed under lower irrigation regimes *i.e.,* one and two irrigation levels with d value ranged from 0.71 to 0.73. Moreover, the deviation percentage between observed and simulated value was observed to be higher in moisture stressed conditions, while, least variation was found with five irrigations ($I_5$).

**Maximum LAI and Grain Yield:** The higher value of maximum LAI (5.3 to 5.4) was observed for non-stressed conditions while the lower values were observed under water stressed conditions. The grain yield increased with increase in number of irrigations from $I_1$ (irrigation at CRI only) to $I_5$ (irrigation from CRI to dough stage). Although there was an increase in grain yield with increase in irrigation, irrigation

**Table 3.** Calibration results for CERES-wheat

| Parameters | Simulated | Observed |
|---|---|---|
| Anthesis date (DAS) | 109 | 109 |
| Physiological maturity date (DAS) | 145 | 144 |
| Grain yield (kg $ha^{-1}$) | 5086 | 5033 |
| Biomass at harvest (kg $ha^{-1}$) | 15894 | 17795 |
| Maximum LAI ($m^2/m^2$) | 5.5 | 5.8 |

**Table 1.** Different irrigation scenarios

| Irrigation scenario | No of available irrigations | Stages | Irrigation amount (mm) |
|---|---|---|---|
| 1 | 4 | CRI (C)+Tillering (T) +Jointing (J) +Anthesis (A) | 200 (50 mm at each stage) |
| 2 | 3 | CRI (C)+Tillering (T) +Jointing (J) | 150 (50 mm at each stage) |
| | | CRI (C)+Tillering (T) +Anthesis (A) | 150 (50 mm at each stage) |
| | | CRI (C)+ Jointing (J) +Anthesis (A) | 150 (50 mm at each stage) |
| 3 | 2 | CRI (C)+Tillering (T) | 100 (50mm at each stage) |
| | | CRI (C)+Jointing (J) | 100 (50 mm at each stage) |
| | | CRI (C)+Anthesis (A) | 100 (50 mm at each stage) |

**Table 2.** Genetic crop coefficients fitted for wheat cultivar HD 2967

| Parameters | Description | Calculated values |
|---|---|---|
| P1V | Days at optimum vernalizing temperature required to complete vernalization | 11.9 |
| P1D | Percentage reduction in development rate in a photoperiod 10 h shorter than the optimum relative that optimum | 94.26 |
| P5 | Grain filling (excluding lag) period duration (GDD) | 520.9 |
| G1 | Kernel number per unit canopy weight at anthesis (g1) | 16.45 |
| G2 | Standard kernel size under optimum condition (mg) | 39.95 |
| G3 | Standard non-stressed dry weight (total, including grain) of a single tiller at maturity (g) | 1.82 |
| PHINT | Phyllochron interval (GDD) | 95.78 |

beyond $I_4$ did not increase the maximum LAI and grain yield significantly (Table 4). The model overestimated the maximum LAI for stressed treatment with normalised RMSE (RMSEn) value of >20% and index of agreement of <0.7 between the measured and simulated value. However, moderate value was found for non-stressed treatment with RMSEn value between 10-20%. There was strong agreement between the simulated and observed grain yield (kg/ha) for $I_3$(RMSE=204 kg/ha, RMSEn =6.3% and d=0.93), $I_4$(RMSE= 239.2 kg/ha, RMSEn =5.41% and d= 0.97) and $I_5$ (RMSE=162.9 kg/ha, RMSEn= 3.47% and d=0.98). Malik and Dechmi, (2019) reported that the DSSAT model performed well in simulating grain yield with the RMSE less than 587 kg $ha^{-1}$and d-statistic higher than 0.7. However relatively moderate agreement was noticed for $I_1$ and $I_2$ with RMSEn value of 19.8% and 18.9%, respectively and d value of 0.70 and 0.77, respectively (Table 4). Mehrabi and Sepaskhah (2019) also reported the model overestimated slightly the maximum leaf area index (LAI) and consequently biomass and yield in water stress condition.

**Evaluation of limited irrigation strategies to improve grain yield and IWP of wheat:** Model was run using Weather data from 2000-2019 with optimum sowing date (S1) under different irrigation scenarios. Percentage of deviation in average rainfall above 19% was considered as wet year, between -19% and 19% as normal year, and below -19% as dry year (as per IMD criteria). Rainfall analysis indicated that among twenty years, nine years were dry, seven years were wet and four years were normal. The, the maximum yield was obtained under four irrigations scenarios i.e. when irrigation was applied at four stages namely, CRI (C), Tillering (T), Jointing (J) and Anthesis (A). But the irrigation water productivity (IWP) was lowest in this scenario (Table 5). Wang et al. (2012) also reported that IWP decreased in non-

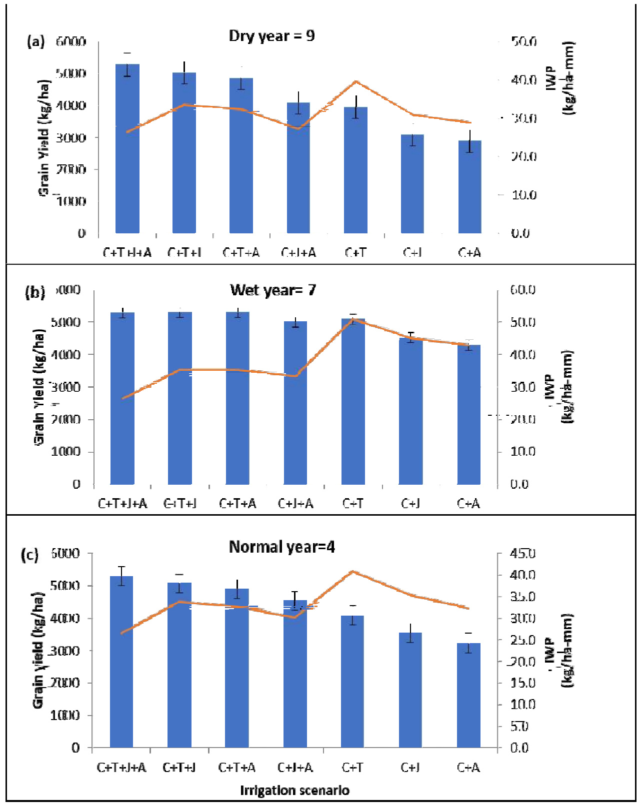


**Fig. 1.** Grain yield and water productivity of wheat for (a) dry year (b) wet year and (c) normal year under different irrigation scenarios

**Table 4.** Statistical indices derived forevaluation of CERES-wheat model for predicting the days to anthesis (DAS), days to physiological maturity (DAS), Maximum (LAI) and grain yield (kg/ha) of wheat cultivar HD-2967 (n=9)

| Treatments | Anthesis (DAS) | | | | | Physiological maturity (DAS) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $O_{mean}$ | $S_{mean}$ | RMSE | RMSEn (%) | d | $O_{mean}$ | $S_{mean}$ | RMSE | RMSEn (%) | d |
| $I_1$ | 90.9 | 97.9 | 7.19 | 7.95 | 0.72 | 116.50 | 126.85 | 11.13 | 9.56 | 0.73 |
| $I_2$ | 91.2 | 98.2 | 7.38 | 8.10 | 0.71 | 116.50 | 127.50 | 11.19 | 9.56 | 0.72 |
| $I_3$ | 99.0 | 101.9 | 3.21 | 3.27 | 0.96 | 120.85 | 125.15 | 4.43 | 3.68 | 0.95 |
| $I_4$ | 101.2 | 103.7 | 2.45 | 2.45 | 0.97 | 124.00 | 127.50 | 3.46 | 2.79 | 0.97 |
| $I_5$ | 101.4 | 103.2 | 2.08 | 2.06 | 0.98 | 124.85 | 127.65 | 3.05 | 2.45 | 0.98 |
| | Maximum LAI | | | | | Grain Yield (kg $ha^{-1}$) | | | | |
| Treatments | $O_{mean}$ | $S_{mean}$ | RMSE | RMSEn (%) | d | $O_{mean}$ | $S_{mean}$ | RMSE | RMSEn (%) | d |
| $I_1$ | 2.9 | 3.8 | 0.85 | 29.44 | 0.52 | 2034.8 | 2470.5 | 451.3 | 19.80 | 0.70 |
| $I_2$ | 3.2 | 4.0 | 0.82 | 25.27 | 0.60 | 2142.9 | 2594.5 | 466.2 | 18.85 | 0.77 |
| $I_3$ | 4.4 | 4.8 | 0.63 | 14.75 | 0.68 | 3525.1 | 3663.5 | 204.0 | 6.30 | 0.93 |
| $I_4$ | 5.4 | 6.0 | 0.66 | 12.22 | 0.76 | 4473.8 | 4660.9 | 239.2 | 5.41 | 0.97 |
| $I_5$ | 5.3 | 5.9 | 0.63 | 10.98 | 0.80 | 4692.6 | 4798.9 | 162.9 | 3.47 | 0.98 |

$S_{mean}$: mean of simulated value, $O_{mean}$: mean of observed value, n: number of observations, LAI: Leaf Area Index, RMSE: root mean square error, RMSEn (%): normalized root means square error, d: Wilmot's index of agreement.Irrigation treatments: $I_1$: CRI, $I_2$: $I_1$+ Tillering, $I_3$: $I_2$+Jointing, $I_4$: $I_3$+Anthesis, $I_5$: $I_4$+Dough

**Table 5.** Grain yield (kg ha$^{-1}$) and irrigation water productivity (IWP) (kg ha$^{-1}$ mm) under different irrigation scenarios

| Irrigation | Dry years (9) | | Wet year (7) | | Normal year (4) | |
|---|---|---|---|---|---|---|
| | Grain yield (kg ha$^{-1}$) | I WP (Kg ha$^{-1}$ mm) | Grain yield (kg ha$^{-1}$) | I WP (Kg ha$^{-1}$ mm) | Grain yield (kg ha$^{-1}$) | I WP (Kg ha$^{-1}$ mm) |
| C+T+J+A | 5288 | 26.4 | 5302 | 26.5 | 5295 | 26.5 |
| C+T+J | 5050 | 33.7 | 5302 | 35.3 | 5074 | 33.8 |
| C+T+A | 4878 | 32.5 | 5302 | 35.3 | 4909 | 32.7 |
| C+J+A | 4100 | 27.3 | 5015 | 33.4 | 4539 | 30.3 |
| C+T | 3968 | 39.7 | 5102 | 51.0 | 4091 | 40.9 |
| C+J | 3100 | 31.0 | 4515 | 45.1 | 3539 | 35.4 |
| C+A | 2891 | 28.9 | 4300 | 43.0 | 3229 | 32.3 |

stressed condition in wheat as compared to mild-stressed because the available soil water during stress conditions was used more effectively as compared to non-stressed conditions. The three irrigations scenario (CRI + Tillering + Jointing) reported the maximum grain yield of 5050 and 5074 kg/ha for dry and normal year conditions, respectively. Similarly, water productivity of 33.7 and 33.8 kg/ha-mm for dry and normal year conditions, respectively was obtained when three irrigations were applied at CRI (C)+ Tillering (T)+ Jointing (J) stage followed by at CRI (C)+Tillering (T)+Anthesis (A) stage and CRI(C)+ Jointing (J)+Anthesis (A) stage. Whereas under wet year there was no difference in grain yield and IWP noticed whether three irrigations applied at CRI (C)+ Tillering (T)+ Jointing (J) stage or CRI (C)+Tillering (T)+Anthesis (A) stage. Grain yield with three irrigations (applied at CRI, tillering and jointing stage or at CRI, tillering and anthesis stage) was similar to that with irrigations at all four stages, during wet years. Under two irrigations scenarios the maximum grain yield as well as IWP was obtained when applied at CRI (C)+ Tillering (T) followed by CRI(C)+Jointing (J) for all the dry, wet and normal year. The minimum grain yield and water productivity was obtained when two irrigations were applied at CRI (C)+Anthesis (A) stage.

## CONCLUSION

This study concluded that the model overestimated slightly the maximum leaf area index (LAI) and consequently the grain yield in water stress condition; however, overall, model could excellently simulate anthesis and maturity as well as grain yield. . The study indicates that with the increase in frequency of irrigation the IWP decreased. Under three irrigations scenario the maximum grain yield and IWP was observed when three irrigations applied at CRI, tillering and jointing followed by at CRI, Tillering, anthesis stage for dry and normal years, whereas grain yield and IWP were at par at this stage. In two irrigations scenario, the maximum grain yield as well as IWP was when irrigation applied at CRI and tillering followed by CRI and jointing stage. This study could guide the farmers and agronomists on best and efficient irrigation management in order to achieve the better yield and improve the irrigation use efficiency.

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# Climate Resilient Practices on Performance and Economics of Transplanted Pigeonpea and Sunflower Intercropping in *Vertisol* of Northern Karnataka

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***Abstract***: A field experiment was conducted during *Kharif* 2019 to evaluate transplanted pigeonpea and sunflower intercropping system at different dates of sowing and fertilizers. Treatment combinations consists of two sowing time and eight intercropping system replicated thrice. Pigeonpea transplanted in second fortnight of July recorded significantly higher grain yield, equivalent yields of pigeonpea (PEY) and sunflower (SEY), over second fortnight of August. However, higher sunflower seed yield and oil content was in second fortnight of August sowing. Among intercropping systems, sole pigeonpea and sunflower recorded significantly higher seed yield (2254 and 1781 kg $ha^{-1}$) over sole drilled pigeonpea as well as intercropping systems. Transplanted pigeonpea + sunflower (1:2) with RDF for both crops recorded superior pigeonpea grain yield (1936 kg $ha^{-1}$), PEY (2914 kg $ha^{-1}$), SEY (3816 kg $ha^{-1}$), gross returns (Rs. 157680 $ha^{-1}$) and net returns (Rs. 108880 $ha^{-1}$). Drilled pigeonpea + sunflower (1:1) considered as farmers practice recorded significantly greater sunflower seed yield (1382 kg $ha^{-1}$), oil content (37.7 %) and B: C (3.49) over rest of the combinations. Transplanted pigeonpea was superior over drilled sown pigeonpea.

***Keywords***: Intercropping, Pigeonpea establishment, Sowing time

Among pulses, pigeonpea [*Cajanus Cajan* (L) Millsp.] holds first place in Karnataka both in area (1.48 m ha) and production (0.94 m t) with a productivity of 647 kg $ha^{-1}$ (Anonymous 2018). Among major production constraints, erratic and scanty rainfall that resulted in lower soil moisture and reducing pigeonpea productivity in *Vertisol* of N-Karnataka. Sunflower (*Helianthus annuus* L.) crop in Karnataka shares 52% of the area and 40% of the production in the country. Amongst factors responsible for yield improvement in both the crops, optimum fertilizers application and timely sowing were of prime important. Wider yield gap can be minimized by the use of adequate and balanced fertilization (Naik et al 2016, Umesh et al 2020). Crop nutrient removal far exceeds than the addition through fertilizers and manures. Application of nutrient requirement of pigeonpea and urdbean intercropping through 100% fertilizer and vermicompost enhances productivity (Pal and Singh 2015). In annual intercropping systems, climate resilient practices with conservation approach was most important to improve the farm productivity (Bitew and Abera 2018). Balanced application of major nutrients can increase sunflower growth and yield substantially. Long duration pigeonpea can adjust to a wider range of population and spacing. It is cultivated on marginal lands in mono/mixed cropping system without or suboptimal fertilizers under rainfed conditions. Delayed sowing shortens the time for growing period, hastens maturity and ultimately reduces the yield. Early sowing may encourage the vegetative growth which may make the crop prone to different insect pests and diseases. Thus, the need for timely planting through alternate feasible means such as transplanting. Farmers adopted different row proportions in pigeonpea based intercropping rather than the recommended optimum. Transplanting of seedlings and seed hand dibbling in pigeonpea is recently adopted techniques in the region. The transplanting of pigeonpea would be one of the better agronomic practices to avoid delayed sowing and also maintain desired plant population (Priyanka et al 2013, Praharaj et al 2015). Raising pigeonpea seedlings well in advance and transplanting in the field on receipt of good rains would help in reaping the benefits of early sowing. Keeping these facts, the present investigation was carried out with an objective to evaluate feasibility of pigeonpea and sunflower intercropping in a changed sowing window and fertilizers supply in *Vertisol* of N Karnataka.

## MATERIAL AND METHODS

A field experiment was conducted during *Kharif* 2019 at Main Agricultural Research Station, Raichur. The soils of the site were medium black having 7.74 soil reaction, 0.6 % organic carbon and 0.21 dS $m^{-1}$EC. The available N, $P_2O_5$ and $K_2O$ before initiation of experiment were 293.3, 39.7 and 365.9 kg $ha^{-1}$. The experiment was carried out in split plot design replicated thrice. Main plots were sowing both the crops in July second fortnight and August second fortnight, sub-plot treatments were transplanted pigeonpea + sunflower (1:1) with RDF for main crop, transplanted pigeonpea + sunflower (1:1) with RDF for both the crops, transplanted pigeonpea + sunflower (1:2) with RDF for main crop, transplanted pigeonpea + sunflower (1:2) with RDF for both the crops, drilled sown pigeonpea + sunflower (1:1) sole sunflower, sole transplanted pigeonpea, sole drilled sown pigeonpea (Table 1). Fertilizers were applied for pigeonpea @ 25-50 kg N-$P_2O_5$ and sunflower @ 90-90-60 kg N-$P_2O_5$-$K_2O$ ha$^{-1}$. Under intercropping system, the fertilizers were applied according to the component crops population in each treatment. The entire quantities of fertilizers were applied to pigeonpea at basal. For sunflower half of recommended N and entire dose of P and K were applied at basal and remaining N was top dressed at 30 DAS. Foliar application of 19:19:19 @ 1% and Pulse magic @ 10 g/l was done at flowering stage. Pigeonpea variety BSMR-736 and sunflower hybrid RSFH-1887 were selected for the trial.

Pigeonpea seeds were sown on first week of June and July in polythene bags (8" x 5") having 3/4$^{th}$ of soil and 20 g of vermicompost for establishing seedlings to match sowing time as per treatment. Polythene bags were watered regularly. After one month, the seedlings were transplanted in the main field at 1.2 m x 0.6 m. For drill sown treatment seeds were sown at 1.2 m x 0.6 m spacing on the day of transplanting. In main field, 30 days old pigeonpea seedlings were transplanted after removing the polythene cover without disturbing the soil at the root zone. Sunflower under intercropping was sown exactly at the center of pigeonpea rows in 1:1, whereas two rows of sunflower at 60 cm apart in 1:2 row proportion. Rest of the production practices for both the crops was followed as per the regional recommendation by the University. Irrigation was provided during long dry spells to avoid stress. Pigeonpea and sunflower equivalent yields were calculated based on market price and yield levels as per the standard procedure (Umesh et al 2002). The cost includes expenditure on seeds, fertilizers, weed management and plant protection chemicals. At maturity, the crop was harvested and plot wise yields were recorded. The data recorded at different stages of crop was subjected to statistical analysis at 5 % probability.

## RESULTS AND DISCUSSION

**Pigeonpea grain yield:** Pigeonpea transplanted in July recorded 35.3 per cent higher grain yield (2130 kg$^{-1}$ ha) over August transplanting (Table 1). Sole transplanted pigeonpea was recorded significantly higher grain yield (2253 kg ha$^{-1}$) over rest of the intercropped treatments and drilled pigeonpea. Application of fertilizers to both the crops in

**Table 1.** Effect of sowing time and row proportions on seed yield, protein content, oil content and equivalent yields of pigeonpea (PEY) and sunflower under (SEY) intercropping system

| Treatment | Pigeonpea | | | | | | Sunflower | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Grain yield (kg ha$^{-1}$) | | Protein content (%) | | PEY (kg ha$^{-1}$) | | Seed yield (kg ha$^{-1}$) | | Oil content (%) | | SEY (kg ha$^{-1}$) | |
| Sowing time | | | | | | | | | | | | |
| July | 2130 | | 21.4 | | 2570 | | 1124 | | 36.1 | | 3354 | |
| August | 1574 | | 20.5 | | 2122 | | 1300 | | 38.3 | | 2778 | |
| C.D. (P=0.05) | 305 | | 0.6 | | 180 | | 186 | | 2.1 | | 82 | |
| *Row proportions and fertilizers* | | | | | | | | | | | | |
| Transplanted pigeonpea + sunflower (1:1) RDF for main crop | 1819 | | 20.9 | | 2453 | | 831 | | 36.8 | | 3213 | |
| Transplanted pigeonpea + sunflower (1:1) RDF for both crops | 1926 | | 21.3 | | 2635 | | 929 | | 37.0 | | 3451 | |
| Transplanted pigeonpea + sunflower (1:2) RDF for main crop | 1778 | | 20.7 | | 2592 | | 1066 | | 36.0 | | 3394 | |
| Transplanted pigeonpea + sunflower (1:2) RDF for both crops | 1936 | | 21.0 | | 2914 | | 1280 | | 36.5 | | 3816 | |
| Drill sown pigeonpea + sunflower (1:1) | 1593 | | 20.0 | | 2648 | | 1382 | | 37.7 | | 3468 | |
| Sole sunflower | - | | - | | 1360 | | 1781 | | 39.1 | | 1781 | |
| Sole transplanted pigeonpea | 2252 | | 22.2 | | 2252 | | - | | - | | 2949 | |
| Sole drill sown pigeonpea | 1659 | | 20.4 | | 1659 | | - | | - | | 2457 | |
| C.D. (p=0.05) | 170 | | 0.4 | | 173 | | 101 | | 1.3 | | 267 | |
| Interaction | I×S | S×I | I×S | S×I | I×S | S×I | I×S | S×I | I×S | S×I | I×S | S×I |
| S.Em. ± | 123 | 89 | 0.3 | 0.2 | 98 | 91 | 70 | 52 | 0.8 | 0.6 | 35 | 122 |
| C.D. (p=0.05) | NS | NS | 277 | 275 | 277 | 275 | NS | NS | NS | NS | 383 | 360 |

transplanted pigeonpea + sunflower (1:2) recorded significantly greater grain yield (1937 kg ha$^{-1}$) over drilled pigeonpea + sunflower (1593 kg ha$^{-1}$). Combined effect of sunflower intercropped with different row proportions and RDF along with time of transplanting found non-significant. Yield advantage in the early sown crop was mainly due to increased growth, yield attributes and physiological characters. It also favored by climatic conditions, temperature during growth, development and maturity stages. Efficient utilization of nutrients and moisture as well as greater light interception had resulted in higher growth and yield attributes. Similar results on yield advantage in sown crops were reported in early studies (Reddy et al 2012, Yu 2014, Uprikar 2017). Channabasavanna et al (2015) reported that the growth and yield benefits in early sown pigeonpea due to long growing period consequently accumulated greater dry matter enhanced leaf area and phenological potential. Intercropping has reduced the yields of both pigeonpea and sunflower. Sole transplanted pigeonpea recorded higher seed and dry matter yield over intercrop with sunflower and was mainly attributed to enhanced growth in terms of plant height, primary branches, LAI and TDMP and yield parameters *viz*., pods per plant, seed yield per plant, seeds per plant and 100 seed weight. Impact of intercropping on growth and yield was reported by Pal et al (2016).

**Sunflower seed yield:** The sunflower has photoperiod benefit in terms of improved yield (15.66%) either by sowing or transplanting in second fortnight of August (1300 kg ha$^{-1}$) over second fortnight of July (Table 1). Sole sunflower out yielded (1781 kg ha$^{-1}$) over rest of the intercropped combinations. Drilled pigeonpea + sunflower (1:1) considered as farmer practice has recorded greater sunflower seed yield (1382 kg ha$^{-1}$) over sunflower as intercrop with transplanted pigeonpea (1:1) with RDF for main crop (831 kg ha$^{-1}$). Intercropping systems reduced the sunflower yield 22.4-55.3% owing to population difference and was compensated by contribution from pigeonpea indicated in terms of equivalent yield. Combined effect of sowing time and intercropping with row proportions and fertilizers application has no significant effect on sunflower seed yield. An uninterrupted availability of various resources *viz*., solar interception, soil moisture and nutrients for sole crop might have helped the crop to utilize the resources to a great extent resulting in enhanced values of varied growth parameters and yield attributes (Umesh et al 2017, Suresh et al 2019). Ahmed *et al.,* (2015) reported that sunflower yield was significantly influenced by date of sowing. The productivity of sunflower was mainly determined by the weather and soil moisture throughout its life cycle and the imposed cultural practices. Delayed sowing increased the yields. The timely sown (May) crop experienced moisture stress during early stage of the crop which adversely affected its growth and yield attributes. However, well distributed rainfall and adequate moisture in late sown might be responsible for enhanced sunflower yield. Additionally, sunflower is a thermo insensitive and it adjust to the late sowing but most important factor is moisture availability for their luxuriant crop growth and yield (Kaleem et al 2011, Demir 2019). Sole sunflower gave higher yields than intercropped has a result of higher plant population (Sandeep Kumar et al 2019). Row proportion of sunflower and pigeonpea had significant effect on seed and stalk yield of sunflower. The higher seed and stalk yield of sunflower was recorded under 2:1 row proportion than 1:1 row proportion.

**Seed protein content:** Crops sown in second fortnight of July recorded significantly higher protein content (21.36 %) than second fortnight of August (20.50 %) (Table 1). Greater accumulation of nutrients in seed and better crop performance might be responsible for enhanced protein content. Sole transplanted pigeonpea recorded higher protein (22.2%) content than intercropped as well as drilled pigeonpea. Application of fertilizers to both the crops in transplanted pigeonpea + sunflower (1:1) also recorded greater protein content (21.32 %) over rest of the treatment combinations. Drilled pigeonpea + sunflower (1:1) and sole drilled pigeonpea was on par to each other but recorded lower than the sole transplanted and intercropped pigeonpea. Combined effect of time of sowing and intercropping system with different row proportion and fertilizer application on protein content was found non-significant. Vishwanatha (2009) reported higher protein content with sole pigeonpea than intercrops. In intercropping supply of balanced nutrients to the crop especially phosphorous may be due to the biochemical role of phosphorous in protein synthesis (Udikeri, 2013). Protein content in seed is a function of N concentration, therefore, higher concentration of N in seed under the superior treatments seems to be the only reason for attaining higher protein content in pigeonpea (Kumar and Paslawar, 2017).

**Sunflower seed oil content:** Sunflower seed oil content was significantly greater in second fortnight of August sown (38.3%) over July (36.1%) (Table 1). Intercropping combinations reduced the oil content over sole sunflower (39.1 %). Combined effect of time and row proportions and fertilizers application was non-significant in oil content and was mainly due to enhanced vegetative growth and development in August sown than July. Late-sown plants increases the seed oil might be due to the fact that the temperature increases during seed development (Allam et al

2003). Application of RDF to both the crops recorded higher oil content and might be due to lower fatty acid synthesis through the pentose phosphate pathway in seeds without fertilizer application to intercrop owing to increased competition and non-availability of required quantity of nutrients but the treatment which received RDF had better synthesis of fatty acid owing to optimum nutrient availability (Vishwanatha, 2009).

**Equivalent yields:** Pigeonpea transplanted in second fortnight of July recorded 21.1% higher PEY (2570 kg ha$^{-1}$) over August (Table 1). Further, was greater in sole transplanted pigeonpea (2252 kg ha$^{-1}$) than drilled pigeonpea and sunflower alone and also improved by application of fertilizers to both the crops in transplanted pigeonpea + sunflower (1:2) (2914 kg ha$^{-1}$). Application of RDF to main crop in transplanted pigeonpea + sunflower (1:1) recorded significantly lower PEY (2453 kg ha$^{-1}$). Prevalence of favorable climatic weather and resources availability has resulted higher yield of both main and intercrop yield with early sowing than delayed sowing (Ravindra 2019). Murali et al (2014) also showed increased PEY with transplanting 4-5 weeks old pigeonpea seedlings than drilled sown pigeonpea as sole crop. It might be due to efficient utilization of natural resources and additional yields of component crops and their better performance in transplanted pigeonpea with higher market prices which intern resulted in higher PEY and net returns. Praharaj et al (2015) reported significantly higher PEY over direct sown in pigeonpea and soybean intercropping and sole cropping. Intercropping system had a significant influence in obtaining higher PEY over either of sole cropping except unfertilized control. This was due to higher seed yields of component crops owing to optimum nutrient availability (RDF to both the crops) coupled with higher price of both the crops contributed to higher PEY (Poornima 2009). Sunflower equivalent yield was 20.7% greater in crops sown in second fortnight of July (3354 kg ha$^{-1}$) over August sown (Table 1). It might be due to better sunflower productivity under timely sowing than delay sowing coupled with higher market price. Intercropped treatments recorded significantly greater SEY than the sole. Further, it also enhanced by application of RDF to both the crops in transplanted pigeonpea + sunflower (1:2). It was significantly reduced under sole sunflower (1781 kg ha$^{-1}$). The interaction effect between sowing time, intercropping system, row proportions and fertilizers application have significant effect on the SEY. The pigeonpea and sunflower 1:2 row proportion was recorded higher SEY as compared to other row proportions.

**Economic returns:** Crops sown/transplanted in second fortnight of July recorded higher gross returns (Rs. 136769 ha$^{-1}$), net returns (Rs. 94421 ha$^{-1}$) and B: C ratio (3.2) over August sown crops (Table 2). Sole transplanted pigeonpea recorded significantly higher gross returns (Rs. 123860) and net returns (Rs. 83560 ha$^{-1}$) over drilled pigeonpea and sunflower. Application of RDF for both crops in transplanted pigeonpea + sunflower (1:2) higher gross returns (Rs.157680 ha$^{-1}$) and net returns (Rs.108880 ha$^{-1}$) over 1:1 row proportions and RDF to main crop. The drilled pigeonpea

**Table 2.** Economic returns of pigeonpea and sunflower intercropping system sown in different months and row proportions

| Treatments | Cost of cultivation (Rs ha$^{-1}$) | Gross returns (Rs ha$^{-1}$) | Net returns (Rs ha$^{-1}$) | B:C ratio |
|---|---|---|---|---|
| Sowing /transplanting time | | | | |
| July | 42339 | 136769 | 94421 | 3.20 |
| August | 39811 | 114163 | 74361 | 2.85 |
| S.Em. ± | - | 1596 | 1539 | 0.04 |
| C.D. @ 5 % | - | 10454 | 10079 | 0.28 |
| Row proportions | | | | |
| Transplanted pigeonpea + sunflower (1:1) RDF for main crop | 43850 | 133285 | 89435 | 3.11 |
| Transplanted pigeonpea + sunflower (1:1) RDF for both crops | 48800 | 143090 | 94290 | 2.99 |
| Transplanted pigeonpea + sunflower (1:2) RDF for main crop | 43850 | 140430 | 96580 | 3.28 |
| Transplanted pigeonpea + sunflower (1:2) RDF for both crops | 48800 | 157680 | 108880 | 3.30 |
| Drill sown pigeonpea + sunflower (1:1) | 44000 | 142895 | 98895 | 3.49 |
| Sole sunflower | 26500 | 71240 | 44740 | 2.69 |
| Sole transplanted pigeonpea | 40300 | 123860 | 83560 | 3.07 |
| Sole drill sown pigeonpea | 32500 | 91245 | 58745 | 2.72 |
| C.D. @ 5 % | - | 8616 | 7126 | 0.23 |

Market price of Pigeonpea: Rs. 55/kg, Sunflower price: Rs. 42/kg

+ sunflower (1:1) considered as farmers practice recorded higher BC ratio (3.49) over transplanted pigeonpea + sunflower in (1:1) and 1:2. Higher grain yield which results in higher gross return. Similar results were also reported by Uprikar (2017). Higher net returns realized from intercropping was due to complementarity between component crops which produced higher yield. Higher returns from drilled pigeonpea + sunflower (1:1) were due to additional cost incurred towards nursery raising and transplanting in transplanting method. Superior performance in transplanted pigeonpea treatments might be due to efficient utilization of natural resources and additional yields of component crops and their better performance in transplanted pigeonpea with higher market prices which intern resulted in higher pigeonpea equivalent yield and net returns. Similarly higher remunerative returns were observed in intercropping system over sole cropping by Vishwanatha et al (2012). Sole transplanted pigeonpea recorded higher BC ratio over sole sunflower (2.69) and drilled sown pigeonpea (2.72) (Table 2). Dibbled pigeonpea and sunflower intercropping recorded higher BC ratio was due to higher cost of cultivation in transplanting method than of dibbling method. Similar results were reported by Priyanka et al (2013) and Ramanjaneyalu et al. (2016).

## CONCLUSION

The pigeonpea either direct sown or transplanted was superior in terms of yield and economic returns. The second fortnight August was benefitted to sunflower. Drill sown pigeonpea and sunflower combination in 1:1 had greater yield advantage over sole drilled pigeonpea. Yield and economic benefit were greater in second fortnight of July sown crop as compared second fortnight of August sown crop. Higher net return was realized in transplanted pigeonpea and sunflower intercropping system with 1:2 row proportion and application of RDF based on both the crops. Transplanted pigeonpea has the greater productive potential than drill sown pigeonpea.

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# Role of Cover Crop, Irrigation Systems and Different Tillage on Soil Physical Properties

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***Abstract:*** The central and southern regions of Iraq are located within the arid and semi-arid regions. The deterioration of the physical properties of the soil due to the low content of organic matter that is less than 1%. The high temperatures, low rainfall and the absence of vegetation cover, as well as the poor use of land and the absence of proper management of irrigation and tillage operations have negative effects on the physical, chemical and biological properties of the soil, which in turn will negatively affect the growth and production of agricultural crops. The experiment was conducted in the Nile district, located within the Babil Governorate, 86 km south of the capital, Baghdad, in a silty clay loam in the fall season 2020, aimed to examine the role of cover crop, irrigation systems and different tillage systems in some physical properties of soil (bulk density, porosity, mean weight diameter, soil resistance to penetration, and saturated soil hydraulic conductivity). The experiment was designed according to the strip-split plot arrangement according to a complete randomized block design. The experiment included three factors, the first that occupied the main plots is the cover crop (C) and included on two levels: without cover crop ($C_0$), and the presence of cover crop ($C_1$), and the second factor was the tillage systems (T) and included on four levels: Zero tillage ($T_0$), minimum tillage ($T_1$), medium tillage ($T_2$) and deep tillage ($T_3$), and the third factor is irrigation systems (I) with three levels: surface drip irrigation ($I_1$), subsurface drip irrigation ($I_2$) and surface irrigation in basins. ($I_3$) The results showed the superiority of treatment $C_1T_1I_2$ in obtaining the lowest value of bulk density, soil resistance to penetration, highest porosity, mean weight diameter rate, and soil hydraulic conductivity saturated while treatment $C_0T_3I_3$ gave the highest bulk density, soil resistance to penetration, less porosity, mean weight diameter and soil hydraulic conductivity saturated.

***Keywords*:** Drip irrigation, Bulk density, Soil hydraulic conductivity, Weighted drip rate, Penetration resistance

The physical properties of the soil play an important role in determining the suitability of the soil for agricultural, environmental and engineering uses. The supporting capacity for water and nutrients readiness, ease of root penetration, air flow and heat, as well as their impact and influence on the chemical and biological properties of soil (Sanchez 2019). One of the most important challenges of the twenty-first century is how humanity can cope with climate change and water scarcity to continue producing food at the levels necessary to feed a growing world population while preserving soil and water resources from degradation (Din et al 2019). Cover crops are a major tool that can contribute to increasing yields, maintaining surface and groundwater quality, reducing erosion potential, and improving soil properties and health in arid and semi-arid areas. Cover crops have a very high potential to reduce erosion and soil erosion. Cover crops appear to be good practice for coping with and mitigating climate change (Kocira et al 2020). Practicing a cover crop system can enhance soil construction by increasing the porosity, increasing the water tip rate as well as decreasing bulk density and decreasing soil resistance to penetration (Çerçioğlu et al 2019). Cover crops are generally considered to improve the properties of the soil in general and the physical properties in particular. The optimal management of tillage and crop residue plays an important role in the physical and chemical properties of the soil and ultimately affects the on crop productivity. A compatible combination of tillage and crop residue management improved soil properties and provided a suitable environment for crop growth (Wasaya et al 2019). Conservative tillage practices such as no-till, minimal tillage and reduced tillage while retaining crop residues on the soil surface have a significant advantage over conventional tillage by adding organic matter and carbon to the soil which is a prerequisite for better physical, biological and chemical properties (Vizioli et al 2021). Leaving crop residues on the soil surface reduces compaction, reducing bulk density, as well as increasing tip rate, Saturated Soil hydraulic conductivity and regulating soil temperature in the case of no-till compared to plowed soil due to better plant growth and increased microbial activity (Singh et al 2018). Salem et al (2015) observed effect different tillage systems such as zero tillage, short tillage and conventional tillage on some physical soil characteristics and maize yield The zero and short tillage outperformed the conventional tillage in terms of productivity, low bulk density and soil resistance to penetration. Ren et al (2018) observed the superiority of the short tillage system at a depth of 0.10 m over the traditional tillage system at a depth of 0.25 m, as the values of the bulk density and soil resistance to penetration decreased by 6.16 and 7.69%. Exploiting, distributing and rationalizing water consumption in an appropriate and efficient manner is one of the soil and water management programs, and choosing the appropriate irrigation method achieves the highest water use efficiency and maintains the good physical properties of the soil as well as providing suitable conditions for plant growth (FAO 2018). To achieve this, unconventional irrigation techniques must be resorted to, such as surface and sub-surface drip irrigation. These technologies have begun to spread widely in dry and semi-arid areas due to their high efficiency of use and their role in maintaining soil construction. As for irrigation, it is one of the common, easy, and low-cost methods, and it is preferable to use for soils that have a good ability to store and soils with high salinity that work to wash the accumulated salts and keep them away from the root zone (Wambua 2020). Al-Hadi and Aodeh (2014) observed that use of drip irrigation contributed to the preservation of the soil structure, which resulted in a significant increase in the values of the average weighted diameter, porosity, saturated Soil hydraulic conductivity, soil water drop rate, and a significant decrease in the apparent density of soil in comparison with flooded irrigation. Rodríguez et al (2016) also observed that the flooded soil recorded the highest bulk density of 1.14 mcg $m^{-3}$ and the lowest porosity ratio of 56.32%, while the non-flooded soil recorded the lowest bulk density value of 1.00 mcg m-3 and the highest porosity. 61.58%. Abd AL- Gabbar and Al-Abaied (2016) observed the performance of center pivot and turbulent irrigation in some physical properties of soil. The adoption of center pivot irrigation method led to a decrease in the average values of the soil bulk density, which amounted to 1.38 mcg $m^{-3}$ compared to 1.44 Mg $m^{-3}$ for the irrigation treatment, and the total porosity of the soil increased to 0.45 compared to 0.42 for the two irrigation treatments on sedimentation. The irrigation method had a role in increasing the saturated soil hydraulic conductivity values, as adopting the center pivot irrigation method led to a significant increase with 9.18 cm $h^{-1}$ compared to 8.51 cm $h^{-1}$ for flooded irrigation . The pivot irrigation method had an important role in increasing the base tip rate as it reached 9.4 cm $h^{-1}$ compared to 8.6 cm h-1 for flooded irrigation treatments This experiment was conducted with the aim of assessment of the physical properties of the soil and the changes that occur under the influence of the presence of cover crop, different plowing and irrigation systems.

## MATERIAL AND METHODS

Field experiment was conducted in Nile sub-district of Babil Governorate, 86 km south of Baghdad, during the fall season of 2020, (latitude 35” 32º 31' north, longitude 21” 36' 44º east, at a height of 31 m above sea level. The study area is characterized by a flat to semi-flat topography with a slope of less than 2%, and the soil of the field was classified as sedimentary with a texture of silty clay loam and classified under the Typic torrifluvent group according to the classification of the soil (Survey 2019). The field was planted with wheat and left residues to cover the soil surface by 30% .Soil samples were taken randomly from the site of the experiment before planting from layers 0-0.30 and 0.30-0.60 m in order to estimate some physical and chemical properties of soil (Table 1). The pocket penetrometer model CL700 with a cylindrical stem and a flat end with a diameter of 0.672 cm and a penetration depth of 1 cm from the surface was used to measure the resistance of the soil to penetration. Undisturbed samples were manually broken and air dried, then the samples were sieved to obtain aggregates with a volume range of 4-9 mm. Soil aggregates were sieved by wet sieving method according to the method mentioned by Aoda and Mahdi (2017) and the weighted diameter ratio was calculated from the following equation:

$$MWD = \sum_i^n = 1\,\acute{X}_i\,W_i$$

**Table 1.** Physical and chemical properties of the experimental site

| Property | Soil layer (m) | |
|---|---|---|
| | 0.30-0 | 60-30 |
| Sand (gm $Kg^{-1}$) | 181 | 230 |
| Silt (gm $Kg^{-1}$) | 471 | 453 |
| Clay (gm $Kg^{-1}$) | 348 | 317 |
| Soil Texture | SiCL | SiC |
| Bulk density Mg $m^{-3}$ | 1.32 | 1.38 |
| Particle density Mg $m^{-3}$ | 2.65 | 2.65 |
| Porosity % | 50.18 | 47.92 |
| Void ratio | 1.007 | 0.920 |
| Volumetric water content at 33 kpa ($cm^3$ $cm^{-3}$) | 0.32 | 0.34 |
| Volumetric water content at 1500 kpa ($cm^3$ $cm^{-3}$) | 0.13 | 0.14 |
| Available water ($cm^3$ $cm^{-3}$) | 0.19 | 0.20 |
| Saturated Soil hydraulic conductivity | 3.20 | 2.91 |
| basic infiltration rate (Double ring method) cm $h^{-1}$ | 2.86 | —— |
| Soil resistance of penetration Mpa | 2.54 | —— |
| MWD mm | 0.87 | 0.58 |
| $EC_e$ ds $m^{-1}$ | 1.70 | 1.75 |
| pH | 7.6 | 7.6 |
| Organic matter (%) | 1.8 | 1.7 |
| CEC (Cmolc $Kg^{-1}$ soil) | 16.83 | 16.05 |

MWD = Mean weight diameter (mm).

Wi = Mass of the aggregates as relative to the total weight of the sample (without units).

Xi = average diameter of those aggregates (mm.)

The saturated soil hydraulic conductivity was measured by constant head method. Soil samples were, dried, crushed, and sieved with a sieve with a diameter of 2 mm. The soil was filled with a glass cylinder with a diameter of 0.038 m and a height of 0.12 m. The soil was saturated from the bottom for 24 hours. A fixed water column of 2 cm was determined above the soil column. The quantities of percolating water were collected over time until reaching the stability state and calculated. The saturated soil hydraulic conductivity was estimated according to the equation of Aoda and Mahdi (2017).

$$K=\frac{V\times L}{At\ (h+L)}$$

The quality of water was determined, which was $C_1S_3$, according to the Irrigation Water Use Manual (Boyd, 2019) (Table 2).

The experiment was designed according to the strip-split plot arrangement according to a complete randomized block design (RCBD) with three replications. The experiment included three factors. The first factor is the cover crop (the remnants of the wheat crop of the previous agricultural season and occupied the main plot) and included two levels: without cover crop $C_0$ and the presence of cover crop $C_1$. The second factor was the occupation of the secondary plot and included four levels: no-till $T_0$, minimum tillage $T_1$(tillage depth 0.10 m by spike harrows pin), medium tillage $T_2$ (tillage depth 0.20 m by chesil plow), and deep tillage $T_3$ (Tillage depth 0.30 m by chisel plow). The third factor is the irrigation systems occupy the sub-sub plot) was at three levels: surface drip irrigation $I_1$, subsurface drip irrigation $I_2$, and surface irrigation in basins $I_3$ (Table 3).

After plowing, the land was divided into slabs with dimensions of 5 x 6 m. A separation distance between the experimental units from all directions was left by about 2 m for the purpose of controlling the irrigation treatments, as well as leaving a separation distance of 3 m between the replicates. A drip irrigation system was used with pipes dedicated to surface and subsurface irrigation, with a diameter of 0.016 m. It contains emitters with a discharge of 4.00 liters per hour$^{-1}$ of the emitter. The experimental units for surface and subsurface drip irrigation treatments were equipped with seven drip lines, the distance between one drip line and another 0.75 m, and the distance between one emitter and another 0.20 m. Subsurface drip lines are installed at a depth of 0.20 m. Irrigation water was added for surface irrigation treatments through field pipes that branched off from the

**Table 3.** Details of experiment treatments

| Symbol | Treatments |
|---|---|
| $C_0T_0I_1$ | Remove cover crop + No tillage + Surface drip irrigation |
| $C_0T_0I_2$ | Remove cover crop + No tillage + Sub-Surface drip irrigation |
| $C_0T_0I_3$ | Remove cover crop + No tillage + Surface irrigation |
| $C_0T_1I_1$ | Remove cover crop + Tillage at depth 0.10 m + Surface drip irrigation |
| $C_0T_1I_2$ | Remove cover crop + Tillage at depth 0.10 m + Sub-Surface drip irrigation |
| $C_0T_1I_3$ | Remove cover crop + Tillage at depth 0.10 m + Surface irrigation |
| $C_0T_2I_1$ | Remove cover crop + Tillage at depth 0.20 m + Surface drip irrigation |
| $C_0T_2I_2$ | Remove cover crop + Tillage at depth 0.20 m + Sub-Surface drip irrigation |
| $C_0T_2I_3$ | Remove cover crop + Tillage at depth 0.20 m + Surface irrigation |
| $C_0T_3I_1$ | Remove cover crop + Tillage at depth 0.30 m + Surface drip irrigation |
| $C_0T_3I_2$ | Remove cover crop + Tillage at depth 0.30 m + Sub-Surface drip irrigation |
| $C_0T_3I_3$ | Remove cover crop + Tillage at depth 0.30 m + Surface irrigation |
| $C_1T_0I_1$ | Cover crop + No tillage + Surface drip irrigation |
| $C_1T_0I_2$ | Cover crop + No tillage + Sub-Surface drip irrigation |
| $C_1T_0I_3$ | Cover crop + No tillage + Surface irrigation |
| $C_1T_1I_1$ | Cover crop + Tillage at depth 0.10 m + Surface drip irrigation |
| $C_1T_1I_2$ | Cover crop + Tillage at depth 0.10 m + Sub-Surface drip irrigation |
| $C_1T_1I_3$ | Cover crop + Tillage at depth 0.10 m + Surface irrigation |
| $C_1T_2I_1$ | Cover crop + Tillage at depth 0.20 m + Surface drip irrigation |
| $C_1T_2I_2$ | Cover crop + Tillage at depth 0.20 m + Sub-Surface drip irrigation |
| $C_1T_2I_3$ | Cover crop + Tillage at depth 0.20 m + Surface irrigation |
| $C_1T_3I_1$ | Cover crop + Tillage at depth 0.30 m + Surface drip irrigation |
| $C_1T_3I_2$ | Cover crop + Tillage at depth 0.30 m + Sub-Surface drip irrigation |
| $C_1T_3I_3$ | Cover crop + Tillage at depth 0.30 m + Surface irrigation |

**Table 2.** Chemical analysis of irrigation water

| Property unit | Ec ds $m^{-1}$ | pH | $Ca^{+2}$ | $Mg^{+2}$ | $Na^{+}$ | $K^{+}$ | $Cl^{-}$ | $SO_4^{-2}$ | $HCO_3^{-1}$ | Classify the water according to (USDA) |
|---|---|---|---|---|---|---|---|---|---|---|
| Value | 0.79 | 7.55 | 3.55 | 3.19 | 2.76 | 0.11 | 2.08 | 4.55 | 2.17 | $C_1S_3$ |

secondary pipe at the middle of the edge of the plate. Seeds of maize *(Zea mays* L.), a hybrid Euphrates cultivar from the Dutch company Monarch, were planted on July 23, 2020 and each plot included 7 lines. The maize was harvested on November 20, 2020. (growing season 120 days). The irrigation process was conducted after depletion 50% of the soil water available for the plant. In calculating the amount of irrigation water added to each irrigation system in the surface irrigation system and was based on measuring the water content in the soil by the gravimetric method, according to the equation of Waller and Yitayew (2016):

$$d = (\theta_{fc} - \theta_l) \times D$$

where, d: is the depth of water added (mm). and $\theta_{fc}$: the volumetric water content at field capacity ($cm^3\ cm^{-3}$). $\theta_l$: the volumetric water content before the irrigation procedure and after depletion 50% of the available water ($cm^3\ cm^{-3}$). and D: depth of the soil layer (mm).

According to the depth of water added (mm) in each irrigation for the drip irrigation system by applying the following equations (Omran and Negm, 2020)

Wet area (%) was calculated as:

$$Pw = \frac{SW}{SR} \times 100$$

where: Pw = is the wet area (%). And Sw = the diameter of the wetted area (m) and it was 0.30 m for the surface dripping and 0.27 m for the subsurface drip. SR = the distance between the drip lines (m), which was 0.75 m. According to the depth of water added in each irrigation system for the drip irrigation system.

$$dn = AW \times Ds \times Pw \times dep$$

where: dn = maximum net depth irrigation for one irrigation (mm). and AW = water storage capacity of the soil (%) = ($\theta_{fc} - \theta_{wpw}$). and Ds = depth of the root zone (m). and Pw = wet area percentage (%). and dep = depletion rate of available water (%). According to the time required for irrigation (T) minutes from the following equation:

$$A = \frac{Ae \times d}{Q}$$

where Ae = The area of wetness for the single emitter, was calculated from the following equation:

$$Ae = 0.8\ (Sw)^2$$

d = depth of water added (cm), which represents the net depth of irrigation (NDI). Q = the given discharge, which was 4 liters per hour$^{-1}$ per emitter.

## RESULTS AND DISCUSSION

**Bulk density (Mg m$^{-3}$):** The influence of cover crop, irrigation systems and different tillage systems on bulk density values, was highest (1.480 mg m$^{-3}$) in $C_0T_3I_3$ and the lowest of 1,200 mg m$^{-3}$ was $C_1T_1I_2$ with a decrease of 23.33%. There were no significant differences in the bulk density of the triple interaction and the interaction between cover crop and tillage, as the highest value of bulk density was 1.453 mg m$^{-3}$ in $C_0T_3$ and the lowest in $C_1T_1$ (1.237 mg m$^{-3}$) with a decrease of 17.88% . The interaction between cover crop and irrigation, indicated the highest bulk density was 1,400 mg m$^{-3}$ in $C_0I_3$ and the lowest was 1.288 mg m$^{-3}$ in $C_1I_2$, with a decrease of 8.69%.

There were significant differences in the average bulk density of tillage and irrigation treatments and the interaction between them. Irrigation treatments affected the average bulk density, as the traditional irrigation treatment $I_3$ gave the highest average bulk density of 1.371 mg m$^{-3}$ and the subsurface drip irrigation $I_2$ the lowest average of 1.313 mg m$^{-3}$ This may be due to the effect of the traditional irrigation treatment In the basins, the movement of fine soil particles during irrigation and their deposition in the large pores and also due to the succession of the cycles of hydration and drying and the confinement of air in the pores of the soil and the occurrence of air explosions leading to the destruction of soil aggregates, which increases the values of the bulk density. This may also be attributed to the different irrigation method used in the transactions. The adoption of the subsurface drip irrigation system led to an improvement in soil construction, while the adoption of the subsurface irrigation system led to the collapse of the building and the redistribution of soil particles within the interspaces, which led to an increase in the values of the bulk density due to the sudden immersion of the tourist irrigation compared to the slow wetting of the drip irrigation and the movement of some fine soil particles. This leads to an increase in compaction and a decrease in porosity when using the irrigation method, and this came in agreement with the results of Cerdà et al (2021). The tillage treatments had a significant effect on the values of the average bulk density, highest average bulk density in $T_3$ (1.427 mg m$^{-3}$) and $T_1$ gave the lowest bulk density of 1.262 mg m$^{-3}$. Perhaps the reason for the increase in the average bulk density is due to the deterioration of the soil structure, including the formation of the deaf layer, as well as the increase in soil cohesion with depth, as well as the compaction of the underlying soil layers as a result of the pressure imposed on it from the surface layers as well as through the passage of agricultural machinery and equipment. These results are in agreement with Pranagal and Woźniak (2021). The largest value of the bulk density was 1.450 mg m$^{-3}$ in $T_3I_3$ and the lowest was 1.225 mg m$^{-3}$ in treatment $T_1I_2$. The bulk density varied within the interactions of the other treatments, as the bulk density decreased in the surface and subsurface drip irrigation $T_0I_1$ and $T_0I_2$ compared to the traditional irrigation $T_0I_3$, with a decrease of 3.90 and

5.13%, respectively. In $T_2I_1$ and $T_2I_2$, the bulk density decreased by 1.09 and 2.58% compared to $T_2I_3$, respectively. $T_3I_1$ and $T_3I_2$, the values of bulk density decreased by 1.75 and 3.20% compared to $T_3I_3$, respectively. The cover crop treatments significantly affected the bulk density values, where the highest value of bulk density was 1.364 mg $m^{-3}$ when treatment $C_0$ and treatment $C_1$ reached 1.313 mg $m^{-3}$ with a decrease of 3.88%, and this result was in agreement with Chalise et al (2018).

**Porosity %:** The total porosity values, as it ranged between 44.15 and 54.71% (Table 5). $C_0T_3I_3$ achieved the lowest value of total porosity, while $C_1T_1I_2$ reached the highest total porosity. The results of the statistical analysis showed that there were no significant differences between the three experimental treatments in total porosity, as well as the interaction between the cover crop treatment and the irrigation treatment. The lowest porosity was in treatment $C_0I_3$ 47.16%, while treatment $C_1I_2$ gave the highest porosity, which amounted to 51.39%, with a percentage decrease of 8.96%. Likewise, the interaction between cover crop and tillage, there were insignificant differences, and the highest porosity was in $C_1T_1$ with porosity of 53.33%, while for treatment $C_0T_3$ gave the lowest porosity of 45.15% with a decrease of 18.11% compared with $C_1T_1$. The interaction between tillage and irrigation, the results showed that there were significant differences in total porosity. The $T_1I_2$ recorded the highest value of the porosity (53.77%,) while $T_3I_3$ gave the lowest porosity( 45.28%, 0 with a decrease of 18.75%. There were significant differences between the levels of each treatment, so that the cover crop had a significant effect compared to the absence of the cover crop. The average total porosity in $C_1$ was 50.45% and was higher than $C_0$, which recorded the average total porosity of 48.51%. This may be due to the role of the cover crop in creating A suitable environment for the activity of soil biology, especially earthworms, which have the ability to improve soil construction by increasing the stability

**Table 4.** Influence of cover crop, irrigation and tillage systems on bulk density (Mg $m^{-3}$)

| Cover crop | Tillage | Irrigation | | | Cover crop* tillage |
|---|---|---|---|---|---|
| | | $I_1$ | $I_2$ | $I_3$ | |
| $C_0$ | $T_0$ | 1.300 | 1.290 | 1.360 | 1.317 |
| | $T_1$ | 1.270 | 1.250 | 1.340 | 1.287 |
| | $T_2$ | 1.400 | 1.380 | 1.420 | 1.400 |
| | $T_3$ | 1.450 | 1.430 | 1.480 | 1.453 |
| $C_1$ | $T_0$ | 1.260 | 1.240 | 1.300 | 1.267 |
| | $T_1$ | 1.220 | 1.200 | 1.290 | 1.237 |
| | $T_2$ | 1.350 | 1.330 | 1.360 | 1.347 |
| | $T_3$ | 1.400 | 1.380 | 1.420 | 1.400 |
| LSD | | | N. S | | N. S |
| Cover crop * Irrigation | | | | | |
| Cover crop | | $I_1$ | $I_2$ | $I_3$ | Average of cover crop |
| $C_0$ | | 1.355 | 1.338 | 1.400 | 1.364 |
| $C_1$ | | 1.308 | 1.288 | 1.343 | 1.313 |
| LSD | | | N. S | | 0.020 |
| Tillage * Irrigation | | | | | |
| Tillage | | $I_1$ | $I_2$ | $I_3$ | Average of tillage |
| $T_0$ | | 1.280 | 1.265 | 1.330 | 1.292 |
| $T_1$ | | 1.245 | 1.225 | 1.315 | 1.262 |
| $T_2$ | | 1.375 | 1.355 | 1.390 | 1.373 |
| $T_3$ | | 1.425 | 1.405 | 1.450 | 1.427 |
| LSD | | | 0.028 | | 0.021 |
| Average of irrigation | | 1.331 | 1.313 | 1.371 | |
| LSD | | | 0.013 | | |

of soil aggregates, as well as affecting the cover crop in the volume distribution of pores and that the decomposition of the components of the cover crop will lead to an increase in the percentage of organic matter in the soil and thus reduce its apparent density and increase its porosity These results were in agreement with the findings of Frazão et al. (2019). Likewise in the plowing treatments, there were significant differences, as the minimum tillage $T_1$ was superior by with highest average total porosity of 52.38%, while the deep tillage $T_3$ gave the lowest mean total porosity and reached 46.16, with a decrease of 13.47%. The reason is that deep plowing destroys the soil structure and forms layers of compacted soils that increase its apparent density and reduce soil erosion. Porous, the other irrigation treatments significantly affected the average total porosity. It was the best result was by using the sub-surface drip irrigation method because it gave the highest average porosity of 50.47%, while the lowest average porosity was when treating the traditional irrigation in basins, with the average porosity reaching 48.25%, with a decrease of 4.60% and perhaps The reason for the increase in the total porosity of the soil when following the subsurface drip irrigation system compared to the traditional irrigation system in basins is due to the growth and penetration of plant roots with the progression of the growing season, which works to bind soil particles, as well as the presence of microorganisms and the substances they secrete that improve soil construction as a result of increased its activities. The tourist irrigation led to the confinement of the air inside the pores and the occurrence of localized explosions that destroyed the soil structure and broke the gatherings, as well as the difference in the expansion of the different parts of the soil assemblies as a result of the rapid wetting. The effect of the succession of wetting and drying played a role in creating a tight compaction of soil particles, which resulted in an increase in the apparent density of the soil and a decrease in its porosity. These results were similar with what was found. Abd AL-Gabbar and Al-Abaied (2016).

**Mean weight diameter (MWD):** The statistical analysis

**Table 5.** influence of cover crop, irrigation and tillage systems on porosity (%)

| Cover crop | Tillage | Irrigation | | | Cover crop* tillage |
|---|---|---|---|---|---|
| | | $I_1$ | $I_2$ | $I_3$ | |
| $C_0$ | $T_0$ | 50.94 | 51.32 | 48.67 | 50.31 |
| | $T_1$ | 52.07 | 52.83 | 49.43 | 51.44 |
| | $T_2$ | 47.16 | 47.92 | 46.41 | 47.16 |
| | $T_3$ | 45.28 | 46.03 | 44.15 | 45.15 |
| $C_1$ | $T_0$ | 52.45 | 53.20 | 50.94 | 52.20 |
| | $T_1$ | 53.96 | 54.71 | 51.32 | 53.33 |
| | $T_2$ | 49.05 | 49.81 | 48.67 | 49.18 |
| | $T_3$ | 47.16 | 47.92 | 46.41 | 47.16 |
| LSD | | | N. S | | N. S |
| Cover crop * Irrigation | | | | | |
| Cover crop | | $I_1$ | $I_2$ | $I_3$ | Average of cover crop |
| $C_0$ | | 48.86 | 49.50 | 47.16 | 48.51 |
| $C_1$ | | 50.64 | 51.39 | 49.32 | 50.45 |
| LSD | | | N. S | | 0.77 |
| Tillage * Irrigation | | | | | |
| Tillage | | $I_1$ | $I_2$ | $I_3$ | Average of tillage |
| $T_0$ | | 51.69 | 52.26 | 49.81 | 51.25 |
| $T_1$ | | 53.01 | 53.77 | 50.37 | 52.38 |
| $T_2$ | | 18.11 | 48.86 | 47.54 | 48.17 |
| $T_3$ | | 46.22 | 46.98 | 45.28 | 48.16 |
| LSD | | | 1.05 | | 0.77 |
| Average of irrigation | | 49.76 | 50.47 | 48.25 | |
| LSD | | | 0.50 | | |

showed that there were no significant differences in the triple interaction between the experimental treatments and the mean weight diameter values (Table 6). The highest mean weight diameter was 3.93 mm in $C_1T_1I_2$ and the in $C_0T_3I_3$ (1.03 mm,) with a decrease of 281.55%. There were significant differences between the treatment of cover crop and different tillage, the highest value of weighted diameter was 1.26 mm in $C_0T_3$ treatment, while $C_1T_0$ excelled by giving the highest value of the average weighted diameter (3.72 mm) with an increase rate of 195.23%. The binary interaction of the cover crop and irrigation treatments gave significant differences in the average weighted diameter, and the lowest average weighted diameter was 2.32 mm for $C_0I_3$, while the highest was 3.11 mm in the $C_1I_2$ with an increase of 33.76%. The interaction between the tillage and irrigation systems did not differ significantly. The $T_3I_3$ gave the lowest value of the average weighted diameter (1.33 mm), while the highest average weighted diameter was in $T_0I_2$ (3.70 mm) with an increase of 173.43%. The treatment $C_1$ achieved the highest value in the MWD of 2.889 mm compared to 2.488 mm in $C_0$. Increasing the activity of soil microorganisms because it provides a fertile environment for the growth of these microorganisms that bind soil particles and thus increase the stability of soil assemblies. These results are in agreement with the findings of Jeghata and Muhawish (2021).

Tillage treatments showed significant differences in the values of the mean weight diameter $T_0$ achieved the highest average of the mean weight diameter of 3.517 mm, while treatment $T_3$ gave the lowest average of 1.565 mm, with an increase of 124.72%. This is due to the role of the no-till treatment in preserving the soil structure and its content of organic matter in the surface layer of the soil because it has a role in improving some soil characteristics through the cohesion and interconnection of soil aggregates to each other and increasing soil water holding through increasing soil porosity as well as decomposition of the organic matter produces viscous gels consisting of disaccharides, cellulose, proteins and glue that bind the soil particles with each other,

**Table 6.** influence of cover crop, irrigation and tillage systems on MWD (mm)

| Cover crop | Tillage | Irrigation | | | Cover crop* tillage |
|---|---|---|---|---|---|
| | | $I_1$ | $I_2$ | $I_3$ | |
| $C_0$ | $T_0$ | 3.350 | 3.440 | 3.150 | 3.313 |
| | $T_1$ | 3.310 | 3.400 | 3.110 | 3.273 |
| | $T_2$ | 2.120 | 2.190 | 2.010 | 2.107 |
| | $T_3$ | 1.300 | 1.450 | 1.030 | 1.260 |
| $C_1$ | $T_0$ | 3.850 | 3.970 | 3.340 | 3.720 |
| | $T_1$ | 3.810 | 3.930 | 3.280 | 3.673 |
| | $T_2$ | 2.300 | 2.480 | 2.100 | 2.293 |
| | $T_3$ | 1.870 | 2.060 | 1.680 | 1.870 |
| LSD | | | N. S. | | 0.141 |
| Cover crop * Irrigation | | | | | |
| Cover crop | | $I_1$ | $I_2$ | $I_3$ | Average of cover crop |
| $C_0$ | | 2.520 | 2.620 | 2.325 | 2.488 |
| $C_1$ | | 2.958 | 3.110 | 2.600 | 2.889 |
| LSD | | | 0.105 | | 0.135 |
| Tillage * Irrigation | | | | | |
| Tillage | | $I_1$ | $I_2$ | $I_3$ | Average of tillage |
| $T_0$ | | 3.600 | 3.705 | 3.245 | 3.517 |
| $T_1$ | | 3.560 | 3.665 | 3.195 | 3.473 |
| $T_2$ | | 2.210 | 2.335 | 2.055 | 2.200 |
| $T_3$ | | 1.585 | 1.755 | 1.355 | 1.565 |
| LSD | | | N.S. | | 0.119 |
| Average of irrigation | | 2.739 | 2.865 | 2.463 | |
| LSD | | | 0.059 | | |

which increases the stability of the aggregates in the soil. The traditional plowing destroy the soil structure. Irrigation treatments affected the values of the mean weight diameter, and the statistical analysis showed that there were significant differences in the values of the MWD. Treatment $I_2$ gave the highest average of the weighted diameter which was 2.865 mm, while treatment $I_3$ gave the lowest average of 2.463 mm. The reasons for the decrease in the values of the MWD of the traditional irrigation treatments in basins are due to the destruction that occurs to large gatherings during the irrigation process, which results in smaller gatherings and individual soil particles, as well as to the role of the traditional irrigation process and its negative effects in wetting the soil aggregates and weakening the bonding strength between them and thus the building collapse. As a result of the rapid and sudden immersion and the rapid escape of air trapped in the pores, which destroys large soil gatherings, as well as the succession of wetting and drying, which leads to a difference in the expansion of clay minerals, causing cracks and cracking of gatherings that further deteriorate soil structure (Al-Shamari et al 2020).

**Soil resistance of penetration (Mpa):** The highest value was 2.54 MPa for $C_0T_3I_3$ and the lowest value was for $C_1T_1I_2$ (0.91 MPa) (Table 7). There were no significant differences between the three treatments in the values of soil resistance to penetration, as well as the bilateral interaction between cover crop and tillage and also between cover crop and irrigation. However, significant differences were found between the treatments of the cover crop, as the percentage increase was 91%, and the highest average was in $C_0$, (1.91 MPa) and the lowest average was in $C_1$ (38 MPa). The decrease in soil resistance to penetration may be attributed to the role of the cover crop in holding the soil to water as a result of the improvement of soil construction, as the research indicated the role of the cover crop in improving the soil structure and improving the capacity of the soil to hold water as a result of increasing the porosity of the soil and the volume distribution of pores of small size (Gabriel et al 2021)

**Table 7.** influence of cover crop, irrigation and tillage systems on soil resistance of penetration ()Mpa

| Cover crop | Tillage | Irrigation | | | Cover crop* tillage |
|---|---|---|---|---|---|
| | | $I_1$ | $I_2$ | $I_3$ | |
| $C_0$ | $T_0$ | 1.69 | 1.66 | 1.75 | 1.70 |
| | $T_1$ | 1.53 | 1.45 | 1.69 | 1.55 |
| | $T_2$ | 2.04 | 2.04 | 2.11 | 2.06 |
| | $T_3$ | 2.45 | 2.16 | 2.54 | 2.38 |
| $C_1$ | $T_0$ | 1.16 | 1.10 | 1.23 | 1.16 |
| | $T_1$ | 0.98 | 0.91 | 1.17 | 1.02 |
| | $T_2$ | 1.54 | 1.54 | 1.64 | 1.57 |
| | $T_3$ | 1.86 | 1.68 | 1.90 | 1.81 |
| LSD | | | N. S | | N. S |
| Cover crop * Irrigation | | | | | |
| Cover crop | | $I_1$ | $I_2$ | $I_3$ | Average of cover crop |
| $C_0$ | | 1.89 | 1.76 | 2.10 | 1.91 |
| $C_1$ | | 1.39 | 1.24 | 1.53 | 1.38 |
| LSD | | | N. S | | 0.013 |
| Tillage * Irrigation | | | | | |
| Tillage | | $I_1$ | $I_2$ | $I_3$ | Average of tillage |
| $T_0$ | | 1.41 | 1.35 | 1.49 | 1.41 |
| $T_1$ | | 1.25 | 1.18 | 1.43 | 1.28 |
| $T_2$ | | 1.79 | 1.79 | 1.89 | 1.82 |
| $T_3$ | | 2.17 | 1.96 | 2.20 | 2.11 |
| LSD | | | 0.056 | | 0.026 |
| Average of irrigation | | 1.65 | 1.57 | 1.75 | |
| LSD | | | 0.032 | | |

This improvement in soil structure and the increase in moisture preservation and the percentage of pores and their regularity made soil particles slip on each other, which facilitated penetration. Tillage treatments showed a significant difference in the average soil resistance to penetration, $T_1$ gave the lowest mean of soil resistance to penetration, (1.28 MPa) while treatment $T_3$ gave the highest mean of soil resistance to penetration (2.11 MPa) with an increase of 111%. This is due to the role of deep plowing in compacting the soil, increasing its apparent density and decreasing its porosity. The results are similar to Altalabani and Saad (2018). The irrigation treatments affected the average soil resistance to penetration, I2 gave the lowest mean of soil resistance to penetration (1.57 MPa) and treatment $I_3$ highest average soil resistance to penetration (1.75 MPa). This also led to a decrease in the total porosity and the values of the average weighted diameter, so this effect was also negatively reflected on the soil's resistance to penetration.

**Saturated soil hydraulic conductivity (cm min$^{-1}$) :** The highest value of the Saturated soil hydraulic conductivity was 3.81 cm min$^{-1}$ in $C_1T_1I_2$ while treatment $C_0T_3I_3$ recorded the lowest of 0.91 cm min$^{-1}$ (Table 8). There were significant differences in the values of the saturated soil hydraulic conductivity for the triple interaction between the treatments of the experiment and also for the bilateral interaction between the treatments of cover crop and tillage. The highest value of the saturated soil hydraulic conductivity was 3.49 cm min$^{-1}$ for $C_1T_1$, while the lowest was 1.08 cm min$^{-1}$ for $C_0T_3$ with an increase of 223.14%. The treatments of cover crop and irrigation and the interaction between them, had a significant effect on the saturated soil hydraulic conductivity as the highest value of the water conductivity was 2.93 cm min$^{-1}$ and the lowest value was 1.64 cm min$^{-1}$ for treatments $C_1I_2$ and $C_0I_3$ according to the sequence, with an increase of 192.5%. The binary interaction between the tillage and irrigation treatments gave values of the saturated soil hydraulic conductivity was significantly different among them. The

**Table 8.** Influence of cover crop, irrigation and tillage systems on saturated soil hydraulic conductivity (cm min$^{-1}$)

| Cover crop | Tillage | Irrigation | | | Cover crop* tillage |
|---|---|---|---|---|---|
| | | $I_1$ | $I_2$ | $I_3$ | |
| $C_0$ | $T_0$ | 2.86 | 2.87 | 2.11 | 2.61 |
| | $T_1$ | 2.93 | 2.94 | 2.16 | 2.67 |
| | $T_2$ | 1.80 | 1.88 | 1.36 | 1.68 |
| | $T_3$ | 1.12 | 1.21 | 0.91 | 1.08 |
| $C_1$ | $T_0$ | 3.75 | 3.75 | 2.81 | 3.43 |
| | $T_1$ | 3.80 | 3.81 | 2.86 | 3.49 |
| | $T_2$ | 2.17 | 2.23 | 1.91 | 2.10 |
| | $T_3$ | 1.78 | 1.86 | 1.32 | 1.65 |
| LSD | | | 0.135 | | 0.149 |
| Cover crop * Irrigation | | | | | |
| Cover crop | | $I_1$ | $I_2$ | $I_3$ | Average of cover crop |
| $C_0$ | | 2.16 | 2.24 | 1.63 | 2.01 |
| $C_1$ | | 2.86 | 2.92 | 2.23 | 2.67 |
| LSD | | | 0.150 | | 0.178 |
| Tillage * Irrigation | | | | | |
| Tillage | | $I_1$ | $I_2$ | $I_3$ | Average of tillage |
| $T_0$ | | 3.31 | 3.31 | 2.46 | 3.02 |
| $T_1$ | | 3.36 | 3.38 | 2.51 | 3.08 |
| $T_2$ | | 1.98 | 2.05 | 1.63 | 1.89 |
| $T_3$ | | 1.45 | 1.53 | 1.11 | 1.36 |
| LSD | | | 0.053 | | 0.02 |
| Average of irrigation | | 2.52 | 2.56 | 1.93 | |
| LSD | | | 0.031 | | |

minimum value of the water conductivity was in the $T_3I_3$ (1.12 cm min$^{-1}$), while the largest was in the $T_1I_2$ (3.38 cm min$^{-1}$) with an increase of 202.69%. The effect of cover crop on the soil saturated soil hydraulic conductivity was significant, and lowest value of the average water conductivity was 2.01 cm min$^{-1}$ when treatment $C_0$ compared to treatment $C_1$, which gave the largest the average water conductivity of 2.67 cm min$^{-1}$ with an increase of 32.68%. The reason for this is that the cover crop provided suitable environment and conditions that improve the physical properties of the soil. When the bulk density is low, the total porosity is high and the construction is good, This is logical that the saturated soil hydraulic conductivity are high. The values of saturated soil hydraulic conductivity were significantly affected by different plowing treatments, and treatment $T_1$ gave the largest of 3.08 cm min$^{-1}$, while the lowest was in $T_3$ (.37 cm min$^{-1}$). The minimal tillage treatment maintained a good soil structure and provided protection against the destruction of soil agglomerations, as evidenced by an increase in the weighted diameter of this treatment. Irrigation treatments affected the average saturated soil hydraulic conductivity significantly, as the $I_2$ irrigation treatment gave the highest mean of saturated soil hydraulic conductivity of 2.57 cm min$^{-1}$, and $I_3$ irrigation lowest of 1.93 cm min$^{-1}$, with a decrease of 33.83%. The reason for the low water conductivity of the soil for treatment $I_3$ is due to the lack of stability of the soil structure and the destruction of its aggregates as a result of immersion of the soil with irrigation water. The soil body then precipitates and closes some of its pores, thus changing the water conductivity value of the soil.

## CONCLUSION

The irrigation management with the presence of cover crop with minimum tillage and subsurface drip irrigation ($C_1T_1I_2$) improved the physical properties of the soil as it preserved the soil structure from breakdown and deterioration in terms of the increase in the mean weight diameter of the soil aggregates. This improved the soil's ability to hold water and nutrients as a result of increase in the total porosity, as well as increasing the ability of the soil to conduct water. On the other hand, the soil became brittle and porous, so the values of its resistance to penetration decreased, and this would stimulate the growth and spread of plant roots. These results encourage the investment of a subsurface drip irrigation system to manage field irrigation for many years with the presence of the remnants of the previous crop and minimum tillage to create a good germination site for seeds and an appropriate growth environment for the plant while maintaining the construction, health and quality of the soil through the role of the cover crop in improving the physical, chemical and biological properties of the soil as well as for reducing the costs of preparing the land , plowing and fertilizers. Long-term investment requires periodic maintenance of the irrigation system to ensure its continued operation and high efficiency and to protect it from damage.

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# Effect of Varying Levels of Sulphur and Sources on Sulphur Fractions in an Acid Alfisol of Himachal Pradesh

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***Abstract***: An investigation was conducted on cauliflower (*Brassica oleracea* L. var. Palam Uphar) at CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur to study the effect of varying levels of sulphur and its Sources on various sulphur fractions in an Acid Alfisol of Himachal Pradesh. The experiment consisted of three levels (12.5, 25, 37.5 kg S $ha^{-1}$) and four sources (Sartaj natural gypsum, locally available gypsum, elemental sulphur and single super phosphate) of sulphur. Available, water soluble, organic form of sulphur and total sulphur increased significantly with increased levels of sulphur. Whereas, in sources Sartaj gypsum recorded maximum available sulphur (12.4 mg $kg^{-1}$) and water soluble (9.8 mg $kg^{-1}$) followed by single super phosphate, locally available gypsum and elemental sulphur. Different sources of sulphur did not show any significant effect on heat soluble sulphur, organic sulphur and total sulphur. All sulphur fractions were significantly and positively correlated with available form of sulphur. However, highest correlation was observed with water soluble sulphur.

***Keywords***: Sulphur, Sources, Varying levels, Fractions

Sulphur deficiencies in India are widespread and scattered. The reports of widespread sulphur deficiencies are coming from different parts of country including Himachal Pradesh. Increasing deficiency of sulphur in Indian soils has become the cause of concern in the new millennium. Intensification of agriculture with high yielding varieties and multiple cropping systems coupled with the use of high analysis sulphur free fertilizers along with the restricted or no use of organic manures leading to depletion of the soil sulphur reserve. Removal of sulphur by crops in India is about 1.26 mt, whereas, its replenishment through fertilizers is only about 0.76 mt (Tiwari and Gupta 2006). Further, the recovery of added sulphur through external sources is also very low, being only 8 -10% (Hegde and Murthy 2005). Continued depletion of native reserves of sulphur during post green revolution period has led to its deficiency in many regions of the country and at present is one of the major constraints for sustainable growth and productivity of several field crops. According to the reports of ICAR soils in over 250 districts are suffering from varying degrees of sulphur deficiency (Majumdar et al 2012). According to recent estimates, on an average 11% of Indian soils are acute deficient, 30% are deficient and about 17.8% are latent deficient in sulphur requiring application of S for sustainable agricultural production (Shukla et al 2021). With persistent demand for S by crops, deficiencies are more likely to occur on soils that inherently supply less available S within rooting zone. Minimum use of low-analysis fertilizers like ammonium sulphate, single super phosphate and organic manures has rendered the Indian soils deficient in sulphur. Continuous removal of S from soils by plants has led to widespread S deficiency all over the world (Aulakh et al. 1977). Responses to the application of sulphur have been observed in many crops. Among these, cole and oilseed crops have been observed to be more responsive as these crops have a significant requirement for sulphur. Limited supply of sulphur results in the reduction of crop yield, storage life and marketable quality.

There are many sources like gypsum, elemental sulphur, sulphur containing fertilizers etc. for supplying sulphur to various crops but sources which are easily available, efficient, economically viable, sustain soil health and environmentally safe are acceptable to the farmers. Therefore, there is an urgent need to assess the effect of sulphur application through different sources for sustaining the productivity of crops. Sulphur pools in the soil are extremely dynamic. Available sulphur content in the soil is used as an index to evaluate soil sulphur fertility status and its contribution towards plant nutrition. However, knowledge of different forms of sulphur is important for assessing their contribution towards yield, quality parameters and sulphur availability in soil.

## MATERIAL AND METHODS

The present study was conducted at CSK Himachal

Pradesh Krishi Vishvavidyalaya, Palampur, during *rabi* 2014-15 in a randomized block design. The experimental site lies in the mid hill wet temperate zone (zone 2.2) of Himachal Pradesh. Geographically, the experimental site is situated at an altitude of about 1290 m above mean sea level. Average rainfall received during the experimental period was 549.9 mm. Taxonomically, the soils of study area fall under order Alfisol and sub-group Typic Hapludalf. The soil of the experimental site was acidic in reaction (5.6), silty clay loam in texture with 19.80 percent sand,42.90 percent silt and 34.10 percent clay and low in available nitrogen (276 kg ha$^{-1}$), high in available phosphorus (30 kg ha$^{-1}$) and medium in available potassium (150 kg ha$^{-1}$). The available sulphur status of the soil was also low (9.1 mg ka$^{-1}$), whereas, organic carbon content at initiation of the experiment was observed medium (9.6 g kg$^{-1}$). Representative soil samples (0-0.15 m depth) were collected from each plot after harvesting of the crop. The collected soil samples were dried in shade, finely grounded in wooden pestle mortar and passed through 2 mm sieve for further laboratory analysis. The processed soil samples were analyzed for sulphur fractions (heat soluble sulphur, water soluble sulphur, total sulphur, sulphate sulphur and organic sulphur) as per the standard procedures given by Chesnin and Yien (1950) and Johnson and Nishita (1952). Whereas, organic sulphur was calculated by subtraction of available sulphur (sulphate) from total sulphur.

## RESULTS AND DISCUSSION

The available sulphur in the soils of experimental site constituted around 6.91 per cent of total sulphur (Table 1). This is in conformity with the findings of Singh et al(2009) with range of 1.84-12.91 percent of total sulphur. The available sulphur content was observed lowest in control (11.6 mg kg$^{-1}$), where no external sulphur was applied. Highest content (12.4 mg kg$^{-1}$) of available sulphur was found with application of sulphurat @ 37.5 kg ha$^{-1}$;which was observed significantly higher over the treatment with the sulphur application of 25 kg ha$^{-1}$ (12.1 mg kg$^{-1}$) and 12.5 kg ha$^{-1}$ (11.7 mg kg$^{-1}$). Such increase in available sulphur content due to Sulphur application was also observed by Dutta et al (2013) and Gourav et a (2021).However the interaction among the levels and sources of sulphur was non-significant. Among sources,the highest content of available sulphur was where sulphur was applied through Sartaj gypsum (12.4 mg kg$^{-1}$) followed by single super phosphate (12.1 mg kg$^{-1}$), local gypsum (12.0 mg kg$^{-1}$)and elemental sulphur (11.8 mg kg$^{-1}$).

Water soluble fraction of sulphur gives an indication about plant available sulphur status of soil and on in an average this sulphur fraction was 5.4 per cent of total sulphur. Similar trend was observed by Das et al (2012) and Ali et al (2014).The highest content of water soluble sulphur was observed, where sulphur was applied @ 37.5 kg ha$^{-1}$, which was however, statistically at par with treatment where application of sulphur was done @ 25 kg S ha$^{-1}$ and significantly superior over application of sulphur @ 12.5 kg S ha$^{-1}$. Among sources, the highest content of water soluble sulphur was observed, where sulphur was applied through Sartaj gypsum (9.8 mg kg$^{-1}$) which was statistically at par with single super phosphate and significantly superior over local gypsum and elemental sulphur, respectively. Singh (2010)

**Table 1.** Effect of different levels and sources of sulphur on sulphur fractions (mg kg$^{-1}$) of soil

| | Sulphate-S | Water soluble-S | Heat soluble-S | Organic-S | Total-S |
|---|---|---|---|---|---|
| Sulphur levels (kg ha$^{-1}$) | | | | | |
| 12.5 | 11.7 | 9.1 | 28.3 | 156.4 | 168.1 |
| 25.0 | 12.1 | 9.5 | 28.7 | 162.3 | 174.4 |
| 37.5 | 12.4 | 9.8 | 28.9 | 167.8 | 180.2 |
| CD (p=0.05) | 0.25 | 0.37 | NS | 6.48 | 6.45 |
| Sulphur sources | | | | | |
| Sartaj gypsum | 12.4 | 9.8 | 29.3 | 166.0 | 178.4 |
| Local gypsum | 12.0 | 9.4 | 28.5 | 160.0 | 172.0 |
| Elemental sulphur | 11.8 | 9.1 | 28.0 | 158.1 | 169.9 |
| Single super phosphate | 12.1 | 9.6 | 28.7 | 164.6 | 176.9 |
| CD (p=0.05) | 0.29 | 0.43 | NS | NS | NS |
| Control vs others | | | | | |
| Control | 11.2 | 8.4 | 27.8 | 152.1 | 163.6 |
| Others | 12.1 | 9.5 | 28.6 | 162.2 | 174.3 |
| CD (p=0.05) | 0.17 | 0.55 | NS | 9.54 | 9.50 |

and Dutta et al (2013) also reported that application of sulphur containing fertilizers significantly increased water soluble sulphur in soil. Heat soluble form of sulphur, provides a measure of sulphate sulphur plus a fraction of organic sulphur). It is an important indicator for evaluating sulphur status of soils. In this experimental study heat soluble sulphur fraction was observed more as compared to available and water soluble sulphur indicating the release of S by wet and dry heating of soil during the extraction and also may be due to liberation of sulphate sulphur during heat treatment. The heat soluble sulphur is more available than water soluble sulphur. These results are in accordance to Das et al (2012). The heat soluble sulphur fraction contributes about 16.5 per cent to total sulphur. There was no significant effect observed with the application of different levels and sources of sulphur on content of heat soluble sulphur in soil. However, numerically the highest content of heat soluble sulphur (28.9 mg $kg^{-1}$) was d where sulphur was applied @ 37.5 kg $ha^{-1}$ followed by 25 kg S $ha^{-1}$ (28.7 mg $kg^{-1}$) and 12.5 kg S $ha^{-1}$ (28.3 mg $kg^{-1}$). Different sources of sulphur also failed to exhibit any significant influence on heat soluble sulphur. However, numerically the highest content of heat soluble sulphur was observed when sulphur was applied through Sartaj gypsum (29.3 mg $kg^{-1}$) followed by single super phosphate (28.7 mg $kg^{-1}$).

Organic sulphur accounted for 93.1 % of total sulphur, thus forming a major fraction of total sulphur. The findings were in strong conformity with the Rongzhong et al (2010). The different sources of sulphur did not have any significant effect whereas; different levels had showed significant effect on organic form of sulphur. Numerically the highest content of organic sulphur was obtained when sulphur was applied @ 37.5 kg $ha^{-1}$which was statistically at par with 25 kg S $ha^{-1}$ and was significantly superior to 12.5 kg $ha^{-1}$. It might be due to the reason that some amount of added S might have immobilized, thus resulting in increased organic S content in soil (Wani 2000, Schmidt et al 2012). Numerically the Sartaj gypsum (166.0 mg $kg^{-1}$) was highest in organic sulphur followed by single super phosphate, local gypsum and elemental sulphur, respectively though the differences were not significant. The overall mean of different levels and sources of sulphur was significantly higher over control. The interaction among levels and sources was also not d significant in respect of organic sulphur total sulphur followed the same trend like organic sulphur. The content of total sulphur was numerically higher when sulphur was applied @ 37.5 kg $ha^{-1}$ which was not statistically different from the treatment where sulphur was applied @ 25 kg S $ha^{-1}$, but was significantly superior over 12.5 kg S $ha^{-1}$. Wani (2000), Dhananjaya and Basavaraj (2002) and Dutta et al (2013) also reported that the increased level of sulphur containing fertilizers significantly increased total sulphur in soil. Among sulphur sources, the total sulphur was observed numerically maximum when sulphur was applied through Sartaj gypsum followed by single super phosphate, local gypsum and elemental sulphur, respectively, though the differences were not significant. The increase in content of total sulphur might be due to the increased content of organic sulphur. The overall effect of sulphur application was significantly higher over control. The interaction among levels and sources was not found significant in respect of organic sulphur. It is observed that among all the sources, the least values of all the fractions of Sulphur were recorded where sulphur was applied through elemental S (Diwakar et al 2014).

**Table 2.** Correlation coefficient (r) between sulphur fractions and available sulphur of soil

| Sulphur fractions | Available sulphur |
|---|---|
| Water soluble sulphur | 0.715** |
| Heat soluble sulphur | 0.465** |
| Organic sulphur | 0.514** |
| Total sulphur | 0.561** |

**Significant at 1% level of significance

**Relationship of different sulphur fractions with available sulphur fraction of soil:** Different sulphur fractions (water soluble sulphur, heat soluble sulphur, organic sulphur and total sulphur) were significantly and positively correlated with available sulphur of soil. The maximum value of correlation coefficient was with water soluble sulphur (r= 0.715) followed by total sulphur (r=0.561), organic sulphur (r=0.514) and heat soluble sulphur (r=0.465). The positive correlation among different fractions and available sulphur was also reported earlier by Dutta et al (2013).

## CONCLUSIONS

Different level and sources of sulphur had significant effect on sulphate sulphur and water soluble sulphur. The maximum available sulphur was observed when sulphur was applied @ 37.5 kg $ha^{-1}$, which was significantly superior to application of 25 kg S $ha^{-1}$ and 12.5 kg S $ha^{-1}$.Water soluble sulphur content was also observed highest when sulphur was applied @ 37.5 kg $ha^{-1}$. Different levels of sulphur significantly improve all the fractions of sulphur except heat soluble sulphur whereas, the significant differences in sulphur fractions under different sources were only observed in available and water soluble S. In general, Sartaj gypsum recorded higher numerical values of all sulphur fractions followed by SSP, local gypsum and elemental sulphur.

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# Evaluation of Diesel Degradation Potential of *Klebsiella pneumoniae* Strain VM18 Isolated from Petroleum Contaminated Soil of Mathura

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***Abstract***: The present investigation was conducted to isolate, characterize and identify one of the best bio degrader bacterial isolate and to measure its biodegradation capacity. *Klebsiella pneumoniae* strain VM18 was the isolated bacteria which showed the degradation efficacy of 62.84% after $35^{th}$ day of incubation in Bushnell Hass medium. GC-MS analysis reveals that, *Klebsiella pneumoniae* strain VM18 degraded $C_{51}$-$C_{60}$ fraction from 2.54% to 1.49% and converted them into $C_{31}$-$C_{50}$ after 21 days of incubation. This can be concluded that bacterial strains have potential to degrade the petroleum hydrocarbons present in contaminated soil environment.

***Keywords***: *Klebsiella pneumoniae,* Bushnell Hass medium, Contaminated, Biodegradation, Hydrocarbon

The petroleum industry has played a significant role in global economy but as usual it also has some demerits on our ecosystem as well. The occurrence of pollution through refining, storage and distribution of petroleum products are a universal problem across the globe (Nogales et al 2011). As petroleum refineries are magnificently large industrial complexes which connected with large chemical processing and producing units via inland and outland incorporated pipelines, carrying various streams of fluids. These pipeline are underground so they passed through the agricultural land and sometimes crossing the water bodies. During transportation of oil from the source of production to various consuming sites, there is a huge risk of accidental spillage (Chang et al 2014). If accidental spillage occurs, it affects the food chain and food web of marine ecosystem drastically. Analysis of soil health is the most important step to maintain or improve the quality of the soil (Schoenholtz 2000). The effect of toxicity mainly depends on their concentration, composition and environmental factors (Ekhaise and Nkwelle 2011). According to the Germany, Federal Environment Agency in 2012, incomplete combustion of oil at a lower temperature and less oxygen supply is the main sources to produce PAHs. Generally, PAHs are considered to be potent atmospheric pollutants that consist of fused aromatic rings. According to behaviour they considered as a carcinogenic, mutagenic, and teratogenic compounds.There are some technologies used for restoring the soil fertility, which was rigorously contaminated with PAHs. Bioremediation is one of the natural approaches that based on microorganisms to remove the toxic pollutants from the environments. Microbial ranges are available to clean up contaminated sites occur due to the presence of petroleum hydrocarbons. Microorganisms have a tendency to convert these chemical compounds into energy, cell mass and biological waste products (Rahman et al. 2002). The present investigation was designed to isolate, identify the petroleum hydrocarbons degrading microbial population. Evaluation of biodegradation potential of each microbial isolates is the major objective of the investigation.

## MATERIAL AND METHODS

Soil sample was collected from automobiles workshops sites around the Mathura. The samples were dug from trowel from 0 to 20 cm below the topsoil surface. In order to remove plants or other waste residues the soil get air dried and sieved through 200 mesh sieves. The soil samples then stored in sample storage bags and kept in refrigerator till further analysis.

**Isolation and Screening of hydrocarbon utilizing bacterial strain:** Enrichment culture technique was used to isolate petroleum hydrocarbon degrading microbes. Bushnell Haas Media was used for the isolation of pure culture and 1% (v/v) diesel was used as a carbon and energy sources (Bushnell and Haas 1941). For screening, 1 gm of contaminated soil samples was suspended and vortexes in 10ml of sterile distilled water. After it 1ml of solution was taken out and used as inoculums for isolation of oil degrading microorganisms. 100ml of BHM broth medium was transferred to each flask and sterilized. Flask was kept in rotary shaker at 150 rpm and 28ºC for 7 days. After one week of incubation, 10ml of sample from primary enrichment was transferred to a fresh BHM broth. Unless otherwise stated, after 2nd enrichment 1 ml of medium was plated after appropriate dilution on BHM agar plate and incubated at 28ºC. After 48-hour incubation, pure colonies were isolated using streak plate method. All isolated microorganisms were stored at 4ºC for further uses. The screening of biodegradation potential was performed using DCPIP method (Montagnolli et al 2015). The organisms were cultivated on Bushnell Hass Broth for 48 h and exposed to different concentrations of Diesel oil in test tubes having a constant amount (0.5 g $L^{-1}$) of DCPIP at pH 7. The experiments were performed in sealed lid test tubes to sustain carbon dioxide saturation and block further aeration. The uninoculated tube serves as control for the study. Test tubes then incubated at 37°C at 180 rpm in digital shaking incubator. Continuous shaking ensured proper oxygen availability to maintain aerobic conditions. The reaction was observed visually till the end of incubation and also spectrophotometrically (600 nm) at an interval of 24 hrs using Elico SL-159 model UV visible spectrophotometer. Active bacterial culture able to reduce DCPIP results colour less cell solution which ultimately indicates 100 % cell biodegrading activity.

**Identification of Bacterial strain by 16S rRNA nucleotide sequencing**: Genomic DNA was extracted by Himedia Bacterial genomic DNA isolation kit. The quality of DNA was analysed by 1% agarose gel electrophoresis stained with ethidium bromide. Moreover, quantity of extracted DNA was measured in µg/µl by using ND-1000, USA, Nanodrop spectrophotometer at 260 nm and 280 nm. The purity of DNA was determined by calculating ratio of absorbance at 260-280nm. The purity of a particular DNA was assessed by considering the 260nm/280nm ratio comes near 1.8 and then DNA were diluted up to the concentration 50ng/µl. Afterwards, DNA was amplified through polymerase chain reaction (PCR), thermal cycler using the primers 16S rDNA (SENSE) 5'TAGGGAGGAAAGGTGTGAA3' (Tm: 54.5ºC) and 16S rDNA (ANTISENSE) 5'CTCTAGCTTGCCAGTCTT3' (Tm: 53.7ºC). PCR run at programme of 30 cycles and amplification was carried out as follows: 94ºC for 5 min, 94ºC for 30sec, 54ºC for 30 sec, 72ºC for 1:30 sec, 72ºC for 10 min and 4ºC incubation at the end of the final cycle. 1% of agarose gel electrophoresis was performed again with loaded DNA ladder (100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1500, 2000 and 3000 base pairs Bangalore Genei, India) for the analysis of yield of amplified product. The amplified DNA bands were then visualized in UV Trans illuminator and photograph was taken into gel documentation system (Alpha-Innotech, USA). The amplified fragment was then sequenced into Applied Bio systems 3500 genetic analyser, USA. The sequence was subjected to BLAST at NCBI (www.ncbi.nlm.nih.gov/blast). The estimation of sequence composition and phylogenetic tree construction was done by using MEGA software version 6.0.

**Gas chromatography/Mass spectrometry analysis:** Analysis of hydrocarbons present in diesel oil was carried out via GC/MS technique. 1 ml of extracted residual oil, after 7, 14, 21, 28, 35 days of incubation was used for the analysis of Gas Chromatography and Mass Spectrometry (GC-MS) (Shimadzu QP-2010 Plus with Thermal desorption system TD20).Volatile compounds present in a mixture are separated by Gas Chromatography. The separated compounds can be identified and quantified through Mass spectrometry. The gas chromatograph equipped with a split–split less injector (split ratios of 50:1) was used for the GC-MS analysis. The oven temperature was initially at 40°C and then programmed to 270°C at a rate of 8°C/min where it was held for 5 min. The temperatures of injector, transfer line and ionization source were all 250°C. The electron impact ionization was tuned at 70 eV and Helium was used as carrier gas with an average linear velocity of 1.0 mL/min.

## RESULTS AND DISCUSSIONS

**Isolation and characterization of *Klebsiella pneumoniae* strain VM18:** The isolate grew well on Bushnell Hass medium with 1% (v/v) diesel oil. The pure culture of microbe was obtained after successful enrichments to the medium. The microbial isolates are characterized morphologically on the basis of their size, shape, opacity, and pigmentation. *Klebsiella pneumoniae* rhizoid in shape having smooth texture. The opacity of the microbes was opaque with flat elevation and white pigmentation. 50µl of DNA stocks were prepared for further molecular analysis which was then diluted after determining the DNA concentrations. Integrity checking of extracted genomic DNA was high intensities of bands compared with Lambda DNA marker. Presence of highly resolved, high molecular weight band indicates good quality of the DNA. Quantity of the DNA was determined by measuring the absorbance at 260nm using spectrophotometer. 50ng/µl was considered as enough concentration for DNA amplification. The concentration of DNA obtained was 288.7, which is then diluted to attain the desired concentration by DNase RNase free water. The absorbance of protein was checked at 280nm, so the $A_{260}/A_{280}$ confirms the purity of the DNA. The ratio of absorbance at 260nm/280nm was found to be 1.67 signifies slight protein contamination which was purified later to acquire the desired value. Molecular sequencing of the conserved part of 16S rRNA gene reveals the most potent diesel oil degrading bacteria is *Klebsiella pneumoniae* strain VM18 which shows remarkable catabolic activity for petroleum hydrocarbons. Sequence similarities were found by aligning sequences through BLAST and identified the closest strains from NCBI database. The partial sequence of 16S rRNA gene of identified bacterial strain, has been deposited into Gene bank with the accession number MG928409 (Fig. 1).

**Preliminary Screening and Biodegradation Potential of *Klebsiella pneumoniae***: The strain showed the decent decolourization activity. The ODs taken at 600nm from 0 to 216 hrs with the interval of 24 hrs was 1.661 to 1.437 (Fig. 2). Growth rate of *Klebsiella pneumoniae* strain VM18 was also determined by taken ODs from 7 to 35 days of incubation at 620 nm through turbidometric

>MG928409.1 *Klebsiella pneumoniae* strain VM18 16S ribosomal RNA gene, partial sequence
ATGCAGTCGAGCGGTAGCACAGAGAGCTTGCTCTCGGGTGACGAGCGGCGGACGGGTGAGTAATGTCTGG
GAAACTGCCTGATGGAGGGGGATAACTACTGGAAACGGTAGCTAATACCGCATAATGTCGCAAGACCAAA
GTGGGGGACCTTCGGGCCTCATGCCATCAGATGTGCCCAGATGGGATTAGCTAGTAGGTGGGGTAACGGC
TCACCTAGGCGACGATCCCTAGCTGGTCTGAGAGGATGACCAGCCACACTGGAACTGAGACACGGTCCAG
ACTCCTACGGGAGGCAGCAGTGGGGAATATTGCACAATGGGCGCAAGCCTGATGCAGCCATGCCGCGTGT
GTGAAGAAGGCCTTCGGGTTGTAAAGCACTTTCAGCCGGGAG

**Fig. 1.** Nucleotide sequence of *Klebsiella pneumoniae* strain VM18 submitted in NCBI with Accession No. MG928409

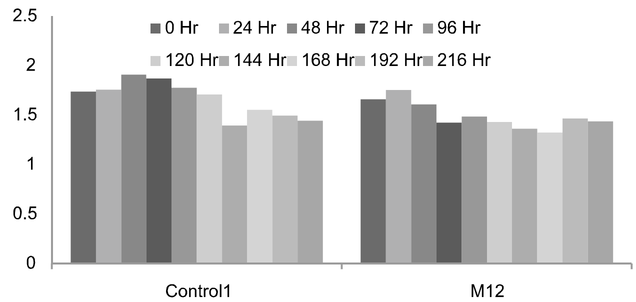


**Fig. 2.** Microbial growth at 620nm in DCPIP assay for *Klebsiella pneumoniae* strain VM18

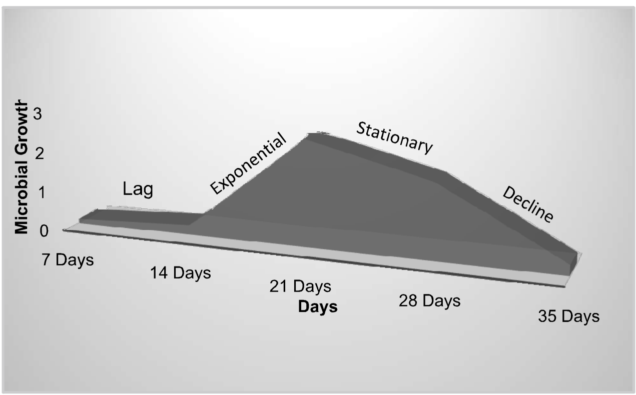


**Fig. 3.** Microbial growth curve of 14 potent Microbial isolates from 7 to 35 days of incubation at 620nm

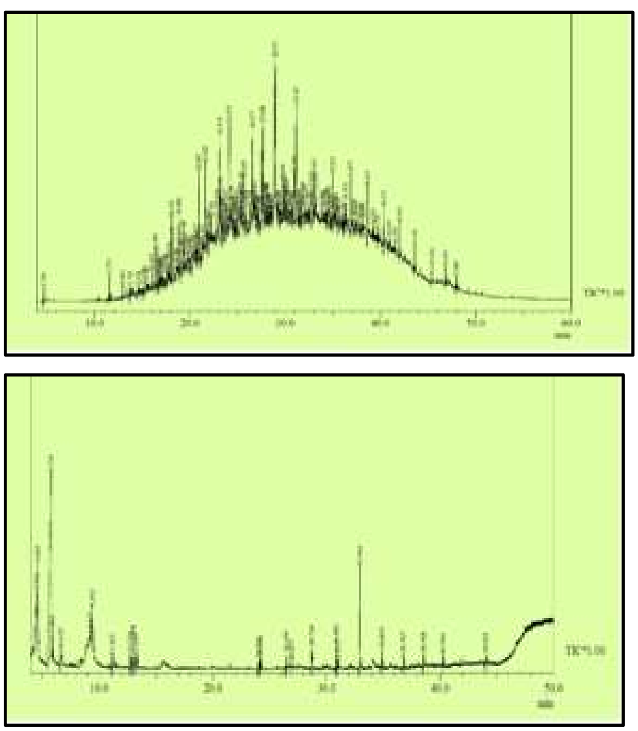

**Fig. 4.** GC-MS Chromatogram of Isolate *Klebsiella pneumoniae* after A) 7[th] day B) 35[th] day of incubation

method (Fig. 3). The degradation efficacy of *Klebsiella pneumoniae* strain VM18 is 62.84% after 35[th] day of incubation (Fig. 4). The major peaks of the isolate were observed of tetrapentacontane, tetratetracontane, tetracontane, pentriacontane at their retention times of 37.210, 34.160, 33.885 and 35.290 respectively. All these compounds present in diesel oil were degraded into butane, pentane, undecane, phenol, nonane, cyclobutanol and docosane.

The microbial strain was identified as *Klebsiella pneumoniae* strain VM18, through 16sRNA sequencing. It is a gram-negative, nonmotile, rod-shaped bacterium with a prominent polysaccharide-based capsule, belongs to family *Enterobacteriaceae.* There are number of strains of *Klebsiella pneumoniae* involved in biodegradation of petroleum hydrocarbons (Zafra et al 2016, Wokem et al 2017, Rajkumari et al 2018). *Klebsiella pneumoniae* strain VM18 degrades diesel oil into compound like butane, pentane, nonane. Similar results were obtained by Rodrigues et al (2009). *Klebsiella pneumoniae* strain VM18 had degraded 62.84% hydrocarbons. However in previous results, *Klebsiella pneumoniae* CR23 degrade 58% of engine oil and 59.7% of petroleum refinery effluent (Oaikhena et al. 2016, Adeleye et al 2018). This might be due to petroleum composition of engine oil, diesel oil and petroleum effluent, environmental conditions or the metabolic activity of microbial strain (Ozyurek and Bilkay (2017) GC-MS analysis reveals that, *Klebsiella pneumoniae* strain VM18 degraded $C_{51}$-$C_{60}$ fraction from 2.54 to 1.49% and converted them into $C_{31}$-$C_{50}$ after 21 days of incubation. It completely removed carbon chain length from $C_{31}$-$C_{50}$ after 35 days of incubation. These results revealed that higher molecular weight hydrocarbons take longer time to degrade and persist in environment (Kanaly and Harayama 2000). *Klebsiella* Sp. considered as a potent biodegrader of petroleum hydrocarbons but it takes longer time to degrade higher molecular weight hydrocarbons. This might be due to physical properties of long hydrophobic carbon chain. As the chain increase their solubility decrease due to increase in hydrophobicity (Zander 1983). The results of GC-MS analysis also confirmed that, *K. pneumoniae* strain VM18 was efficiently degraded $C_{11}$-C30 up to 46% to 50% after 28 days of incubation.

## CONCLUSION

*Klebsiella pneumoniae* strain VM18 is capable to utilize the diesel oil as an energy source. The capability to degrade diesel oil makes it a potential degrader and can be considered as bioremediation tool. However, individual organisms often prefer to metabolize a limited range of hydrocarbon substrates. Several microorganisms are not able to function when cultured in environment so it required more research particular in this field.

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# Influence of Planting Geometry and Nitrogen Levels on Nutrient Content, Uptake and Soil Fertility Status in Scented Rice (*Oryza sativa* L.)

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***Abstract***: An experiment was carried out during *kharif* 2018 at Research Farm, College of Agriculture, Kaul (Kaithal) to study the influence of planting geometry and nitrogen levels on nutrient (N, P and K) content, uptake and soil fertility status under scented rice (Pusa 1121). The experiment was conducted using split plot design with four replications having three planting geometry in main plots and five nitrogen levels in sub plots. Grain and straw yield were significantly higher at 20 cm x 15 cm and 120 kg N/ha. N, P and K concentrations in grain and straw were non-significant with planting geometry. However, these concentration increases significantly with increase in nitrogen level and maximum at 120 kg N/ha. N, P and K uptake by both grain and straw were significant at planting geometry 20 cm x 15 cm and nitrogen rate of 120 kg/ha. The available N, $P_2O_5$ and $K_2O$ of experimental field before cultivation were 163, 27 and 379 kg/ha, respectively. N, $P_2O_5$ and $K_2O$ content in soil after cultivation was higher under 30 cm x 20 cm. However, N content in soil after cultivation was maximum at 120 kg N/ha, but $P_2O_5$ and $K_2O$ content was in control.

***Keywords:*** Scented rice, Planting geometry, Nitrogen levels, Soil fertility

Rice (*Oryza sativa* L.) is the most important cereal food crop of the developing world and staple food for more than three billion people. Mainly two types of rice *i.e.*, non scented and scented are grown in the country. Scented rice gives a distinctive scent due to the presence of natural chemical compounds and having unique quality features, excellent cooking and eating quality characters. Apart from special natural fragrance, scented rice also has high nutritional value and contains many kinds of amino acids, proteins, alkaloids, vitamin $B_1$ and $B_2$ and other essential nutrients for human beings (Shen et al 2016). The increased rice production might be due to the adoption of high yielding varieties, use of chemical fertilizers and increase in irrigated area from last few decades. For yield and quality increment and also for maintaining soil quality, sustainable technologies are highly essential which may include cost minimization by saving resources and adoption of low cost or non-monetary inputs (Haque et al 2016). Hence crop management practices like judicious application of nitrogen fertilizer and maintenance of planting geometry are of prime importance in rice crop production. Nitrogen is an imperative limiting nutrient in almost all Indian soils and also for rice crop growth in all environments. Since, 75 % of leaf nitrogen is associated with chloroplast, it is very essential in rice which physiologically helps in dry matter production through photosynthesis. Apart from enhancing growth, it also benefits the quality of crop by improving the concentration of nutrients in the vegetative mass and boosting the uptake of nutrients. It also involved in synergistic mechanism with few essential nutrients and improving their efficiency to the benefit of crop and maintaining soil quality (Kabat and Satapathy 2011). Planting geometry and spatial configuration exploit the initial vigour of the genotypes with enhanced soil aeration creating favourable condition for better crop establishment (Shukla et al 2014). Optimum planting geometry measures the optimum plant density that ensures the plant to grow properly with their aerial and underground parts by utilizing more solar radiation and optimum soil nutrients and also helps in maintaining the nutrient status of crop and soil after the cultivation. Hence, planting geometry is directly or indirectly responsible for the nutrients uptake especially nitrogen, phosphorous and potassium in the rice crop apart from maintaining soil nutrient balance. Hence by knowing the importance of nitrogen and planting geometry, an experiment was conducted to study the effect of nitrogen levels and planting geometry on nutrient (N, P and K) content, uptake and soil fertility status under scented rice (Pusa 1121).

## MATERIAL AND METHODS

**Experimental site:** A field experiment was conducted at Research Farm, College of Agriculture, Kaul (Haryana) during *kharif* season of 2018 which is situated at 29° 51' N latitude and 76° 41' E longitude, with an altitude of 241 m above mean sea level. The region is characterized by sub-humid climate with desiccating hot winds of average velocity during summer and severe cold winds during winter. The mean weekly meteorological data of crop season *kharif* 2018 was recorded at meteorological observatory, College of Agriculture, Kaul (Fig. 1). The experimental field soil was sandy clay loam in texture. The soil was medium in organic C (5.4 g/kg), low in available N (163 kg/ha), medium in available $P_2O_5$ (27 kg/ha) and high in available $K_2O$ (379 kg/ha) with pH of 7.7 and EC 0.29 dS/m.

**Treatment details and crop management:** The experiment was carried out in split-plot design having fifteen treatment combinations including three planting geometry *viz.*, 20 cm x 15 cm, 30 cm x 15 cm and 30 cm x 20 cm in main plots and five nitrogen levels *viz*., control (0 kg/ha), 30 kg/ha, 60 kg/ha, 90 kg/ha and 120 kg/ha in subplots with four replications. An extra-ordinary scented rice variety Pusa 1121 was used as experimental material and urea as a nitrogen source in the experiment. The nursery was raised in the field itself using seed rate of 40-50 g/m$^2$ area and the field was puddled thoroughly at the time of transplanting. The 30 days old seedlings were transplanted manually in the experimental field keeping main plot treatments of different planting geometry with 2 seedlings per hill. At the time of transplanting, half dose of each level of nitrogen along with 60 kg $P_2O_5$/ha and 25 kg zinc sulphate ($ZnSO_4$) per ha were applied in their respective sub plots. Remaining doses of each level of nitrogen for their respective sub plots were applied in two splits, first at 20 days after transplanting (DAT) and second at 40 DAT as top dressing. Other agronomic practices were followed as per the standard package of practices in rice cultivation.

**Plant sample analysis:** The samples of grain and straw were collected through destructive plant sampling and dried properly and then ground to digest them with di-acid mixture of $H_2SO_4$ and $HClO_4$ for the estimation of total nitrogen through Nessler's Reagent Method (Linder 1944). Phosphorus and potassium were estimated by digesting the grain and straw sample in di-acid mixture of $HNO_3$ and $HClO_4$ through vanadomolybdophosphoric by Yellow Color Method (Koening and Johnson, 1942) and Flame Photometer Method (Piper 1966), respectively. The harvested crop from each treatment plot were threshed and then weighed separately to record grain and straw yield per plotafter drying and expressed per hectare. N, P and K uptake by grain and straw were determined in kg/ha by using grain and straw yield, respectively as per the following formulas:

$$\text{Nutrient uptake by grain (kg/ha)} = \frac{\text{Nutrient content in gram (\%)} \times \text{Grain yield (kg/ha)}}{100}$$

$$\text{Nutrient uptake by straw (kg/ha)} = \frac{\text{Nutrient content in straw (\%)} \times \text{Straw yield (kg/ha)}}{100}$$

**Soil sample analysis:** The soil samples were collected from the experimental field of 0-15 cm depth soil from 10 different

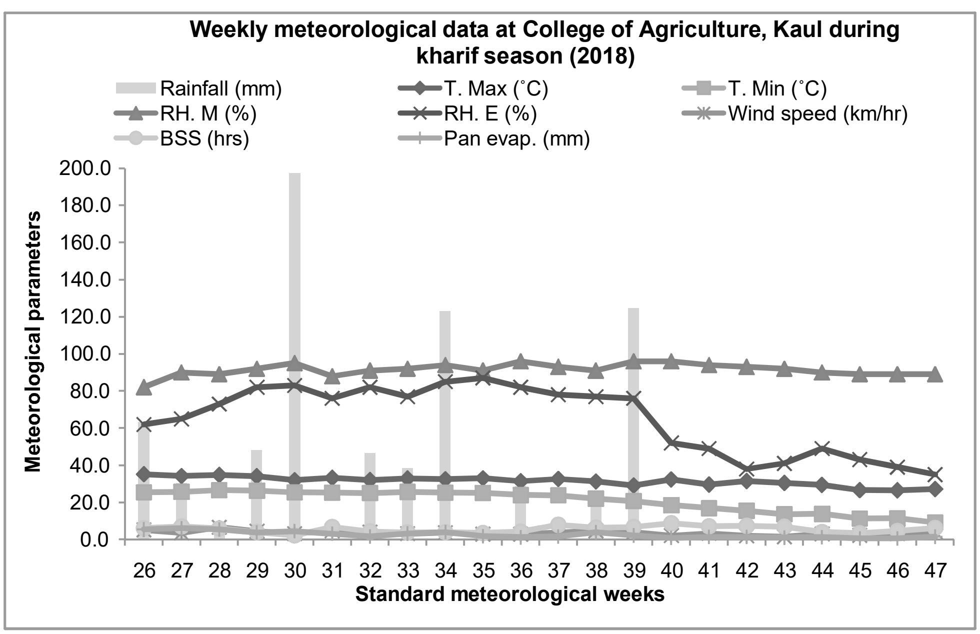


**Fig. 1.** Weekly meteorological data at College of Agriculture, Kaul during *kharif* season (2018)

spots in zig-zag pattern before cultivation and also collected from all experimental plots of different treatments after harvesting the rice crop and these samples were dried under shade, grounded gently with the help of mortar to pass through 2 mm sieve. Finally, soil samples were subjected to chemical analysis as per the standard analytical procedures. The available nitrogen was determined by alkaline permanganate Method (Subbaiah and Asija 1956), available phosphorus was determined by Olsen's Method (Olsen et al 1954) and available potassium was determined by Flame Photometer Method (Jackson 1973).

**Statistical analysis:** The experimental data obtained were statistically analyzed by using standard procedure to determine the significance of difference between treatment means.

## RESULTS AND DISCUSSION

**Grain and straw yield:** Significant response was observed for grain and straw yield under varying planting geometry and nitrogen rates as depicted in Figure 2. Among planting geometry, 20 cm x 15 cm recorded significantly higher grain (4394 kg/ha) and straw yield (5939 kg/ha) as compared to 30 cm x 15 cm and 30 cm x 20 cm. This was due to higher number of effective tillers, dry matter accumulation and higher plant population under narrow geometry. Similar findings were published by Das et al (2013). The rate of increase in grain and straw yield was more up to 30 kg N/ha and reached to maximum at 120 kg N/ha (4458 and 5829 kg/ha, respectively) which was significantly higher over remaining nitrogen levels except the fact that grain yield at 120 kg N/ha was statistically at par with 90 kg N/ha. This trend of increasing grain and straw yield with increase in nitrogen rates was due to better overall growth of plants under higher nitrogen levels. Similar pattern of results were reported by Dubey et al (2016) and Narayan et al (2017).

**N, P and K content in grain and straw:** The effect of planting geometry was non-significant on nitrogen (N), phosphorus (P) and potassium (K) content in grain and straw but N, P and K concentration in grain and straw increased significantly with successive increment in nitrogen level (Table 1). However, higher concentration of N, P and K in grain (0.93, 0.18 and 0.43 %, respectively) and straw (0.52, 0.14 and 1.25 %, respectively) were at planting geometry of 20 cm x 15 cm. The similar results were reported by the findings of Singh et al (2013). Among nitrogen levels, higher concentration of N and K in grain (1.10 and 0.52 %, respectively) and straw (0.64 and 1.41 %, respectively) were at 120 kg N/ha which were significantly higher than lower concentration and control. The higher P concentration in grain (0.22 %) and straw (0.18 %) was also at 120 kg N/ha which was statistically at par with nitrogen level of 90 kg/ha but significantly higher than the concentration at 60 and 30 kg N/ha and control. The higher N, P and K concentration at higher nitrogen level was due to more nitrogen input and synergistic interaction between N, P and K. The results were similar to the findings of (Kabat and Satapathy 2011).

**N, P and K uptake by grain and straw:** N, P and K uptake by grain and straw influenced significantly with planting geometry and nitrogen levels (Table 2). N, P and K uptake by grain and straw decreased with increase in planting geometry. Maximum N and K uptake by grain (42.0 and 19.2 kg/ha, respectively) were with planting geometry of 20 cm x 15 cm which was significantly higher than 30 cm x 15 cm and 30 cm x 20 cm. P uptake by grain was also higher (8.3 kg/ha)

**Table 1.** Nutrient (N, P and K) content of scented rice as affected by planting geometry and nitrogen levels

| Treatments | N, P and K content in grain (%) | | | N, P and K content in straw (%) | | |
|---|---|---|---|---|---|---|
| | N | P | K | N | P | K |
| Planting geometry | | | | | | |
| 20 cm x 15 cm | 0.93 | 0.18 | 0.43 | 0.52 | 0.14 | 1.25 |
| 30 cm x 15 cm | 0.91 | 0.17 | 0.42 | 0.51 | 0.13 | 1.23 |
| 30 cm x 20 cm | 0.90 | 0.16 | 0.41 | 0.50 | 0.13 | 1.21 |
| CD (p=0.05) | NS | NS | NS | NS | NS | NS |
| Nitrogen levels (kg/ha) | | | | | | |
| Control | 0.71 | 0.11 | 0.31 | 0.35 | 0.08 | 0.98 |
| 30 | 0.81 | 0.16 | 0.37 | 0.44 | 0.11 | 1.17 |
| 60 | 0.93 | 0.18 | 0.42 | 0.53 | 0.14 | 1.26 |
| 90 | 1.02 | 0.20 | 0.48 | 0.59 | 0.17 | 1.35 |
| 120 | 1.10 | 0.22 | 0.52 | 0.64 | 0.18 | 1.41 |
| CD (p=0.05) | 0.04 | 0.02 | 0.03 | 0.03 | 0.02 | 0.04 |

than planting geometry of 20 cm x 15 cm, but it was statistically at par with 30 cm x 15 cm and significantly higher than the 30 cm x 20 cm. Maximum N and P uptake by straw (31.1 and 8.7 kg/ha, respectively) were with planting geometry of 20 cm x 15 cm which were statistically at par with 30 cm x 15 cm and significantly higher as compared to 30 cm x 20 cm. K uptake by straw was also higher (75.0 kg/ha) with planting geometry of 20 cm x 15 cm which was significantly more than the K uptake by straw with planting geometry of 30 cm x 15 cm and 30 cm x 20 cm. N, P and K uptake by grain and straw was higher at closer planting geometry of 20 cm x 15 cm because of higher grain and straw yield. These results were also supported by Bommayasamy et al (2010). N, P and K uptake by grain and straw at different nitrogen levels showed that it increased significantly with each increment in nitrogen level. Maximum N, P and K uptake by grain (49.2, 9.8 and 23.0 kg/ha, respectively) were at 120 kg N/ha which were significantly higher when compared with the N, P and K uptake by grain at 90, 60, 30 kg N/ha and control. Maximum N and K uptake by straw were at 120 kg N/ha which were significantly higher than N and K uptake at 90, 60, 30 kg N/ha and control. P uptake by straw was also higher (10.6 kg/ha) at 120 kg N/ha, but it was statistically at par with P uptake by straw at 90 kg N/ha and significantly higher than the P uptake at 60, 30 kg N/ha and control. Higher N, P and K uptake was with higher nitrogen level at 120 kg/ha due to improved growth of above and below ground plant parts and higher grain and straw yield. This finding was similar to the earlier findings (Majumdar et al 2005, Oq et al 2007, and Singh et al 2015).

**Available N, $P_2O_5$ and $K_2O$ status of soil before and after cultivation:** The available N, $P_2O_5$ and $K_2O$ of experimental

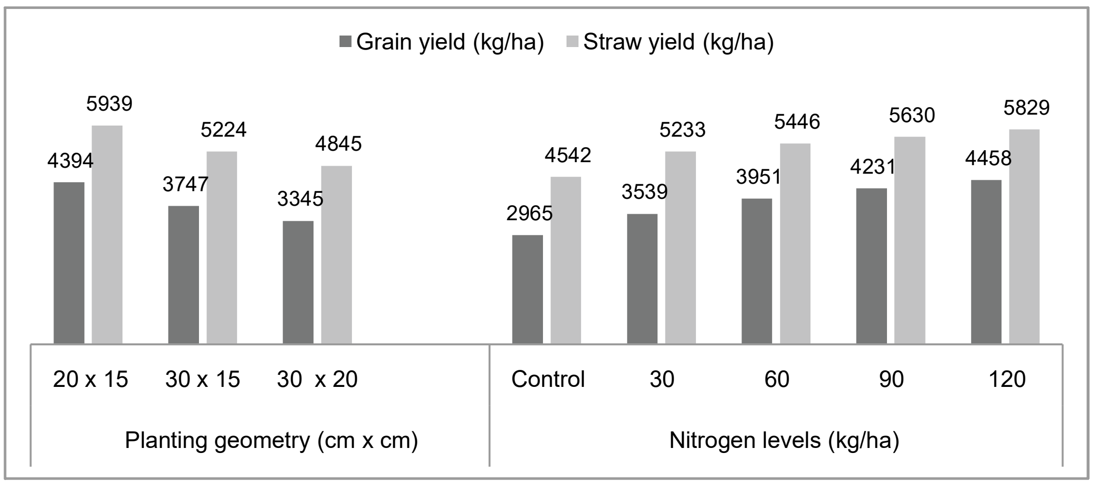


**Fig. 2.** Grain and straw yield as influenced by planting geometry and nitrogen levels

**Table 2.** Nutrient (N, P and K) uptake by scented rice as affected by planting geometry and nitrogen levels

| Treatments | N, P and K uptake by grain (kg/ha) | | | N, P and K uptake by straw (kg/ha) | | |
|---|---|---|---|---|---|---|
| | N | P | K | N | P | K |
| Planting geometry | | | | | | |
| 20 cm x 15 cm | 42.0 | 8.3 | 19.2 | 31.1 | 8.7 | 75.0 |
| 30 cm x 15 cm | 35.0 | 6.6 | 16.0 | 27.0 | 7.1 | 65.0 |
| 30 cm x 20 cm | 30.4 | 5.6 | 13.9 | 24.6 | 6.6 | 59.5 |
| CD (p=0.05) | 5.7 | 1.7 | 3.0 | 4.3 | 1.7 | 9.6 |
| Nitrogen levels (kg/ha) | | | | | | |
| Control | 21.0 | 3.2 | 9.0 | 15.7 | 3.6 | 44.8 |
| 30 | 28.8 | 5.5 | 13.0 | 23.2 | 6.0 | 61.0 |
| 60 | 36.7 | 7.1 | 16.5 | 28.6 | 7.7 | 68.7 |
| 90 | 43.1 | 8.5 | 20.1 | 33.2 | 9.4 | 75.9 |
| 120 | 49.2 | 9.8 | 23.0 | 37.1 | 10.6 | 82.1 |
| CD (p=0.05) | 3.2 | 1.1 | 1.7 | 2.8 | 1.3 | 5.2 |

**Table 3.** Nutrient (N, $P_2O_5$ and $K_2O$) status of soil after cultivation of scented rice as affected by planting geometry and nitrogen levels

| Treatments | N, $P_2O_5$ and $K_2O$ status of soil after cultivation (kg/ha) | | |
|---|---|---|---|
| | N | $P_2O_5$ | $K_2O$ |
| Planting geometry | | | |
| 20 cm x 15 cm | 106.7 | 8.9 | 142.3 |
| 30 cm x 15 cm | 119.9 | 9.1 | 145.1 |
| 30 cm x 20 cm | 132.8 | 9.3 | 148.1 |
| CD (p=0.05) | 2.3 | 0.1 | 2.2 |
| Nitrogen levels (kg/ha) | | | |
| Control | 102.0 | 10.4 | 152.1 |
| 30 | 110.1 | 9.8 | 150.2 |
| 60 | 121.2 | 9.1 | 144.9 |
| 90 | 129.3 | 8.3 | 141.3 |
| 120 | 136.4 | 7.9 | 137.2 |
| CD (p=0.05) | 1.6 | 0.2 | 1.8 |

field before cultivation were 163, 27 and 379 kg/ha, respectively. The effect of planting geometry and nitrogen levels were significant on available N, $P_2O_5$ and $K_2O$ of soil after cultivation of scented rice (Table 3). Among planting geometry, higher available N, $P_2O_5$ and $K_2O$ in soil after cultivation (132.8, 9.3 and 148.1 kg/ha, respectively) were at wider planting geometry of 30 cm x 20 cm which were significantly higher than 30 cm x 15 cm and 20 cm x 15 cm. Available N, $P_2O_5$and $K_2O$ content in soil after cultivation were higher under wider planting geometry of 30 cm x 20 cm might be due to lesser uptake of nutrients by the crop under wider planting geometry because of less number of populations per unit area. The higher available N in soil after cultivation (136.4 kg/ha) was at 120 kg N/hawhich was significantly higher than 90, 60, 30 kg N/haand control. Available $P_2O_5$ and $K_2O$ of soil were higher (10.4 and 152.1 kg/ha, respectively) at control which were significantly higher than 30, 60, 90 and 120 kg N/ha. The condition in which available N content in soil after cultivation was also higher at 120 kg N/ha, but P and K content was higher at control might be due to increasing nutrients uptake with increase in nitrogen level. Similar results were also reported by Sikdar et al (2008) and Singh et al 2010).

## CONCLUSIONS

The maximum amount of N, P and K content in grain and straw were with 120 kg N/ha but revealed non-significant response with planting geometry. N, P and K uptake by grain and straw were maximum with closer planting geometry of 20 cm x 15 cm at 120 kg N/ha. In case of available nutrient content after cultivation of scented rice, maximum available N, $P_2O_5$ and $K_2O$ with wider planting geometry of 30 cm x 20 cm. However, maximum available N was recorded at 120 kg N/ha but available $P_2O_5$ and $K_2O$ content was higher at control.

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# Effect of Zinc as Foliar Application on Seed Yield in Radish

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***Abstract*:** A field experiment was conducted to study the effect of zinc as foliar application on seed yield and quality in radish which was carried out in Pandah farm of Department of Seed Science and Technology, Dr YS Parmar University of Horticulture and Forestry Nauni, Solan during 2018-19. Treatments involved four zinc levels ( 0g $l^{-1}$, 1g $l^{-1}$, 2g $l^{-1}$, 3g $l^{-1}$) and three stages of application (Bolting, Bolting +14 days after first application, Bolting +14 days + 28 days after first application) resulting in 12 treatment combinations. $Zn_3S_1$(2g/L zinc at the time of bolting) was found superior over all the treatment combinations for growth and seed yield parameters viz: plant height (118.92 cm), number of siliquae plant$^{-1}$ (146.40), siliqua length (7.09 cm), number of seeds siliqua$^{-1}$ (6.34), days to maturity (104.67), average seed weight siliqua$^{-1}$(0.185 g), seed yield plant$^{-1}$(27.03 kg) and seed yield ha$^{-1}$(9.90 q ha$^{-1}$).

***Keywords*:** Radish, Micronutrient, Zinc, Foliar application, Seed yield

Radish is an important root crop of cruciferae family and is cultivated in tropical as well as temperate regions of the world and is native of Europe and Asia. The production of seed per unit area in radish is low which might be increased by improved management practices conventionally by foliar application of micronutrients. The micronutrients play an important role in germination and seedling formation from cell wall development to respiration, photosynthesis, chlorophyll formation etc. The uptake of all the plant nutrients is hastened by the application of micronutrients and they also generate the mechanism against insect-pests and diseases, therefore improving growth and yield (Anuprita et al 2005). The requirement of the micronutrients is very diminutive but its deficiency can limit the growth and production. Foliar spray is latest method for nourishment of crops, usually of micronutrients applied to leaves in liquid form. Efficacy of foliar spray is 6 to 20 times more in comparison to soil application (Arif et al 2006). Micronutrients like zinc play an important role in growth and plant development and production of biomass as it is vital for the formation of Indole Acetic Acid (IAA). It also helps in energy production, protein and growth regulator synthesis (Kumar et al 2016) and is necessary in pollen development, sexual fertilization and germination (Cakmak 2008), higher seed yield and number of seeds fruit$^{-1}$. It also enhances growth hormone biosynthesis, formation of starch, production and maturation of seeds (Brady and Weil, 2002). Zinc also increases the viability as well as vigour of seed. It is an essential part of ribosome and is important for their structural integrity (Trivedi, 2013). Zinc has many insignificant roles in the growth of plant and a regular and continuous supply is required for better growth and maximum yield (Acquaah, 2002). The form of zinc available to plants is the $Zn^{2+}$ ion. Zinc applied through foliar spray is more effective than soil application due to its adsorption with soil particles and lesser contact with roots of crop (Wissuwa et al 2008).

## MATERIAL AND METHODS

The investigation was carried out at Panda Farm of the Department of Seed Science and Technology, Nauni, Solan during 2018-19. Research Farm is situated at an altitude of 1250 meters above mean sea level in the mid-hill zone of Himachal Pradesh. The climate of the area is sub-tropical to sub-temperate and semi-humid characterized by cold winters. The Research Farm had loam to clay loam type of soil with pH from 6.85-7.05.The seeds were sown in September on the raised beds. All the measures were taken during the production of the roots as per Package of Practices recommended by Dr Yashwant Singh Parmar, University of Horticulture and Forestry, Nauni (Anonymous, 2014). Fully matured roots were uprooted carefully in the month of January in year 2019. True to type roots were selected according to the characteristics of the variety (Japanese White). The roots which were diseased, deformed, forked, split and over matured were discarded for preparation of the stecklings. Stecklings were prepared by keeping 10 cm portion at the top and 10 cm root portion. The prepared stecklings were transplanted in the month of

January on the flat beds of size 3.0 × 1.8 m at spacing of 60 × 30 cm. Four different levels of zinc were used viz. 0g $l^{-1}$, 1g $l^{-1}$, 2g $l^{-1}$, 3g $l^{-1}$ and stages of application were Bolting, Bolting + 14 days after first application, Bolting + 14 days and 28 days after first application.

Plant height of the ten randomly selected plants was recorded from the soil level to the tip of the plant at the end of the crop season with the help of a scale and mean height was expressed in centimetres. Days to seed maturity were counted from the date of sowing to fully develop mature pods for getting seeds. The number of siliqua from each harvest of ten randomly selected plants were counted and averaged to work out mean number of pods plant$^{-1}$. Length of ten randomly selected healthy siliqua was measured from the point of attachment to the tip of pod with the help of a scale. The siliqua used for measuring siliqua length were shelled for counting the seeds and the mean value of seeds pod$^{-1}$ was determined. In each replication, 100 seeds were counted with the help of an electronic counter from the total seed produced in each plot and were weighed on electronic balance to record the weight. For seed yield per plant, ten plants randomly selected from each replication per treatment for pod characters were harvested at complete physiological maturity stage, and thus obtained seeds properly dried in shade. The seeds were cleaned properly and weighed with the help of an electronic balance and average was worked out. Seed yield per hectare was worked out on the basis of seed obtained per m$^2$ as per the formula:

$$\text{Seed yield ha}^{-1}\text{ (q)} = \frac{\text{Seed yield/m}^2\text{ (kg)} \times 8000}{100}$$

While calculating the seed yield per hectare, twenty per cent area was considered as depreciation for construction of channels in the field.

## RESULTS AND DISCUSSION

**Plant height**: The zinc levels, stages of application and their interaction significantly influenced the plant height (Table 1). The maximum plant height (110.90 cm) was observed in $Zn_3$ and thereafter there was a decrease in plant height at $Zn_4$. Minimum plant height was recorded in $Zn_1$ (Water spray). Zinc increases the height of plant due to its involvement in chlorophyll formation which might help in cell division, expansion of cell and formation of cell wall. It is also engaged in synthesis of tryptophan a major precursor of IAA (indole acetic acid) responsible for synthesis of amino acid favouring plant growth. The decrease in plant height might be due to high inflation of zinc which retarded the growth of the plant and development of roots (Wang et al 2009) through a reduction in mitotic index as a result of restraint of DNA synthesis. Among stages of application, maximum plant height (105.70cm) was in $S_1$ (Bolting) and with every subsequent spray, there was a decrease in plant height and minimum plant height (99.44 cm) was in $S_3$. In case of interaction, maximum plant height was observed in $Zn_3S_1$ and minimum (89.33 cm) in $Zn_1S_3$. Similar result was obtained by Pariari et al (2009) in fenugreek

**Number of siliquae plant$^{-1}$**: Number of siliques plant$^{-1}$ was significantly influenced by zinc levels, stages of application and their interaction (Table 1). Maximum number of siliques plant$^{-1}$ (118.11) was in $Zn_3$ (2g $l^{-1}$) and after that there was a significant decrease in number of siliques plant$^{-1}$ in $Zn_4$. Increased number of siliques plant$^{-1}$ may be due to the reason that zinc is responsible for more number of new filling sinks which affects the mitochondrial activities of the plant and increases photosynthetic rate which ensure higher translocation and assimilation of metabolites in the sink (Singh et al 2015). In stages of application, $S_1$ (Bolting) revealed maximum number of siliques plant$^{-1}$ (124.08) and there was a decrease in number of siliques plant$^{-1}$ with every stage of application and minimum (99.26) was recorded in $S_3$. Zinc applied at bolting stage might have increased silique number attributably to high rate of protein synthesis and metabolism of carbohydrates during bolting stage which is directly involved in increasing number of siliques plant$^{-1}$. Among the interactions, maximum number of siliques plant$^{-1}$ (146.40) was observed in $Zn_3S_1$ and minimum (77.73) was in $Zn_1S_3$.

**Siliqua length (cm)**: Zinc levels, stages of application and their interaction significantly affected the siliqua length (Table 1). Linear increase in siliqua length (6.48 cm) was noticed in up to $Zn_3$ and after that a decrease in siliqua length was observed in $Zn_4$. The increase in siliqua length might be due to the reason that zinc is convoluted in synthesis of tryptophan which is a precursor of growth promoting hormone (auxins) and leads to growth and development of cells and finally resulted in increased silique length (Krishna, 2000). In stages of application, $S_1$ revealed maximum siliqua length (6.43 cm) and minimum (6.13 cm) was observed in $S_3$. Maximum siliqua length during bolting stage might be due to more tryptophan synthesis which enhances the auxin production and resulted in increased siliqua length. The $Zn_3S_1$ recorded maximum siliqua length (7.09 cm) and minimum (5.86 cm) was observed in $Zn_1S_1$. The above findings are in line with Pariari et al (2009) in fenugreek.

**Number of seeds siliqua$^{-1}$**: Zinc levels and stages of application significantly affected zinc levels, maximum number of seeds silique$^{-1}$ (5.58) was observed in $Zn_3$ which was at par with $Zn_4$ and minimum (4.47) was in $Zn_1$. Among stages of application, maximum number of seeds silique$^{-1}$ (5.36) was recorded in $S_1$ which was at par with $S_2$ and minimum (4.92) was obtained in $S_3$.

**Average seed weight siliqua$^{-1}$(g):** Among zinc levels, maximum average seed weight silique$^{-1}$ (0.171 g) was in $Zn_3$ (2g $l^{-1}$) which was at par with $Zn_2$ and minimum (0.158 g) was in Zn) (Table 2). Zinc is known to upgrade the biosynthesis of growth hormones, formation and maturation of starch which eventually increased average seed weight (Tariq et al 2014). Among stages of application, maximum average seed weight siliqua$^{-1}$ (0.171 g) was in $S_1$ and minimum (0.162 g) was in $S_3$, which was at par with $S_2$. Zinc at bolting might have increased the starch content in the seed because of its increased synthesis that resulted in development of seeds and led to maximum average seed weight silique$^{-1}$. Among treatment combinations, maximum weight of seed silique$^{-1}$ (0.185 g) was in $Zn_3S_1$ and minimum (0.156 g) was in $Zn_1S_1$ being statistically at par with $Zn_1S_1$ and $Zn_1S_2$.

**Days to seed maturity:** Minimum days to seed maturity (109.78) was when zinc was applied @ 2g $l^{-1}$ ($Zn_3$) being significantly different from other levels of zinc while maximum days to seed maturity (119.67) were observed in $Zn_1$ (Water spray) (Table 2). In case of stages of application, significantly minimum days to seed maturity (110.00) were in $S_1$ and maximum (116.58) in 3$^{rd}$ stage. In case of treatment combinations, minimum days to seed maturity (104.67) were in $Zn_3S_1$ being significantly lower than other treatment combinations, whereas, maximum days to seed maturity (120.00) were observed in $Zn_1S_3$ (which had statistical similarity with $Zn_1S_1$ and $Zn_1S_2$.

**Seed yield plant$^{-1}$ (g)**: The increase in seed yield (20.08 g plant$^{-1}$) was noticed up to $Zn_3$ level of zinc (2g $l^{-1}$) and a significant reduction was then observed in $Zn_4$ with a minimum seed yield of 13.65 g plant$^{-1}$ in $Zn_1$ (Table 2). Foliar application of zinc also played a significant role in enhancing seed yield potential as zinc applied through foliar sprays brings vast changes in different metabolic processes within the plant system. In case of stages of application, maximum seed yield (21.35 g plant$^{-1}$) was in $S_1$ and thereafter there was a sharp reduction in seed yield at successive stages, being

**Table 1.** Effect of foliar application of zinc, stages of application and their interaction on growth parameters in radish

| Factors | Plant height (cm) | Number of siliquae plant$^{-1}$ | Siliqua length (cm) | Number of seeds siliqua$^{-1}$ |
|---|---|---|---|---|
| Zinc levels | | | | |
| $Zn_1$ | 91.76 | 86.93 | 5.99 | 4.47 |
| $Zn_2$ | 106.90 | 113.40 | 6.28 | 5.20 |
| $Zn_3$ | 110.90 | 118.11 | 6.48 | 5.58 |
| $Zn_4$ | 102.60 | 113.70 | 6.19 | 5.23 |
| CD (p=0.05) | 0.92 | 1.39 | 0.06 | 0.36 |
| Stages of application (S) | | | | |
| $S_1$ | 105.70 | 124.08 | 6.43 | 5.36 |
| $S_2$ | 103.99 | 100.77 | 6.15 | 5.08 |
| $S_3$ | 99.44 | 99.26 | 6.13 | 4.92 |
| CD (p=0.05) | 0.80 | 1.21 | 0.05 | 0.31 |
| Interaction Zn× S | | | | |
| $Zn_1S_1$ | 90.82 | 93.53 | 5.86 | 4.50 |
| $Zn_1S_2$ | 95.15 | 89.53 | 6.04 | 4.50 |
| $Zn_1S_3$ | 89.33 | 77.73 | 6.06 | 4.40 |
| $Zn_2S_1$ | 106.27 | 132.83 | 6.44 | 5.20 |
| $Zn_2S_2$ | 107.33 | 104.13 | 6.26 | 5.30 |
| $Zn_2S_3$ | 107.10 | 103.23 | 6.13 | 5.10 |
| $Zn_3S_1$ | 118.92 | 146.40 | 7.09 | 6.34 |
| $Zn_3S_2$ | 113.34 | 108.33 | 6.13 | 5.23 |
| $Zn_3S_3$ | 100.44 | 99.60 | 6.23 | 5.17 |
| $Zn_4S_1$ | 106.77 | 123.57 | 6.33 | 5.40 |
| $Zn_4S_2$ | 100.13 | 101.07 | 6.16 | 5.30 |
| $Zn_4S_3$ | 100.89 | 116.47 | 6.09 | 5.00 |
| CD (p=0.05) | 1.59 | 2.41 | 0.11 | NS |

**Table 2.** Effect of foliar application of zinc, stages of application and their interaction on seed parameters in radish

| Factors | Average seed weight siliqua$^{-1}$ (g) | Days to seed maturity | Seed yield plant$^{-1}$ (g) | Seed yield ha$^{-1}$ (q) |
|---|---|---|---|---|
| Zinc levels (Zn) | | | | |
| $Zn_1$ | 0.158 | 119.67 | 13.65 | 6.76 |
| $Zn_2$ | 0.169 | 110.00 | 19.23 | 8.30 |
| Zn3 | 0.171 | 109.78 | 20.08 | 8.76 |
| $Zn_4$ | 0.164 | 112.22 | 18.61 | 8.18 |
| CD (p=0.05) | 0.003 | 1.15 | 0.58 | 0.37 |
| Stages of application (S) | | | | |
| $S_1$ | 0.171 | 110.00 | 21.35 | 8.63 |
| $S_2$ | 0.164 | 112.16 | 16.25 | 7.85 |
| $S_3$ | 0.162 | 116.58 | 16.09 | 7.52 |
| CD (p=0.05) | 0.003 | 1.00 | 0.50 | 0.32 |
| Interaction Zn× S | | | | |
| $Zn_1S_1$ | 0.159 | 119.67 | 14.86 | 6.97 |
| $Zn_1S_2$ | 0.157 | 119.33 | 13.98 | 7.10 |
| $Zn_1S_3$ | 0.156 | 120.00 | 12.12 | 6.22 |
| $Zn_2S_1$ | 0.177 | 108.00 | 23.57 | 8.73 |
| $Zn_2S_2$ | 0.167 | 108.00 | 17.28 | 8.01 |
| $Zn_2S_3$ | 0.164 | 114.00 | 16.92 | 8.17 |
| $Zn_3S_1$ | 0.185 | 104.67 | 27.03 | 9.90 |
| $Zn_3S_2$ | 0.1643 | 110.33 | 16.93 | 8.21 |
| $Zn_3S_3$ | 0.164 | 114.33 | 16.29 | 8.17 |
| $Zn_4S_1$ | 0.162 | 107.67 | 20.01 | 8.93 |
| $Zn_4S_2$ | 0.167 | 110.00 | 16.80 | 8.07 |
| $Zn_4S_3$ | 0.163 | 118.00 | 19.01 | 7.53 |
| CD (p=0.05) | 0.005 | 2.00 | 1.00 | 0.64 |

minimum (16.25 g plant$^{-1}$) in $S_3$ which was at par with $S_2$. However, among interactions, maximum seed yield (27.03 g plant$^{-1}$) was recorded in $Zn_3S_1$ and minimum (12.12 g plant$^{-1}$) in $Zn_1S_3$ .These findings are in line with Kiran (2006) in brinjal, Pariari et al (2009) in fenugreek and Lakshami et al (2017) in black gram.

**Seed yield ha$^{-1}$ (q):** There were significant differences in seed yield hectare$^{-1}$ for zinc levels, different stages of application and their combinations (Table 2). There was a linear increase in the seed yield (8.76 q ha$^{-1}$) up to 2g l$^{-1}$ ($Zn_3$) and thereafter there was a significant decrease in the seed yield hectare$^{-1}$ at the highest level, however, minimum value of seed yield (6.88 q ha$^{-1}$) was in $Zn_1$ whereas among stages of application, maximum seed yield (8.63 q ha$^{-1}$) was in first stage of application, $S_1$ with a significant reduction at later stages and minimum yield (6.83 q ha$^{-1}$) was obtained in stage $S_3$. In case of interaction, maximum seed yield (9.90 q ha$^{-1}$) was in $Zn_3S_1$ while minimum (6.57 q ha$^{-1}$) was with $Zn_1S_3$.

## CONCLUSION

Among different zinc levels, $Zn_3$ (2g l$^{-1}$) was significantly superior over other zinc levels for most of the growth as well as seed yield parameters. In case of stages of application, $S_1$ (Bolting stage) proved its superiority over other stages of application for most of the growth parameters related to seed yield. Resultantly, treatment combinations, $Zn_3S_1$(2g l$^{-1}$ at the time of bolting) was superior over other treatment combinations for most of the growth and seed yield and quality parameters namely plant height, number of siliquae plant$^{-1}$, siliqua length, number of seeds siliqua$^{-1}$, average seed weight siliqua$^{-1}$, minimum days to seed maturity, seed yield (plant$^{-1}$ and ha$^{-1}$).

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# Water Productivity of Capsicum and Tomato under different Growing Environments

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***Abstract***: Effect of growing environments and fertigation levels on capsicum and tomato crops were studied at Precision Farming Development Centre, ICAR-Central Institute of Agricultural Engineering, The experiments were designed with six treatments consisting of three growing environments namely open field, shade net and poly house with two levels of fertigation (100 % and 80 % ) through the drip irrigation. Recommended dose of fertilizer 100 % was found better in all the growing environments for both the crops as compared to 80 %. Water productivity of capsicum under 100 % drip fertigation treatment was 28.0, 17.1 and 9.6 kg/m$^3$ respectively for growing environments of poly house, shade net house and open field cultivation. For tomato crops under these environments water productivities were as 18.4, 13.7 and 12.9 kg/m$^3$ respectively. Since, there was no significant difference in the yield was observed between 100% drip fertigated and 80% drip fertigated treatments of both the crops in polyhouses, the study recommended to adopt 80% drip fertigation for cultivating capsicum and tomato as there would be a saving of 20% of water and fertilizers.

***Keywords***: Drip irrigation, Poly house, Shade net house, Fertigation and water productivity

Among the many vegetable grown across the world capsicum (*Capsicum annuum* L) and tomato *(Lycopersicon esculentum* Mill.) are most important crops which are very sensitive to externalities of weather conditions. For proper growth and yield capsicum requires little lower temperatures as compared to tomato, but cultivation of these crops under shade nets and poly houses may be effective because it protects the plants from pest infestation and from cold injury since, night temperature inside these structures are higher than outside. In these structures, the factors like temperature, relative humidity and light intensity are changed as per crop requirements to gain maximum production during off-seasons. During the establishment and fruit setting these crops' requirement of water and fertilizers are very high. To produce more crop per unit area with enhanced efficiency of inputs, polyhouse technology is a good option input use efficiency. Different types of structures are being used for improving the productivity and profitability of horticultural crops as well as growing of the crops and planting material throughout the year. The greenhouse/polyhouse technology can be utilized for control of environmental parameters such as temperature, relative humidity, light intensity, light duration, $CO_2$ level, irrigation, nutrient supply and uptake, spacing, growing medium and root development (Baghel et al 2003). It is, therefore, necessary to adopt technologies to produce more crop per unit of cropped area to meet the demand of the Indian population otherwise per capita availability of vegetables will further go down (Bini and Regeena 2014). The area under different protected cultivation practices in India today is around 250000 ha in which about 2000 ha area is under polyhouses (Senthilkumar et al 2018). In this study, vegetable crop's tomato and capsicum were performed under protected conditions inside the poly house and shade net houses was compared with their performance in open conditions. Various climatic parameters, biometric observations and yield were recorded for performance evaluations.

## MATERIAL AND METHODS

**Weather and soil**: Investigations were carried out to assess the effect of growing environments, fertigation levels on capsicum and tomato crops in three *rabi* seasons (2015-16, 2016-17 and 2017-18). Soils of the experimental site are classified as heavy clay soils with clay content varying between 49.7 to 53.7 % and with field capacity ranging from 28.5 to 31.0 %. The study area is located at North of Bhopal (23º 18' 35'' N and 77º 24' 10'' E) at an elevation of 495 m above mean sea level. During winter, temperature varies between 10°C and 25°C and in summer between 25°C and 44°C. The normal annual rainfall of the region is about 1090 mm.

**Experimental details:** The drip irrigation system having discharge of 3 litre per hour spacing at 40 cm was operated at 1.5 kg cm$^{-2}$ pressure. The experimental treatments were performed under open field, shade net house (white colour with 50 % shade factor) and inside a polyhouse. The experiment was conducted with following treatments

T1=100% drip fertigation in open field; T2 = 80% drip fertigation in open field ; T3=100% drip fertigation in shade net ; T4 = 80% drip fertigation in shade net; T5 = 100% drip fertigation in polyhouse and T6 = 80% drip fertigation in polyhouse.

**Fertilizer application:** Recommended doses of fertilizer (RDF) were applied in all the treatments. For capsicum RDF applied @ 200:150:250 NPK kg $ha^{-1}$ and for tomato @ 350:120:390 NPK kg $h^{-1}$. One third portion of nitrogen of RDF was applied as a basal dose of fertilizer for each treatment and the remaining fertilizers were applied in fifteen days interval.

**Varieties:** Thirty days old seedlings prepared in protrays were transplanted in the third week of December in experimental plots. *Heemsonha* and *Swarna* varieties of tomato and capsicum crops were considered in the study, as they are popular in the region.

**Crop water requirement:** The daily weather data during the crop growth period were collected from the meteorological observatory of ICAR-Central Institute of Agricultural Engineering, Bhopal. The daily irrigation water requirement for both the crops were estimated by using the following relationship

$WR = ET_0 * Kc * Wp * A$

Where, WR = Crop water requirement (mm $d^{-1}$); $ET_0$ = Reference evapotranspiration (mm $d^{-1}$) ; Kc = Crop coefficient ; Wp = Wetting fraction (taken as 1 for close growing crops) ; A = Plant area, $m^2$ (i.e. spacing between rows, m x spacing between plants, m)

The values of pan coefficient and crop coefficients were taken from Doorenbos and Pruitt (1977). Daily time to operate drip irrigation system was worked out taking the application rate per plant. Working of drip system was scheduled on alternate days. Water applied for tomato crop in poly house, shade net house and open filed were 719, 719.4 and 354.2 mm respectively in 100 % drip irrigation likewise water applied in capsicum crop were 213, 318 and 353 mm respectively as 100 % drip Irrigation.

**Data collection and analysis:** The plants were spaced 50 x 50 cm between plant-to-plant and row-to-row, respectively for both of crop tomato and capsicum. Each treatment was replicated three times. Five plants were randomly selected from each experimental plot for recording of plant height, number of flowers per plant, number of fruits per plant, air temperature, relative humidity, light intensity, root development parameters, maximum fruit weight and yield per plant, water productivity ($kgm^{-3}$) and total yield (kg $ha^{-1}$) were recorded. The data collected were analyzed by using Fisher's analysis of variance technique and CBD test with the confidence level at 5% was used to compare the differences among the treatment means.

**Plant data:** Plant height was measured from the ground surface to the top of the plant. Chlorophyll content was measured with a SPAD-502 chlorophyll meter (Konica, Minolta), which gives chlorophyll index. Measurements were taken from apical leaves at 45 days after transplanting from the bottom of the plants.

**Weather data:** Air temperature was measured at 1.5 m above the ground surface at 14.00 h by Hygro-thermometer (Testo 623). Light intensity was measured at the same location by Lux meter (Testo -540) at same time

**Water productivity:** Water productivity of each treatment was calculated using the following equations: Water productivity (WP) ($kgm^{-3}$) = CY / WA; Where CY = Crop Yield (kg $ha^{-1}$); WA = Water applied ($m^3$ $ha^{-1}$)

**Root analysis:** The root studies were carried out by measuring root length (cm), root volume (ml) and root dry mass (g) at crop maturity stage in five randomly sample plants.. Root characters were assessed by modified trench method (Bohm et al 1977). The plants were carefully excavated until the tip of each plant root was just visible. Debris and dead roots were manually removed from vital roots. Roots kept for deep soaking in saturated NACL (winRHIZO method) for one night (Delory 2017). After drying, roots were placed on plane surface and then measured their length from the crown gall region to tip of the deepest root. Root samples were air dried initially followed by oven drying at 65 ± 5°C till a constant weight is attained and root mass was expressed as g per plant.

## RESULTS AND DISCUSSION

**Crop parameters:** Plant growth parameters such as plant height, number of flowers per plant and were measured under open field; shade net and poly house (Table 1). Plant height of capsicum crop was highest in polyhouse (66.2 cm and 62.7cm) followed by shade net house (53.9 cm and 52.8 cm) in both the treatments of 100 and 80% drip fertigation as compared to open field (33.97cm & 33.12 cm). Similarly tomato crop also were recorded highest plant height under polyhouse (172.1 and 143.6 cm) and shade net (127.0 and 122.7cm) as compared to open field (85.2 and 82.8 cm). The highest numbers of leaves per plant were recorded from the crop grown under poly house followed by shade net and open field in both the treatments 100 and 80% fertigation in both of crop capsicum and tomato.

**Phenology:** Flowering, fruit setting and fruit maturity in polyhouse and shade net plants were advanced by about 6, 7, 8 and 3, 4, 5 days, respectively compared to the crop raised in open field condition in case capsicum cultivation. SPAD (58.0) was also highest under the poly house followed by shade net (54.1) and open field (51.8).

**Yield:** The highest fruit yield of capsicum per plant were obtained from the polyhouse (2.84 and 2.26 kgplant$^{-1}$) followed by shade net and open field (Fig. 2). Similarly highest fruit yield of tomato crop were recorded from polyhouse (5.40 kg plant $^{-1}$ and 4.10 kg plant$^{-1}$) followed by shade net and open field conditions (Fig. 3).

**Temperature:** Thee maximum temperatures under polyhouse were 2-5 °C higher than that of open field temperatures during December to February months (Fig. 2). The open field temperatures are more thereafter, where as temperatures under polyhouse were managed by operating foggers and passive cooling systems. The temperatures inside shade net house are mostly lower than the temperatures of open field conditions as well as under polyhouses. Further it is also observed that the variations between maximum and minimum temperatures are minimum under polyhouse as well as in shade net house conditions as compared to open field conditions (Fig. 2 and 3). According to Halim and Islam (2013) under the protected structures crop is protected from biotic and abiotic stresses. Protection of plants from low night temperature during heavy cold, from mite and insects are the prime prerequisite for successful capsicum production. Jakhar et al (2017) concluded that Indira variety of capsicum can be better cultivated under shadenets. The present study also observed similar findings under protected conditions.

**Relative humidity**: The relative humidity values during the day time were maintained at around 60 per cent in polyhouse by operating foggers, where as in shadenet house and in open field atmospheric relative humidity fluctuated from 50 per cent to 30 per cent.

**Root characteristics:** The root characters were observed maximum for both the crops under polyhouse with 100% RDF as compared to shade net with 100% RDF and lowest in open field condition (Table 2) .

**Water productivity:** Water productivity is highest for both the crops grown under the polyhouse with the magnitude of

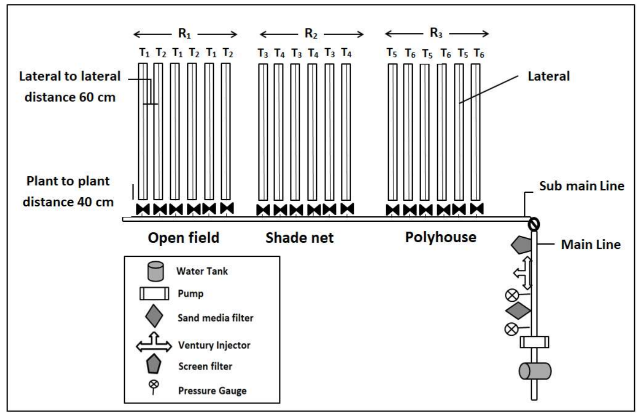


**Fig. 1.** Layout of drip irrigation system for capsicum and tomato

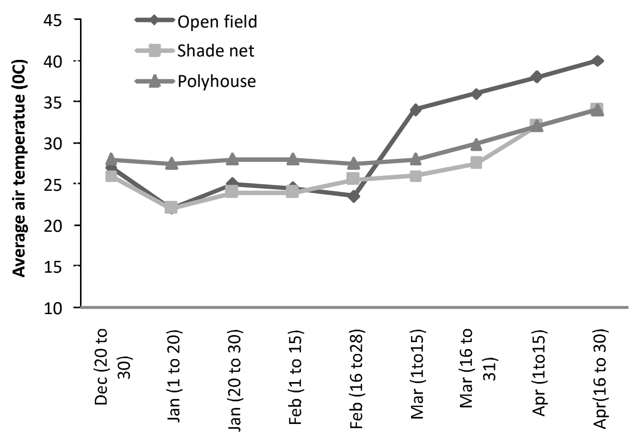


**Fig. 2.** Average maximum temperature (°C) during cropping period

**Table 1.** Growth and yield contributing parameters of capsicum and tomato

| Treatments | | Capsicum | | | | Tomato | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Plant height (m) | No. of flowers /plant | SPAD value | Yield /plant (kg) | Plant height (m) | No. of flowers/plant | SPAD value | Yield/ plant (kg) |
| Open field | T1 | 0.34 | 29.71 | 51.80 | 0.66 | 0.85 | 48.5 | 52.2 | 1.32 |
| | T2 | 0.33 | 28.60 | 51.30 | 0.51 | 0.83 | 44.1 | 51.0 | 1.20 |
| Shade net | T3 | 0.54 | 32.51 | 54.10 | 1.73 | 1.3 | 59.3 | 54.4 | 3.60 |
| | T4 | 0.53 | 30.61 | 52.70 | 1.34 | 1.2 | 57.7 | 52.5 | 3.10 |
| Poly-house | T5 | 0.66 | 35.48 | 58.00 | 2.84 | 1.7 | 72.1 | 57.0 | 5.40 |
| | T6 | 0.63 | 33.50 | 55.80 | 2.26 | 1.4 | 70.4 | 54.1 | 4.10 |
| SEM± | | 0.07 | 1.45 | 1.83 | 0.58 | 0.16 | 1.78 | 1.2 | 0.34 |
| CD (p=0.05) | | 22.2 | 4.32 | 5.40 | 1.7 | 46.8 | 5.12 | 3.6 | 1.02 |

**Table 2.** Average root parameters of capsicum and tomato

| Treatments | Root length (cm) | | Root volume (ml) | | Root dry mass (gm) | |
|---|---|---|---|---|---|---|
| | Capsicum | Tomato | Capsicum | Tomato | Capsicum | Tomato |
| T1 | 17.11 | 19.52 | 11 | 12 | 2.38 | 3.42 |
| T2 | 10.20 | 17.67 | 08 | 11 | 1.76 | 2.50 |
| T3 | 21.15 | 24.85 | 26 | 25 | 4.52 | 4.22 |
| T4 | 17.41 | 22.40 | 20 | 23 | 4.4 | 3.96 |
| T5 | 8.39 | 29.78 | 32 | 28 | 5.86 | 4.56 |
| T6 | 0.22 | 27.48 | 31 | 27 | 4.48 | 4.32 |

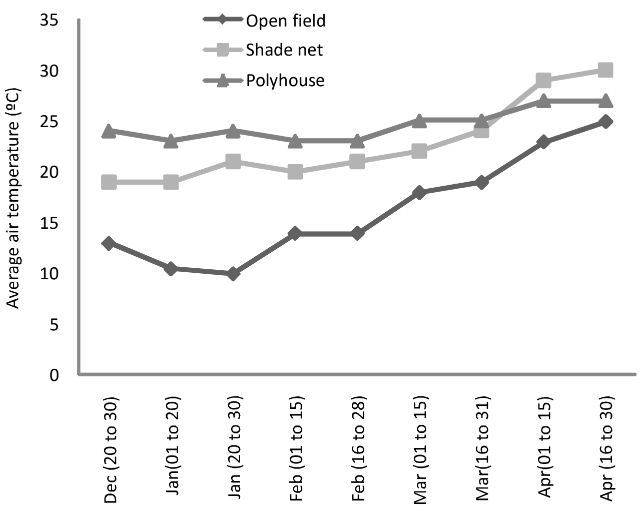


**Fig. 3.** Average minimum temperature (°C) during cropping period

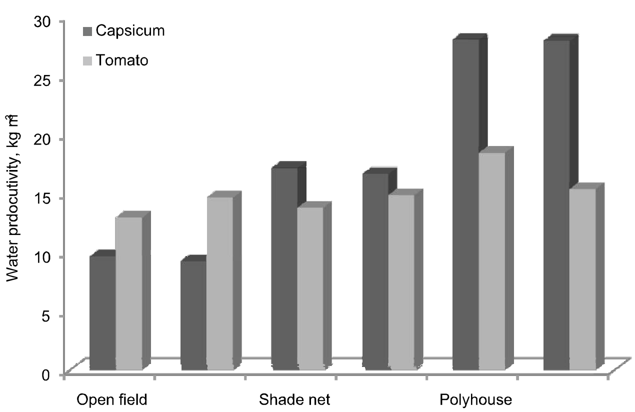


**Fig. 4.** Water productivity of capsicum and tomato from different growing environments

mean values is in order T6>T5>T4>T3>T2>T1 (Fig. 4). This may be due to the higher water losses through evaporation and transpiration in open environment conditions as compared to protected environment. Water productivity of capsicum crop under 100 % drip irrigation and fertigation treatment was 28.0 17.1 and 9.6 kgm$^{-3}$ respectively for growing environments of poly house, shade net house and open field cultivation. In case of tomato crop also similar results were found. The water productivity of tomato under poly house, shade net house and open field conditions were 18.4, 13.7 and 12.9 kgm$^{-3}$ respectively for 100 % drip irrigation and fertigation treatments. Thus, use of protected structure like polyhouse and shade net house would lead to more crop per drop of water.

## CONCLUSIONS

The present study concludes that for better growth, development, productivities of capsicum and tomato can achieve under polyhouse due to the optimum temperature and relative humidity during the winter months. Both the crops gave higher yield (> 3 times higher than open field) if grown under polyhouse conditions with 100% drip irrigation and fertigation as compared to open field cultivation. Since, there is no significant difference in the yield was observed between 100% drip fertigated and 80% drip fertigated treatments for both the crops in polyhouses, the study recommended to adopt 80% drip fertigation for cultivating tomato and capsicum.

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# Effect of different Irrigation Regimes and Fertigation on Biochemical Properties of Mango (*Mangifera indica* L.) cv. Dashehari

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***Abstract*:** A two year study was undertaken to examine the effect of differential irrigation (Regulated deficit irrigation and partial root zone drying) on shelf life of mango grown in open field conditions. The experimental treatments included ten levels of irrigation. The study revealed that with the advancement of storage life, the per cent TSS, acidity, reducing, non-reducing sugar, total sugar and carotenoids increased significantly up to 6$^{th}$ day of storage and then decreased on 8$^{th}$ and 10$^{th}$ day of storage. On mean value basis maximum TSS (17.42 %), reducing sugar (6.40 %), non-reducing sugar (9.15 %) and total sugar (16.03 %) was in PRD 50% ETc + F whereas maximum carotenoids content (8.43 mg/100g of pulp) was with no irrigation treatment whereas the pectin content of fruit pulp decreased with corresponding increase in storage period. On mean value basis maximum pectin content was recorded in PRD 50% ETc + F (0.295 per cent )whereas, minimum pectin content (0.200 per cent) in the pooled data was r in no irrigation treatment throughout the storage period.

***Keywords*:** Regulated deficit irrigation, Partial root zone drying, Mango, Fertigation

Mango is a climacteric fruit, often harvested at the mature, hard green pre-climacteric stage and undergoes numerous biochemical changes during ripening within 9-12 days at ambient temperature. The short ripening period and low temperature sensitivity (below 13ºC) limits its potential for distant market. Ripening of fruits is triggered by ethylene, whether derived from endogenous or exogenous sources. The area and production of mango in India is 2288 thousand hectares and production 21253 thousand million tonnes (Anonymous, 2018) whereas, in Jammu province of J&K union territory, the total area under mango cultivation is 13037 ha with the total production of 30478 metric tonnes, respectively (Anonymous 2019). In India, mangoes are mainly grown in tropical and sub-tropical regions from sea level to an altitude of 1,500 m.

Availability of irrigation water is the major constraint to crop production in many parts of the world. The advantage of deficit irrigation is a significant technological improvement in irrigation system, which helps to combat water scarcity in agriculture. In recent years, regulated deficit irrigation (RDI) has emerged as one of the potential tools to be used for sustainable crop production in water scarce regions. Reducing water supply to optimal level of crop water requirement in certain growth stages of the crop improves water use efficiency and quality of produces, without affecting the yield significantly (Panigrahi et al 2012). Partial rootzone drying (PRD) is an innovative irrigation technique which is thought to reduce plants water consumption based on the induction of changes in the plants hormonal balance and chemical signalling of roots in the drying soil (Davies et al 2002). To stimulate these responses, under PRD one side of the root system is well watered, while the other falls dry. In the drying part of the roots increased amounts of abscisic acid (ABA) are produced which make the plant reduce its water consumption(Dry et al 2000). Fertigation enables adequate supplies of water and nutrients with precise timing and uniform distribution to meet the crop nutrient demand. Further, fertigation ensures substantial saving in fertilizer usage and reduces leaching losses (Kumar et al 2007). The impact of water deficit on fruit quality has been investigated for several fruit species. Pickering et al (2000) found a positive influence of water deficit on mango fruit quality. Aly and Isamail(2000) reported that boron has beneficial effect on quality of guava fruits. Moreover, for rapid response and correction of deficiencies of mineral nutrients, application of nutrients especially Ca, B, and K in combination, is beneficial for accelerating development of growth characters, quality and shelf life of fruits. Therefore, the aim of the present study is to determine the fruit quality and storability after subjecting the tree in the field to different regimes of irrigation water.

## MATERIAL AND METHODS

The present study was conducted in the farmers field at Akhnoor which is located in the foothills of the Himalayas with latitude 32° 53' 49.0452'' N and longitude 74° 44' 7.7604'' E to observe effect of different irrigation regimes on shelf life of mango during the year 2017 and 2018 on 12 year old mango trees of cv. Dashehari having uniform vigour and size. The experiment was laid out in randomized block design with ten irrigation treatments. For shelf life studies fruits after harvest were stored at room temperature in baskets and parameters were recorded on 0, 2$^{nd}$, 4$^{th}$, 6$^{th}$, 8$^{th}$ and 10$^{th}$ days of storage. Different treatment combinations were $T_1$ 100%ETc, $T_2$ RDI 75%ETc, $T_3$ PRD 75%ETc, $T_4$ RDI 50%ETc, $T_5$ PRD 50%ETc, $T_6$ RDI 75%ETc +Fertigation, $T_7$ PRD 75%ETc +Fertigation, $T_8$ RDI 50%ETc + Fertigation, $T_9$ PRD 50%ETc+ Fertigation, $T_{10}$ no irrigation.

**Total soluble solid:** The total soluble solids (TSS) of the fruit juice were recorded with the help of Erma hand refractometer (0-32$^0$B), according to standard procedure as given in AOAC (1995) in terms of degree Brix ($^0$B) at room temperature. The refractometer was calibrated with distilled water before use.

**Reducing sugars:** Reducing sugars of lead free solution were estimated by titrating it against boiling standard Fehling solutions A and B (5 ml each), using methylene blue as indicator to a brick red colour at end point. The reducing sugars were expressed as %.

$$\text{Reducing sugars (\%)} = \frac{\text{Factor x Dilution}}{\text{Aliquot used x Sample weight}} \text{ x } 100$$

**Non-reducing sugars:** The non-reducing sugars were obtained by subtracting reducing sugars from total sugars and multiplying the difference by standard factor 0.95, the calculation was done as per the procedure described in A.O.A.C (1995).

**Total sugars:** Twenty five gram of fruit pulp was thoroughly homogenized with distilled water and volume made up to 250 ml. To it was added 5 ml of potassium lead acetate and precipitated was filtered into a flask containing 5 ml of potassium oxalate. The content were shaken and filtered again. 100 ml of filtrate was taken into 250 ml flask and few drops of concentrated HCL was added and kept it overnight to obtain complete hydrolysis of sugars. Excess HCL was neutralized by standard NaOH solution using phenolphthalein as an indicator. Boiling mixture aliquot in a burette using methylene blue indicator to a brick red end point (AOAC1994)

$$\text{Total sugars (\%)} = \frac{\text{Factor x Dilution}}{\text{Aliquot used x Sample weight}} \text{ x } 100$$

**Carotenoids:** Total carotenoids was measured by using a spectrophotometer and expressed in mg/100g pulp (Mahadevan and Sridhar, 1986).

**Pectin:** Pectin was extracted by the method of (Rangana 1977). Data were analyzed statistically by Panse and Sukhtame 2000.

## RESULTS AND DISCUSSION:

**Total soluble solid:** The percent total soluble solid of mango cv. Dashehari increased significantly up to 6$^{th}$ day of storage and decreased thereafter on 8$^{th}$ and 10$^{th}$ day of storage. The maximum TSS content was $T_9$ (PRD 50% ETc+ F) (17.42 %) throughout the storage period whereas, minimum TSS content was recorded in $T_{10}$ (no irrigation) (13.92 %). The minimum TSS in mango fruits showed a significant increasing trend from 0 day (10.09 %) to 6$^{th}$ day of storage (19.29 %) and showed a significant and continuous decrease thereafter and

**Table 1.** Effect of different irrigation regimes and fertigation on total soluble solid (%) of mango cv. Dashehari during storage

| Treatments | | Storage (Number of days) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0 day | 2 day | 4 day | 6 day | 8 day | 10 day | Mean |
| $T_1$ | 100% ETc | 8.37 | 11.21 | 15.15 | 18.27 | 16.18 | 15.61 | 14.13 |
| $T_2$ | RDI 75% ETc | 9.28 | 12.16 | 16.30 | 18.46 | 17.23 | 16.24 | 14.94 |
| $T_3$ | PRD 75% ETc | 9.41 | 12.25 | 16.46 | 18.51 | 17.37 | 16.42 | 15.07 |
| $T_4$ | RDI 50% ETc | 10.20 | 13.38 | 16.20 | 19.06 | 18.27 | 17.25 | 15.72 |
| $T_5$ | PRD 50% ETc | 10.44 | 13.86 | 16.72 | 19.37 | 18.62 | 17.83 | 16.14 |
| $T_6$ | RDI 75% ETc+ F | 11.04 | 14.11 | 18.21 | 20.12 | 19.10 | 18.14 | 16.79 |
| $T_7$ | PRD 75% ETc+ F | 11.21 | 14.37 | 17.54 | 20.26 | 19.27 | 18.27 | 16.81 |
| $T_8$ | RDI 50% ETc+ F | 11.38 | 15.25 | 18.58 | 20.38 | 19.41 | 18.48 | 17.24 |
| $T_9$ | PRD 50% ETc +F | 11.51 | 15.47 | 18.72 | 20.43 | 19.77 | 18.66 | 17.42 |
| $T_{10}$ | No Irrigation | 8.08 | 11.15 | 15.00 | 18.10 | 16.00 | 15.22 | 13.92 |
| Mean | | 10.09 | 13.32 | 16.89 | 19.29 | 18.12 | 17.21 | |

CD (p=0.05) for A=0.75, B=0.58, AxB= NS

was 17.21 % on 10th day of storage i.e., at the end of storage period. However, interaction between treatments and storage was non-significant. Zheng et al( 2012) and Bhat et al (2014) also reported that TSS increased in the juice of mango fruit during storage. The increase in TSS might be due to the breakdown of the complex form of carbohydrates into simple sugars during storage period. Rathore et al( 2007) observed that increase in TSS is directly correlated with hydrolytic changes in starch and conversion of starch to sugar being an important index of ripening process in mango. Abdel-Razik (2012) showed that TSS increased with the reduction of irrigation water given to the orchard and the maximum increase was recorded at 70% of Etc. The increase in TSS up to certain period signified the period of active synthesis of carbohydrates in fruits, while declining trend in TSS followed thereafter, indicated the degradation and fermentation of sugars signalling the onset of senescence stage.

**Sugars:** The non-reducing sugar and total sugar, during storage presented showed that the per cent reducing sugar, non-reducing sugar and total sugar, increased significantly up to 6th day of storage and then decrease on 8th and 10th day of storage (Table 2, 3 and 4). The maximum reducing sugar (7.75 %), non-reducing sugar (11.11 %) and total sugar (19.44 %) was under fertigated plants in $T_9$(PRD 50% ETc+ F) on 6th day of storage and was followed by $T_8$(RDI 50% ETc + F) on 6th day of storage whereas, minimum reducing sugar (5.10%), non-reducing sugar (7.39 %) and total sugar (12.87 %) was observed in $T_{10}$ (no irrigation) on 10th day of storage. During storage reducing sugar, non-reducing sugar and total sugar in mango fruits showed a significant increasing trend from 0 day (1.97 %), (4.12 %) and (6.31 %) to 6th day of storage (6.57 %), (10.20 %) and (17.30 %) and showed a significant and continuous decrease thereafter and was recorded to be 6.11 %, 9.08 % and 15.67 % on 10th day of storage. Kahlon and Uppal (2005) suggested that conversion of starches and polysaccharides into simple sugar with the advancement of storage was responsible for the increase of reducing sugar, and onward decline was due to the utilization of sugar in evapotranspiration and other biochemical activities. The increase in sugar may be due to break down of complex polymers in to simple substances by hydrolytic enzymes. Boron facilitated sugar transport within the plant and it was also reported that borate react with sugar to form a sugar borate complex. The fruits treated with potassium nitrate exerted highest non-reducing sugar and might be possible due to the reason that potassium treatment could be attributed to enhance photosynthetic efficiency of the leaves and a possible increase in translocation of assimilates into the fruit. These findings are in conformity with several workers (Kumar and Reddy 2008, Sarker and Rahim 2013, Bhat et al 2014, Baiea et al 2015) in mango fruit.

**Carotenoids:** The carotenoids content in mango fruits was found to increased significantly up to 6th day of storage and then decreased on 8th and 10th day of storage (Table 5). The maximum carotenoids were in $T_{10}$ (no irrigation) on 0th, 2nd, 4th and 6th day of storage i.e., 2.29, 6.46, 6.49 and 12.96 mg/100g pulp respectively and later on decreased on 8th and 10th day of storage i.e. 11.79 mg/100g pulp and 10.61 mg/100g pulp and minimum carotenoids were in $T_9$ (PRD 50% ETc + F. Ramkrishna et al 2001 in papaya also reported that the rate of increase in total carotenoids was more in the control fruits as compared to fruits sprayed with higher concentration of calcium chloride and calcium nitrate. It was observed that the carotenoids content of the pulp increased steadily as the storage period increased.Similar result was reported in mango cultivar Dashehari by Periyathambi (2013).

**Table 2.** Effect of different irrigation regimes and fertigation on reducing sugar (%) of mango cv. Dashehari during storage

| Treatments | | Storage (Number of days) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0 day | 2 day | 4 day | 6 day | 8 day | 10 day | Mean |
| $T_1$ | 100% ETc | 1.55 | 2.57 | 3.57 | 5.85 | 5.40 | 5.27 | 4.03 |
| $T_2$ | RDI 75% ETc | 1.57 | 2.96 | 4.16 | 6.03 | 5.92 | 5.51 | 4.35 |
| $T_3$ | PRD 75% ETc | 1.62 | 3.08 | 4.24 | 6.11 | 6.17 | 6.06 | 4.54 |
| $T_4$ | RDI 50% ETc | 1.68 | 3.16 | 4.61 | 6.23 | 6.27 | 6.12 | 4.67 |
| $T_5$ | PRD 50% ETc | 1.73 | 3.34 | 4.86 | 6.50 | 6.31 | 6.19 | 4.82 |
| $T_6$ | RDI 75% ETc+ F | 2.16 | 4.12 | 5.21 | 7.07 | 6.57 | 6.24 | 5.22 |
| $T_7$ | PRD 75% ETc+ F | 2.18 | 4.45 | 5.47 | 7.20 | 6.80 | 6.47 | 5.42 |
| $T_8$ | RDI 50% ETc+ F | 2.75 | 5.68 | 7.14 | 7.57 | 7.35 | 7.08 | 6.26 |
| $T_9$ | PRD 50% ETc +F | 2.96 | 5.81 | 7.23 | 7.75 | 7.53 | 7.13 | 6.40 |
| $T_{10}$ | No Irrigation | 1.51 | 2.13 | 3.05 | 5.41 | 5.22 | 5.10 | 3.73 |
| Mean | | 1.97 | 3.73 | 4.95 | 6.57 | 6.35 | 6.11 | |

CD (p=0.05) for A=0.21, B=0.09, AxB= 0.32

**Pectin:** The pectin content of fruit pulp decreased with corresponding increase in storage period (Table 6.) The maximum pectin content was recorded in $T_9$ (PRD 50 % + F) 0.295 per cent whereas, minimum pectin content (0.200 per cent) was in $T_{10}$ (no irrigation) throughout the storage period. The fall in total pectin during storage was observed to be associated with the occurrence of slight mealiness in the fruit, presumably through the degradation of polygalacturonic acid chains since, the viscosity of extracted pectin was decreased in fruits .This may be due to fact that these nutrients retarded process of softening which resulted in corresponding retardation of both polygalacturonase (PG) and galactosidase activities. Such losses of sugars could possibly be attributed to hydrolysis of galactanes and arabino galactans by galactosidase having galactonase activity, tissue softness and increased pectin solubility and degradation suggest that β-galactocidase might play an important role in the cell wall pectin modification and softening of mango fruits during ripening. Several other workers (Jayachandran 2005) and (Sharma et al 2009) also recorded higher pectin content and lower PME activity application with calcium in guava fruits.

## CONCLUSION

The present investigation reveals that out of various deficit irrigation methods $T_9$ i.e., PRD 50% ETc + Fertigation expresses the best result in improving the shelf life of mango fruit with maximum total soluble solid, reducing sugar, non-reducing sugar, total sugar, and pectin content whereas

**Table 3.** Effect of different irrigation regimes and fertigation on Nonreducing sugar (%) of mango cv. Dashehari during storage

| Treatments | | Storage (Number of days) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0 day | 2 day | 4 day | 6 day | 8 day | 10 day | Mean |
| $T_1$ | 100% ETc | 3.25 | 5.41 | 6.87 | 8.95 | 8.51 | 7.75 | 6.78 |
| $T_2$ | RDI 75% ETc | 3.51 | 5.73 | 7.50 | 9.99 | 9.65 | 8.46 | 7.47 |
| $T_3$ | PRD 75% ETc | 3.74 | 5.85 | 7.68 | 10.15 | 9.87 | 8.60 | 7.64 |
| $T_4$ | RDI 50% ETc | 4.06 | 6.17 | 8.28 | 10.27 | 10.18 | 9.40 | 8.06 |
| $T_5$ | PRD 50% ETc | 4.21 | 6.31 | 8.45 | 10.42 | 10.25 | 9.52 | 8.19 |
| $T_6$ | RDI 75% ETc+ F | 4.29 | 6.66 | 8.54 | 10.57 | 10.32 | 9.70 | 8.34 |
| $T_7$ | PRD 75% ETc+ F | 4.45 | 6.93 | 8.72 | 10.75 | 10.40 | 9.78 | 8.50 |
| $T_8$ | RDI 50% ETc+ F | 5.29 | 7.44 | 9.09 | 10.97 | 10.45 | 9.84 | 8.84 |
| $T_9$ | PRD 50% ETc +F | 5.37 | 7.84 | 9.32 | 11.11 | 10.90 | 10.41 | 9.15 |
| $T_{10}$ | No Irrigation | 3.09 | 5.23 | 6.55 | 8.83 | 8.30 | 7.39 | 6.56 |
| Mean | | 4.12 | 6.35 | 8.10 | 10.20 | 9.88 | 9.08 | |

CD (p=0.05) for A=0.11, B=0.08, AxB= 0.20

**Table 4.** Effect of different irrigation regimes and fertigation on Total sugar (%) of mango cv. Dashehari during storage

| Treatments | | Storage (Number of days) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0 day | 2 day | 4 day | 6 day | 8 day | 10 day | Mean |
| $T_1$ | 100% ETc | 4.97 | 8.26 | 10.80 | 15.27 | 14.35 | 13.42 | 11.17 |
| $T_2$ | RDI 75% ETc | 5.26 | 8.99 | 12.05 | 16.54 | 16.07 | 14..41 | 12.21 |
| $T_3$ | PRD 75% ETc | 5.55 | 9.23 | 12.32 | 16.79 | 16.55 | 15.11 | 12.59 |
| $T_4$ | RDI 50% ETc | 5.95 | 9.65 | 13.32 | 17.04 | 16.98 | 16.01 | 13.15 |
| $T_5$ | PRD 50% ETc | 6.16 | 9.98 | 13.75 | 17.46 | 17.10 | 16.21 | 13.44 |
| $T_6$ | RDI 75% ETc+ F | 6.67 | 11.13 | 13.66 | 18.19 | 17.42 | 16.45 | 13.92 |
| $T_7$ | PRD 75% ETc+ F | 6.86 | 11.74 | 14.64 | 18.51 | 17.74 | 16.76 | 14.37 |
| $T_8$ | RDI 50% ETc+ F | 8.31 | 13.51 | 16.70 | 19.11 | 18.35 | 17.43 | 15.56 |
| $T_9$ | PRD 50% ETc +F | 8.61 | 14.06 | 17.04 | 19.44 | 19.00 | 18.08 | 16.03 |
| $T_{10}$ | No Irrigation | 4.76 | 7.63 | 9.94 | 14.70 | 13.95 | 12.87 | 10.64 |
| Mean | | 6.31 | 10.41 | 13.42 | 17.30 | 16.74 | 15.67 | |

CD (p=0.05) for A=0.75, B=0.38, AxB= NS

**Table 5.** Effect of different irrigation regimes and fertigation on Carotenoids (mg/100g pulp) of mango cv. Dashehari during storage

| Treatments | | Storage (Number of days) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0 day | 2 day | 4 day | 6 day | 8 day | 10 day | Mean |
| $T_1$ | 100% ETc | 2.21 | 6.34 | 6.37 | 12.62 | 11.50 | 10.46 | 8.25 |
| $T_2$ | RDI 75% ETc | 2.16 | 6.23 | 6.26 | 12.38 | 11.20 | 10.33 | 8.09 |
| $T_3$ | PRD 75% ETc | 2.14 | 6.14 | 6.18 | 12.15 | 11.02 | 10.07 | 7.95 |
| $T_4$ | RDI 50% ETc | 1.20 | 5.37 | 5.32 | 11.75 | 10.65 | 9.44 | 7.28 |
| $T_5$ | PRD 50% ETc | 1.16 | 5.27 | 5.25 | 11.53 | 10.45 | 9.22 | 7.14 |
| $T_6$ | RDI 75% ETc+ F | 1.11 | 5.20 | 5.17 | 11.37 | 10.26 | 9.05 | 7.02 |
| $T_7$ | PRD 75% ETc+ F | 1.07 | 5.13 | 5.13 | 11.25 | 10.13 | 8.96 | 6.94 |
| $T_8$ | RDI 50% ETc+ F | 1.02 | 5.08 | 5.11 | 11.14 | 10.07 | 8.90 | 6.88 |
| $T_9$ | PRD 50% ETc +F | 0.98 | 4.00 | 4.04 | 10.15 | 9.01 | 8.85 | 6.17 |
| $T_{10}$ | No Irrigation | 2.29 | 6.46 | 6.49 | 12.96 | 11.79 | 10.61 | 8.43 |
| Mean | | 1.53 | 5.52 | 5.53 | 11.73 | 10.60 | 9.58 | |

CD (p=0.05) for A=0.20, B=0.09, AxB= 0.35

**Table 6.** Effect of different irrigation regimes and fertigation on Pectin (%) of mango cv. Dashehari during storage

| Treatments | | Storage (Number of days) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0 day | 2 day | 4 day | 6 day | 8 day | 10 day | Mean |
| $T_1$ | 100% ETc | 0.442 | 0.328 | 0.269 | 0.113 | 0.053 | 0.022 | 0.205 |
| $T_2$ | RDI 75% ETc | 0.445 | 0.334 | 0.273 | 0.118 | 0.061 | 0.026 | 0.210 |
| $T_3$ | PRD 75% ETc | 0.448 | 0.340 | 0.277 | 0.124 | 0.068 | 0.033 | 0.215 |
| $T_4$ | RDI 50% ETc | 0.452 | 0.347 | 0.282 | 0.136 | 0.082 | 0.038 | 0.223 |
| $T_5$ | PRD 50% ETc | 0.457 | 0.361 | 0.287 | 0.153 | 0.091 | 0.044 | 0.232 |
| $T_6$ | RDI 75% ETc+ F | 0.503 | 0.412 | 0.328 | 0.207 | 0.103 | 0.050 | 0.267 |
| $T_7$ | PRD 75% ETc+ F | 0.510 | 0.424 | 0.346 | 0.214 | 0.112 | 0.053 | 0.277 |
| $T_8$ | RDI 50% ETc+ F | 0.512 | 0.447 | 0.357 | 0.225 | 0.118 | 0.061 | 0.287 |
| $T_9$ | PRD 50% ETc +F | 0.522 | 0.464 | 0.360 | 0.234 | 0.124 | 0.067 | 0.295 |
| $T_{10}$ | No Irrigation | 0.439 | 0.324 | 0.267 | 0.106 | 0.048 | 0.018 | 0.200 |
| Mean | | 0.473 | 0.378 | 0.305 | 0.163 | 0.086 | 0.041 | |

CD (p=0.05) for A=0.05, B=0.03, AxB= NS

maximum carotenoids content was recorded under treatment $T_{10}$(no irrigation).

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# Impact and Analysis of Horticulture and Allied Venture Interventions on Socio- Economic Status, Nutritional and Livelihood Security of Scheduled Caste Communities of District Ludhiana, India

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***Abstract***: The present study carried out in Punjab Agricultural University, Ludhiana under DST- SCSP project to analyze the impact of horticulture and allied venture, on socio-economic status, livelihood and nutritional security of SC beneficiaries. There is no such study conducted in this context in these areas for SC population. Data to assess the impact of DST Project collected from 83 beneficiaries across the four blocks containing 08 villages from Ludhiana district through a structured questionnaire developed by the department of food and nutrition. The information on respondent's food consumption was collected using (24-hour recall). It was observed that around 70% beneficiaries had poor dietary quality largely based on cereals & pulses. Land holding varies 0.008 ha to 0.10 ha and literacy rate includes 36% illiterate. The unavailability of seed, land and low purchasing powers were major barrier in the vegetable consumption before the intervention period. Dietary Diversity Score (DDS) and Food Variety Score (FVS) was calculated before and after the implementation of horticulture interventions with the same set of respondents. DDS and FVS reached from 5.98 to 8.48 and 17.78 to 26.18 respectively after interventions. In addition to this, mean consumption of green leafy vegetables, roots and tubers and other vegetables increased significantly from 1.5, 1.8, 1.8 to 4.2, 3.1, 5.0 respectively after establishing vegetable nutrition gardens in their home. As a result of interventions around 80 percent of respondents achieved dietary diversity with adequate micronutrient intake.

***Keywords***: Vegetable nutrition garden, DDS, FVS, NAR, Horticulture interventions, SC beneficiaries

Though India is third largest economy in terms of purchasing power parity, but the people living in rural areas specially scheduled caste communities are deprived of adequate nutrients and minerals, is still a biggest concern (Food and Nutrition Security Analysis India 2019). Despite, India is progressing in economic sector but poor nutrient intake leading to poor socio-economic status and health. Lack of awareness about the importance of nutrient intake, unavailability of seed material and land for cultivation of vegetables, low purchasing power and access to market were the major barriers in nutrient intake. The factors related to the decline of dietary variety among the rural community dwelling Japanese elderly people was examined by (Kwon et al 2006). Any change in the nutrient intake can lead to malnutrition with its potentially serious consequences (Singh et al 2014). Vegetables are good source of antioxidants that reduce the incidence of cardiovascular diseases. Evidences suggested that horticulture based nutrition interventions like establishing vegetable nutrition gardens and nutrition education; offer a potentially sustainable approach to reducing multiple nutritional deficiencies (Jones et al 2005). Studies conducted on food consumption suggest that cereal-based diets are much prevalent among rural people due to the cheapest source of energy (Kaur 2005). Dietary diversity is a measure of the number of individual foods or food groups consumed in a given time period. It can reflect household access to a variety of foods and can also act as a proxy for individual nutrient adequacy. A diverse diet increases the probability of nutrient adequacy among people and leads for positive health outcomes such as reduced complications of diabetes, incidence of several cancers and all- cause mortality. As dietary factors are associated with increased risk of chronic diseases, local and international dietary recommendations promote increased dietary diversity but limiting saturated fats, refined sugar and salt. Dietary diversity has been universally identified as a key element of high quality diets (Rathnayake et al 2012). However, lack of dietary diversity is a major nutritional concern among deprived people from the low income countries. Changing from a monotonous diet to one with varied food types has been shown to improve energy and nutrient intakes in the people from developing countries (Jayawardena et al 2013). The diversity in the diet is important to meet the requirements for energy and other essential nutrients especially for those who are in the risk of nutrition deficiencies. There is direct relation between DDS, production and consumption of seasonal vegetables however, exotic vegetables do not take in to consideration conducted by World Vegetable Centre in Tanzania during 2006-2007(Gudrun and Bruce Cogill 2011. Moreover, increasing food production and crop diversification can only cure malnutrition when it reaches to vulnerable and poor rural people. Therefore, there is need to implement agriculture-based interventions for the nutritional and livelihood security of poor people. Establishing nutrition garden is a direct approach to fulfil the requirement of minerals and nutrients and to ensure the food security as it allows the harvesting of seasonal vegetables on regular basis. The main oobjectives of study was ccollection of baseline data on present socio-economic status, land holding, cropping preference of Scheduled Caste community in the selected villages and beneficiaries and to impart the training.

## MATERIAL AND METHODS

### Selection of Subjects

**Location, time and respondents:** For this study, 3 surveys were conducted i.e. one survey was conducted to collect the baseline data of selected beneficiaries to collect information about their socioeconomic status and dietary food habits before the implementation of project during March- April 2019 and remaining two surveys were conducted in different season in whole year i.e. summer season (April to September) and winter season (November to March) 2020-2021 from 83 Scheduled Caste farmers consisting of 50 farm women and 33 farmers across the 4 block containing 8 villages i.e. Block Doraha Latitude: 30° 48' 59.99" N, Longitude: 76° 00' 60.00" E (Village: Rampur & Begowal), Block Khanna Latitude 30° 42' 19.69" N, Longitude: 76° 13' 19.06" E (Village: Bijja & Mandiala Kalan), Block Samrala Latitude 30° 50' 24.00" N , Longitude: 76° 11' 24.00" E (Village: Chawa & Ajlaud) and Block Dehlon 30.7425° N, 75.8461° E (Village: Jaspal Banger & Tibba) in Ludhiana district of Punjab through structured questionnaire developed by the Department of Food & nutrition PAU. In the selected villages, land holding of all farmers ranges from 0.008 ha to 0.10 ha and 80 % of beneficiaries belongs to labour class and below poverty line (BPL) families.

**Data collection:** During surveys, 24 hour recall method (for three consecutive days was used to collect detailed information regarding daily food habits. Dietary diversity questionnaire includes 12 groups of food like cereals, pulses, green leafy vegetables, roots ,tubers, fruits, vegetables, milk & milk products, egg, fat, sugar, meat and miscellaneous. In addition to this, demographic questions included to determine socio-economic status were about their age, education, monthly and subsidiary income, occupation, family type, livestock, agriculture land and land for vegetable production.

**Dietary survey:** Dietary intake of subjects was recorded for the three consecutive days by “24 hour recall method” to assess the food intakes of the subjects. Dietcal software was used to calculate Nutrient Adequacy Ratio (NAR) for protein, energy and 5 different micro-nutrients such as β-carotene, vitamin C, folate, iron, calcium (Kaur 2014 and Singla et al 2017). The average raw amount in grams of each and every item of food consumed for three consecutive days for each subjects was fed in the software and nutritive value of the diets was recorded and compared with RDA. Nutrient intake was compared with recommended dietary allowances (RDA) of ICMR (2010).

**Nutrient adequacy ratio:** To estimate the nutrient adequacy of the diet, a Nutrient Adequacy Ratio (NAR) was calculated for the energy, protein, fat intake and nine micronutrients (vitamin A, vitamin C, folic acid, thiamine, riboflavin, niacin, calcium and iron)

NAR%= Intake of nutrients/ Recommended dietary allowance (RDA) x 100

NAR were classified as adequate (100% and above); marginally adequate (75 to 99.9%); inadequate (Below 50%); marginally inadequate (50 to 74.9%) (Jood et al 1999).

**Food variety score:** Food variety score (FVS) is defined as the number of food items consumed over a period of seven days. A list of 49 food items commonly consumed by the studied community was prepared. One point was given for each food category eaten either once or at any frequency throughout the week and each food category was scored only once. Points were added and the resultant score represented the Food variety score (FVS) of the respondent. Average FVS for was calculated by dividing the sum of FVS with total number of respondents and the relation between food variety score (FVS) and dietary adequacy was determined using the following classification given by (Savige et al 1997):

**Table 1.** Relationship between food variety score (FVS) and dietary adequacy

| Total food variety score/week | Dietary adequacy |
|---|---|
| >30 | Very good |
| 25-29 | Good |
| 20-24 | Fair |
| <20 | Poor |
| <10 | Very poor |

**Dietary diversity score:** DDS were calculated using a set of 12 food groups .The choice of 12 food groups was based on outcomes of Food and Nutrition technical assistance (FANTA) project (Swindale and Bilinsky 2006). Information on respondent's food consumption was collected using the previous 24-hours as a reference (24-hour recall). One code was given for food group consumed during the previous 24-hour and '0' code was given for food group not consumed. DDS was calculated by summing the number of different food groups. Average DDS was calculated separately for consumption of green vegetables pre and post project interventions by dividing the sum of DDS with total number of respondents.

## RESULTS AND DISCUSSION

**General demographic details:** The demographic and socio economic characteristics of 83 SC beneficiaries are presented in Table 2.

**Assessment of the nutritional status:** There was significant increase in consumption of different nutrient after growing vegetables in their kitchen garden during the project period (Table 3). Beneficiaries were used to grow one or two vegetables like bottle gourd, fenugreek, spinach, mustard before the intervention. Due to low purchasing powers, less quantity of other vegetables was purchased from the market that does not provide essential nutrients in sufficient amount. Mushroom production was one of the components of the project for landless beneficiaries and mushroom was a new food item for beneficiaries. Training for mushroom production was provided to the beneficiaries for consumption to meet their protein requirements and commercial purpose.

**Table 2.** Socio economic and demographic details of beneficiaries selected under the project: n=83

| Particulars | Category | Percentage |
|---|---|---|
| Gender | Female | 60.32 |
| | Male | 39.71 |
| Education | Illiterate | 36.14 |
| | Middle | 40.90 |
| | High school | 12.01 |
| | Secondary | 8.432 |
| | Graduate and above | 2.42 |
| Occupation | Working (DPLs) | 79.82 |
| | Non-working | 20.21 |
| Monthly income | 0-10,000 | 53.05 |
| | 10,000-20,000 | 12.50 |
| | 20,000-30,000 | 15.64 |
| | 30,000-40,000 | 12.03 |
| | 40,000-50,000 | 4.84 |
| | 50,000 above | 2.45 |
| Family type | Nuclear | 62.62 |
| | Joint | 37.32 |
| Livestock | Yes | 19.23 |
| | No | 80.74 |
| Agriculture | Farming | 6.02 |
| | Non farming | 93.91 |
| Dietary habit | Vegetarian | 44.53 |
| | Non vegetarian | 34.92 |
| | Eggitarian | 20.44 |
| Average land holding size | | 0.02ha |

**Nutrient intake:** Before the project, Nutrient adequacy ratio (NAR) of calorie intake in Scheduled Caste population was 1290kcal with percent adequacy of 57.8 that was marginally inadequate and increased significantly to 1370Kcal with 61.4% percent adequacy and 1781 Kcal with 79.8% marginally adequate after the implementation of horticulture intervention. With the increase in the consumption of mushrooms and pulses, daily protein intake inclined from 57.8 percent adequacy to 94.7 and 108.1% which is perfectly adequate after the implementation of intervention. However, amount of fat intake is 30.6 g day$^{-1}$ was higher than RDA (25 g day$^{-1}$) due to the higher use of vanaspati ghee to make vegetables. The major source of carbohydrates is the intake of cereals (wheat and maize) in the form of chapattis and no significant difference has been reported in daily intake of carbohydrates before and after the project. The mean daily intake of β carotene was extremely less (3.6 g day$^{-1}$) in comparison to RDA, but after the intervention intake of β carotene (27.2 g day$^{-1}$) increased by 86.7%. The percent adequacy of riboflavin, niacin, folic acid are 76.9, 87.8 and 92 respectively which are marginally adequate after the intervention, however, the mean intake of same was marginally inadequate before the intervention. High consumption of green leafy vegetables increased the amount of iron intake drastically with percent adequacy 68% to 96% during the intervention period. Rahman et al (2008), Nandal et al (2009) and Biswas et al (2009) also reported the similar results. and shows strong interrelationship among DDS and FVS and can be used as effective indicators of food security. The food group consumed by the elderly during the previous 24hr period was scored '1' and the food not consumed was given '0'.

The DDS & FVS reached from 5.98 to 8.48 & 17.78 to 26.18 respectively. Gitagia et al (2019) and Renu Jethi et al (2020) reported low DDS of 3.78and 3.9among women of reproductive age as 69.8 percent were found to be consuming less than five food groups in their diet. However, DDS reached to 5.5 and more than ninety percent of women achieved minimum dietary diversity and they are more likely to have higher (more adequate) micronutrient intake after the implementation of horticulture interventions. The lower mean of the diversity score was related to the non-vegetarian sources, other vegetables and fruits and the higher one was for cereals, and milk and milk products. The data showed a trend with a higher food variety and dietary diversity with good mean adequacy ratio among selected beneficiaries. A study conducted in Sharpeville, South Africa where food and dietary diversity as indicators of the dietary adequacy and health status of 170 elderly randomly selected respondents calculated and observed low dietary diversity score (3.41) and food variety score (4.77) compared with poverty parameters confirmed household food insecurity in selected elder population. Although three daily meals were

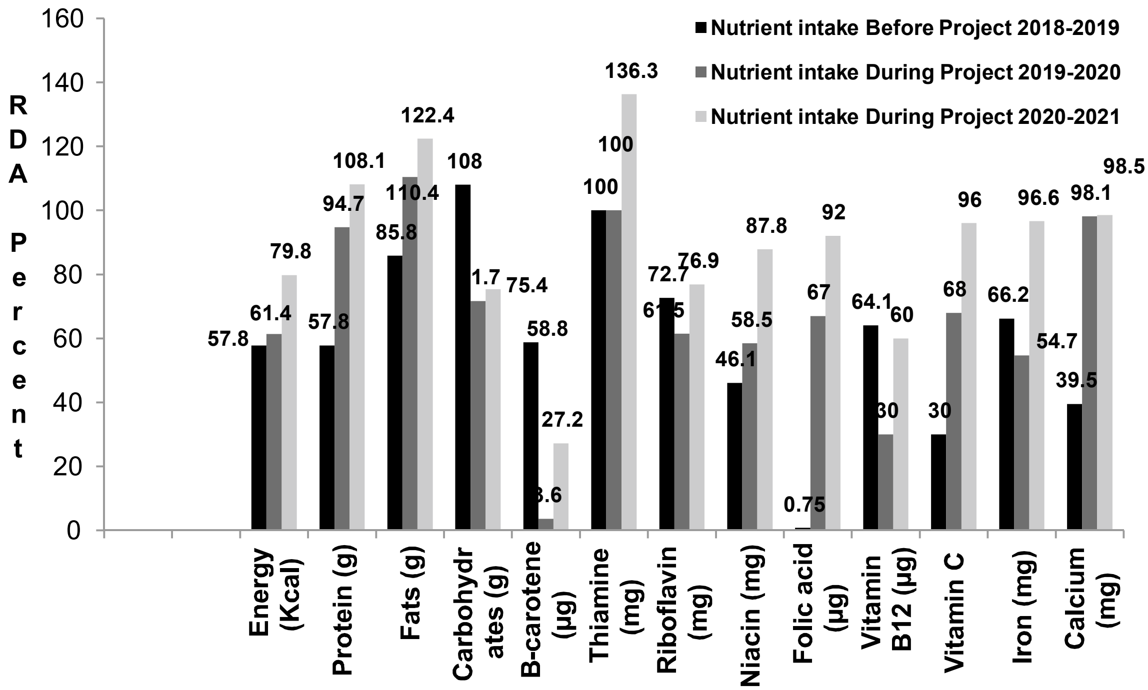


**Fig. 1.** Nutrient adequacy ratio (NAR) of SC beneficiaries before and after the intervention

**Table 3.** Average daily nutrient intake before the implementation and after the implementation of project (Mean±SD)

| Nutrients | Nutrient intake (Before project) 2018-2019 | Nutrient intake (During project) 2019-2020 | Nutrient intake (During project) 2020-2021 | RDA* |
|---|---|---|---|---|
| Energy (kcal) | 1290 ±52.0 | 1370.0±57.4 | 1781.5±54.7 | 2230 |
| Protein (g) | 47.2±2.1 | 52.1±2.2 | 59.5±1.5 | 55 |
| Fats (g) | 27.2±1.2 | 27.6±1.5 | 30.6±2.5 | 25 |
| Carbohydrates (g) | 212.4±8.2 | 258.4±7.9 | 271.5±7.5 | 360 |
| B-carotene (µg) | 172.0±52.2 | 176.0±53.2 | 1309.6±169.5 | 4800 |
| Thiamine (mg) | 1.1±0.1 | 1.1±0.1 | 1.5±0.04 | 1.1 |
| Riboflavin (mg) | 0.6±0.03 | 0.8±0.04 | 1.0±0.02 | 1.3 |
| Niacin (mg) | 10.5±0.6 | 8.2±0.7 | 12.3±0.4 | 14 |
| Folic acid (µg) | 128.3±5.2 | 134.0±6.8 | 184.1±7.1 | 200 |
| Vitamin $B_{12}$ (µg) | 0.3±0.02 | 0.3±0.02 | 0.6±0.02 | 1.0 |
| Vitamin C | 26.5±6.0 | 27.2 ±6.2 | 38.4±4.3 | 40 |
| Iron (mg) | 8.3±0.5 | 11.5±0.6 | 20.3±0.6 | 21 |
| Calcium (mg) | 570.2±30.4 | 589.1±31.4 | 591.5±38.6 | 600 |

mostly consumed but these were mainly carbohydrate-based and nutrient-deficient (Kruger et al 2008). Hoddinott et al (2002) noticed that DDS increased significantly with the increase in household per capita energy intake due to the introduction of micronutrients in the diet. Ruel (2003) and Torheim et al (2003), Steyn et al (2006) show significant and positive associations between *DDS* and micronutrient intake at the individual level. In addition to this, Rathnayake et al 2012 reported the average of the food variety score, dietary diversity score and dietary serving score was 8.4 (2), 4.4 (0.9) and 11.4 (2.5), respectively.

Consumption of green leafy vegetables, roots and tubers and other vegetables increased significantly and consumption of vegetables increased upto around 67 and 89 percent in 2019-2020 & 2020-2021 respectively after the introduction of vegetable nutrition gardens (Table 5). Renu jethi et al (2020) observed the same results that after introducing horticulture interventions, 76.2 percent women have started consuming vegetables on the daily basis in spite of weekly basis. Talukder et al (2010) also reported that establishment of nutrition garden volume and variety of vegetables produce inclined to three to four times approximately. Susana Akrofi et al *(*2010) reported the contribution of food items from the vegetable nutrition garden to the DDS (6.8) was significantly higher in HIV-positive (14.9%) than in HIV-negative households (9.1%) that don't have vegetable nutrition garden in their home and have DDS 6.0. The 24 hour recall method demonstrates the dietary pattern of selected beneficiaries in rural areas which suggests that micronutrient deficiency among the beneficiaries can be compensated by growing green vegetables in their nutrition garden. During the survey all beneficiaries had monotonous diet with less dietary diversity follows the same pattern like chapatti (wheat) with potatoes and pulses and less frequent vegetables with oils/fats. However, after the implementation of horticulture based nutrition sensitive interventions, cultivation of seasonal vegetables introduced dietary diversity in the dietary pattern and helped them to achieve nutritional security.

**Table 4.** Dietary diversity score (DDS) and Food variety score (FVS) of the selected beneficiaries

| Food items | Before intervention | After intervention | p-value |
|---|---|---|---|
| DDS | | | |
| Mean ± SE | 5.98±0.13 | 8.48 ± 0.14 | 0.001*** |
| FVS | | | |
| Mean ± SE | 17.78 ± 0.39 | 26.18 ± 0.51 | 0.001*** |

*** Significant at 1%

**Table 5.** Mean Consumption of green leafy vegetables, roots and tubers, and other vegetables before and after intervention

| | Before intervention | After intervention | t-value |
|---|---|---|---|
| Green leafy vegetables | 1.5 | 4.2 | 23.1 |
| Roots and tubers | 1.8 | 3.1 | 35.8 |
| Other vegetables | 1.8 | 5.0 | 23.0 |

t*- tabulated value = 12.7

## CONCLUSIONS

The agriculture based interventions have improved nutrient intak of selected beneficiaries have improved their nutrient intake and meet their nutritional requirements. Therefore, future policies and long term interventions focusing on livelihoods and crop diversification should be encouraged to enhance the socio economic status especially in SC population. In addition to this, population belonging to SC category in rural areas should be nutritionally educated about the importance of consuming seasonal vegetables and balanced diet for the supplementation of micronutrients. Furthermore, some food groups that were not usually consumed i.e., mushroom must be prioritized and targeted by the government. This should be done by government agencies to organize training camps at KVKs to SC community for production and consumption of mushroom.

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# Diversity of Termite Species and their Distribution in Various Habitats in Palakkad District, Kerala

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***Abstract***: Information on termites' diversity and distribution in Palakkad district of Kerala was observed. In total, 50 species were recorded under two families. The family Termitidae dominated with 49 species while the other one was Rhinotermitidae. Different termites' habitats were observed for the different sampling blocks. The damp wood and subterranean species were dominant and the epigeal and hypogeal mounds were frequently observed than arboreal mounds in the sampling blocks analysed. Moderate species diversity was also observed and species were rather similar in abundance. Of the total termite samples collected, 98% belonged to the single species *O. obesus*, which was the major detritivorous species of termites indicates the beneficial role of these termites as efficient decomposers of tropical ecosystem.

***Keywords***: Termites, Isoptera, Palakkad, Diversity, Distribution, Habitat

Termites (order Isoptera) is dominant soil macro arthropods in tropical ecosystems (Govorushko 2019) and play an important role in ecosystem functioning as decomposers, especially in the tropics. Among the soil invertebrates, termites act as ecosystem engineer, contribute to spatial heterogeneity, which in turn has important consequences for ecosystem structure and functioning in terms of soil turnover, litter decomposition, nutrient cycling and productivity (Acanakwo et al 2019, Chakraborty and Singh 2020) as well as alteration of microhabitats, associated species assemblages and vegetation characteristics (Beaudrot et al 2011, Muvengwi et al 2017). Certain termite species are vigorous pests of wooden structures and vegetation in urban settings, agricultural and forested ecosystems leading to substantial economic loss (Paul et al 2018, Chakraborty and Singh 2020). This populous insect order is also associated with a significant contribution to greenhouse gas emissions (Sugimoto et al 2000). Such negative ecological impacts prompted scientists to quantify and suggest models of termite populations, biomass and abundance (Sapunov 2008). There are areas as well as habitat-wise differences in termite species assemblages, abundance, spatial distribution and mound-building habits. At the regional scale, major environmental determinants are temperature, rainfall, topography, altitude and edaphic conditions (Jones et al 2010). The variation in diversity of termites in various habitats is attributed to anthropogenic disturbance, cropping patterns, topography, and bioclimatic factors (Kalleshwaraswamy et al 2018). At the local scale, vegetation, soil type and condition, food availability, disturbances, competition, and predation mainly determine mound architecture, abundance and spatiality (Korb 2010). Proper understanding and up-scaling of the roles of termites in ecosystem progressions need region specific baseline information, estimates and observing of abundance and spatial ecology. Two-thirds of described termite species belong to the family Termitidae. They are the most dominant and widely distributed group and comprise of 8 subfamilies, 238 living genera and living 2072 species (Krishna et al 2013). Although, the economic importance of termites has become apparent, intensive studies during the last two decades have specifically indicated the roles played by diverse termite populations in different habitats.

## MATERIAL AND METHODS

**Study area:** The investigations were carried out in different sampling sites selected in various blocks of Western Ghats region of Palakkad district of Kerala, India (Fig. 1). Termite species were collected from fifty different sampling sites varying in habitat and geographical conditions. The geographical data about the experimental sites in various

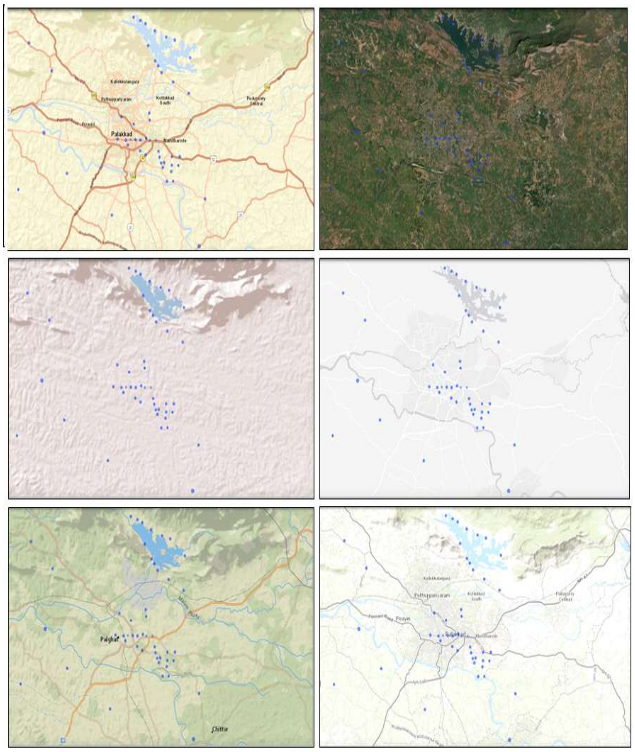

**Fig. 1.** Map showing different view of sampling station in Palakkad district of Kerala

blocks were recorded with the use of the global positioning system (GPS). The location of the sampling blocks and their habitat was noted manually.

**Sampling blocks:** Palakkad is situated as a, right at the central part of Kerala and is the largest district in Kerala having geographical area of 4475.94 sq km and is the gateway to Kerala due to the presence of the Palakkad Gap, in the Western Ghats. The district covers 13.5% of the total forest area in the State and 37% of the total ecological fragile land (EFL) in the State. The total forest zone in Palakkad district is 1527.35 sq km, out of these 51.77 sq km belonging to EFL zone, 276 sq km is dense forest, 693 sq km is moderate forest and the rest 606 sq km is open forest land. In view of the physical features, the district is distributed into two natural divisions-midland and highland. The midland region entails of valleys and plains. It leads up to the highland which involves high mountain peaks, long spurs, extensive ravines, dense forests and tangled jungles.The normal annual temperature in Palakkad is 27.8°C | 82.0°F and in a year, the rainfall is 2135 mm. The sampling blocks of the district is rich in termite mound which is ecologically very sensitive and economically important for soil fertility. A survey was carried out to analyze and document the distribution of the termite species in various land use patterns.

**Field survey:** A field survey was conducted at various sampling blocks of Palakkad district. Termite mound in different transect was documented. In each section the collectors searched the microhabitats which are common sites for termites: from surface soil to above 50 cm deep; accumulations of litter and humus at the base of trees; inside the dead logs, tree stumps, branches and twigs; the soil within and beneath rotten logs, all subterranean mounds, carton sheeting and runways on vegetation and arboreal nests up to a height of three meter above the ground level.

The procedure was intended to offer a flexible approach to the sampling, whereby the collectors used their experience to search and locate as many sample species of termite in available mounds. Samples from each termite population encountered were collected. All castes were collected, but priority was given for finding soldiers and workers. Samples were put in grease proof paper bags and these bags were taken to the laboratory where each one was opened and the termites present were placed in vials labeled with the section number and preserved with 100% ethanol for later identification. Termite identification was done at the Department of Entomology, University of Agricultural and Horticultural Sciences (UAHS), Shivamogga, Karnataka, India where the samples were sent.

**Determination of diversity:** The number of species encountered was used as an indicator of relative abundance of species within each habitat. Richness (number of species) and abundance (number of individuals) were assessed. Termite species richness was calculated using Shannon's diversity index (H), Simpson's diversity index (D). The Shannon index explains the abundance of species, while the Simpson index (D) is less sensitive to species richness but more sensitive to the most abundant species.

Relative abundance is the proportion of a species in an ecosystem or sample of a community. The relative abundance ($p_i$) of each species was expressed as

$$P_i = n_i / N * 100$$

Where $n_i$ is the number of individuals of the same species and N is the total number of individuals for all species.

Shannon diversity index is an informative statistic index, which means it assumes all species are represented in a sample and they are randomly sampled.

$$H = -\Sigma_{i=1}^{S} p_i \ln p_i$$

In the Shannon index, p is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N), ln is the natural log, Σ is the sum of the calculations, and s is the number of species.

The Simpson index is a dominance index because it gives more weight to common or dominant species. In this case, a few rare species with only a few representatives will not affect the diversity.

$$D = \frac{1}{\sum_{i=1}^{S} p_i^2}$$

In the Simpson index, p is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N), Σ is still the sum of the calculations, and s is the number of species.

Simpson's index of diversity= D

Simpson's Reciprocal Index = 1/D

## RESULTS AND DISCUSSION

**Profile of the experimental sites:** The research was undertaken in the various blocks of Palakkad district of Kerala, India. The geographical locations of various blocks in Palakkad district (Table 1). Sampling was carried out in different land use patterns *viz*., barren, cultivated land in the plains and forest of tropical and subtropical region of Palakkad district. The plains recorded the elevations ranging from 70m at Mathur to 232m at Kava-Aanakkal. The land use pattern varied from barren land to cultivated land in plain and forest area which reflected the species richness and distribution of termite in various habitats. The mound area forms a part of species biodiversity which is ecologically very important for agricultural production and soil fertility.The most dominant species recorded in various sampling sites were *Odontotermes obesus.*

**Species composition and abundance:** Fifty (50)

**Table 1.** Survey of termite in various blocks of Palakkad district

| Sampling blocks | Name of the block | Latitude | Longitude | Altitude (m) | Habitat | Termite species |
|---|---|---|---|---|---|---|
| P1 | Venoli road Puthur | 10.47' 4.737" N | 76.40'28.919" E | 98 | Mound | *Odontotermes globicola* |
| P2 | Kutupatha | 10.46' 27.84" N | 76.39'22.499" E | 86 | Mound | *Ododntotermes wallonensis* |
| P3 | Chandranagar | 10.46'20.721" N | 76.40'41.63" E | 98 | Mound | *Ododntotermes wallonesis* |
| P 4 | Erattiyal | 10.45' 4.433" N | 76.41'59.577" E | 98 | Mound | *Odontotermes ceylonicus* |
| P 5 | Prime college | 10.45' 7.296" N | 76.42'5.024" E | 98 | Subterranean | *Odontotermes vaishno* |
| P 6 | Nellepilli | 10.43' 47.1" N | 76.47'5.28" E | 120 | Damp wood | *Odontotermes ceylonicus* |
| P 7 | Mundur | 10.50' 7.596" N | 76.34'19.516" E | 105 | Damp teak | *Odontotermes ceylonicus* |
| P 8 | Kongad | 10.51'14.835" N | 76.31'39.421" E | 101 | Wet news paper | *Odontotermes anamallensis* |
| P9 | Kottayi | 10.45'40.557" N | 76.32'35.061" E | 73 | Subterranean | *Ododntotermes obesus* |
| P10 | Mathur | 10.44'12.814" N | 76.34'45.122" E | 70 | Subterranean | *Ododntotermes obesus* |
| P11 | Thenkurissi | 10.42' 6.014" N | 76.37'55.80" E | 93 | Subterranean | *Odontotermes bellahunisensis* |
| P12 | Kuthannur east | 10.43' 2.895" N | 76.32'39.901" E | 70 | Mound | *Odontotermes wallonensis* |
| P13 | Mithunampallam | 10.44' 9.604" N | 76.42'22.319" E | 94 | Dry wood | *Odontotermes globicola* |
| P14 | Chittur | 10.41' 4.494" N | 76.43'38.314" E | 116 | Dry wood | *Odontotermes yadevi* |
| P15 | Pattanchery | 10.39' 0.35" N | 76.44'15.895" E | 118 | Dry wood | *Odontotermes horni* |
| P16 | Chittur-Vannamadai road | 10.40' 3.815" N | 76.46'32.501" E | 134 | Damp wood | *Odontotermes anamallensis* |
| P17 | Kalvakulam | 10.47' 5.984" N | 76.40'31.372" E | 95 | Damp wood | *Odontotermes ceylonicus* |
| P18 | Mankavu | 10.46' 6.626" N | 76.39'43.691" E | 86 | Dry wood | *Odontotermes anamallensis* |
| P19 | Kalpathi | 10.47' 7.273" N | 76.38'48.321" E | 86 | Damp wood + soil | *Odontotermes globicola* |
| P20 | Manjakulam | 10.46' 1.973" N | 76.38'58.257" E | 86 | Subterranean | *Heterotermes malabaricus* |
| P21 | Palakkad-Malampuzha Road | 10.47' 7.609" N | 76.39'39.499" E | 86 | Mound | *Odontotermes bellahunisensis* |
| P22 | Tharekkad | 10.46' 7.419" N | 76.39'3.506" E | 86 | Subterranean | *Odontotermes bellahunisensis* |
| PW 23 | Malampuzha bypass | 10.49' 7.963" N | 76.41'10.305" E | 95 | Damp wood | *Odontotermes ceylonicus* |
| PW 24 | Kava-Aanakkal | 10.50' 9.586" N | 76.43'47.812" E | 232 | Small mound + tree | *Odontotermes globicola* |
| PW 25 | Malampul reservoir road | 10.51' 9.354" N | 76.39'41.856" E | 138 | Subterranean in teak | *Odontotermes obesus* |
| PW 26 | Asuru home, kava Aanaikkal | 10.51' 5.699" N | 76.42'38.29" E | 232 | Small mound | *Odontotermes vaishno* |
| PW 27 | GTW Higher Secondary School, Kava | 10.51' 2.982" N | 76.41'58.43" E | 114 | Small mound | *Odontotermes vaishno* |
| PW 28 | Akamalavanam | 10.51' 4.086" N | 76.40'51.611" E | 114 | Small mound | *Odontotermes brunneus* |

**Cont...**

**Table 1.** Survey of termite in various blocks of Palakkad district

| Sampling blocks | Name of the block | Latitude | Longitude | Altitude (m) | Habitat | Termite species |
|---|---|---|---|---|---|---|
| PW 29 | Malampuzha Rese rvoir Road | 10.49' 1.347” N | 76.40'52.692” E | 95 | Projection in teak tree | *Odontotermes obesus* |
| PW 30 | Malampuzha Reservoir Road | 10.50' 3.805” N | 76.40'39.097” E | 114 | Small horizontal subterranean | *Odontotermes obesus* |
| PW 31 | Kava-Aanakkal | 10.52' 24.9” N | 76.39'40.697” E | 138 | Mound | *Odontotermes obesus* |
| PW 32 | Kava-Aanakkal | 10.52' 15.19” N | 76.39'50.276” E | 138 | Damp wood | *Odontotermes obesus* |
| PW 33 | Olavakkode | 10.52' 5.48” N | 76.39'21.54” E | 138 | Small mound | *Odontotermes obesus* |
| PW 34 | Malampuzha Kanjikode route 1 | 10.48' 0.617” N | 76.42'57.833” E | 117 | Big mound | *Odontotermes bellahunisensis* |
| PW 35 | Malampuzha Kanjikode bypass route 2 | 10.48' 52.469” N | 76.41'56.576” E | 95 | Wood and plastic bottom | *Odontotermes anamallensis* |
| P36 | Manjakulam | 10.46' 26.475” N | 76.39'10.86” E | 86 | Mound | *Odontotermes obesus* |
| P37 | Kannara street | 10.46' 21.39” N | 76.39'22.95” E | 86 | Small mound | *Odontotermes obesus* |
| P38 | Kenathuparambu road | 10.45' 46.102” N | 76.39'40.292” E | 86 | Small mound | *Odontotermes obesus* |
| P39 | Kunnathumedu | 10.45' 6.068” N | 76.39'58.136” E | 86 | Dry palm leaf | *Odontotermes bellahunisensis* |
| P40 | St. Sebastian School, Kodunbu | 10.45' 33.05” N | 76.41'12.912” E | 98 | Dry coconut flower waste | *Odontotermes redemanni* |
| P41 | Govt Polytechnic College | 10.45' 0.031” N | 76.41'33.769” E | 98 | Small mound on palm root | *Odontotermes obesus* |
| P42 | Kalmandapam | 10.46' 7.591” N | 76.40'28.381” E | 98 | Small mound | *Odontotermes obesus* |
| P43 | Salem-Kochi-Kanniyakumari highway | 10.46' 2.225” N | 76.41'35.931” E | 98 | Small projection under tree | *Odontotermes bellahunisensis* |
| P44 | Devaki nandhanam home stay | 10.45' 9.693” N | 76.41'31.606” E | 98 | Small projection under tree | *Odontotermes obesus* |
| P45 | Palakkad-Chittur Road | 10.44' 0.533” N | 76.41'37.785” E | 94 | Damp wood (rubber) | *Odontotermes bellahunisensis* |
| P46 | Nellikad | 10.45' 2.997” N | 76.42'2.968” E | 98 | Damp wood (rubber) | *Odontotermes anamallensis* |
| P47 | Prime College Palakkad | 10.45' 19.39” N | 76.42'10.384” E | 98 | Damp wood (palm) | *Odontotermes yadevi* |
| P48 | Palakkad - Polachi Road | 10.45' 43.37” N | 76.42'6.676” E | 98 | Damp wood (coconut) | *Odontotermes vaishno* |
| P49 | Primary health center - Kudumbu | 10.45' 28.8” N | 76.41'4.144” E | 98 | Damp wood (rubber) | *Odontotermes anamallensis* |
| P50 | Kallingal | 0.45' 16.885” N | 76.41'1.918” E | 98 | Damp wood (coconut) | *Odontotermes anamallensis* |

N= Number of individuals; RA= Relative abundance

**Table 2.** Taxonomic composition, species composition and relative abundance of different species of Termites in Palakkad

| Termitidae /Rhinotermitidae. | Sub family | N | n/N | $p_i$ | $p_i^2$ | ln $p_i$ | $p_i$ ln $p_i$ | RA |
|---|---|---|---|---|---|---|---|---|
| *Odontotermes globicola* | Macrotermitinae | 4 | 4/50 | 0.08 | 0.0064 | -2.525 | -0.202 | 8 |
| *Ododntotermes wallonensis* | Macrotermitinae | 3 | 3/50 | 0.06 | 0.0036 | -2.813 | -0.168 | 6 |
| *Odontotermes vaishno* | Macrotermitinae | 4 | 4/50 | 0.08 | 0.0064 | -2.525 | -0.202 | 8 |
| *Odontotermes ceylonicus* | Macrotermitinae | 5 | 5/50 | 0.1 | 0.01 | -2.302 | -0.230 | 10 |
| *Odontotermes anamallensis* | Macrotermitinae | 7 | 7/50 | 0.14 | 0.0196 | -1.966 | -0.275 | 14 |
| *Ododntotermes obesus* | Macrotermitinae | 14 | 14/50 | 0.28 | 0.0754 | -1.272 | -0.356 | 28 |
| *Odontotermes bellahunisensis* | Macrotermitinae | 7 | 7/50 | 0.14 | 0.0196 | -1.966 | -0.275 | 14 |
| *Odontotermes yadevi* | Macrotermitinae | 2 | 2/50 | 0.04 | 0.0016 | -3.218 | -0.128 | 4 |
| *Odontotermes horni* | Macrotermitinae | 1 | 1/50 | 0.02 | 0.0004 | -3.912 | -0.001 | 2 |
| *Heterotermes malabaricus* | Heterotermitinae | 1 | 1/50 | 0.02 | 0.0004 | -3.912 | -0.001 | 2 |
| *Odontotermes redemanni* | Macrotermitinae | 1 | 1/50 | 0.02 | 0.0004 | -3.912 | -0.001 | 2 |
| *Odontotermes brunneus* | Macrotermitinae | 1 | 1/50 | 0.02 | 0.0004 | -3.912 | -0.001 | 2 |
| Total | | 50 | | | 0.1442 | | 1.84 | 100 |

individuals were collected in July 2020 from two different sub families of termite's species. The majority of the individuals (Table 2) belonged to sub family Macrotermitinae with relative abundance 28%.The most dominant species recorded in various sampling sites were *Odontotermes obesus* with relative abundance 28%, *Odontotermes bellahunisensis* with relative abundance 14%, *Odontotermes anamallensis* with relative abundance 14%, *Odontotermes ceylonicus* with relative abundance 10%.Among the species identified, 49 samples representing single family Termitidae and one from Rhinotermitidae. Termitidae are the largest group dominating the order Isoptera with over 80 % of the genera and 74 % of the species which include the most advanced and diverse group with a wide variety of social specializations (Edwards and Mill 1986, Breznak 1982). Nearly all identified termite species are detritivorous (Gudeta et al 2010, Sileshi et al 2010).

The biodiversity of termite recorded a notable variation in the sampling blocks with a greater number of species abundance in open pasture land and the termite mound distribution showed a striking variation in the different habitats with different land use patterns (Table 1). Higher termites were recorded in all fifty sampling blocks. Biodiversity of termite species in Palakkad district revealed that there a greater number of subterranean mounds colonized by *O. obesus* in the sampled blocks which maintain fungal comb as symbiotic association in their mounds. The richness in species diversity recorded in hilly forest blocks was similar in natural ecosystem of tropical region. The poor diversity of other species recorded during the survey could be explained by the degradation of habitat, vegetation types, microclimate fragile ecosystem along with changes in the physico chemical components.

**Species diversity:** Species diversity was calculated for the seven transects using the Shannon Index of Diversity and Simpson's index of diversity. The mean Shannon diversity of termites in Palakkad was 1.84 which is moderately diverse. In the Simpson index of individuals of one particular species D= 0.87. This diversity can be explained by the availability of moisture particularly climate of that region, which can serve both as food and habitat for termites.

## CONCLUSION

There is variation in the abundance and diversity of termite in Palakkad district of Kerala. High abundance of active *Odontotermes obesus* species in the moist tropical regions in and around the Malampuzha region of the sampling blocks. All termites were listed as detritivorous. The baseline data generated from this study will be useful for monitoring the presence of dominant species in Palakkad district and their habitat distribution will helpful to analyse key role of termites in understanding the decomposition process important in the functioning of tropical ecosystem.

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# Butterfly Checklist of Central Academy for State Forest Service Campus, Burnihat, Assam

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***Abstract*:** Central Academy for State Forest Service (CASFoS) is located in the border area of two northeastern states, Assam & Meghalaya. One side of this campus is in the Kamrup district of Assam and other side Khasi hill, Riboi district of Meghalaya. Despite the interstates faunal significance of the area, the area remains poorly documented in terms of butterfly community and hence data deficient. The present study was taken therefore with an objective of providing a baseline data of the butterfly community in CASFoS, Assam. This documentation is the first scientific report on the butterfly faunal diversity from this academy campus. A total of 121 species representing 82 genera and six families have been recorded. The family Nymphalidae was dominant with 45 species under 11 subfamilies, followed by Lycaenidae 25 species under 3 subfamilies, Hesperiidae 24 species under 3 subfamilies, Peridae 14 species under 2 subfamilies, Papilionidae 12 species under 1 subfamily, and Riodininae 1 species under 1 subfamily.

***Keywords*:** Butterfly diversity, CASFoS, Burnihat, Urban area

Among the insects, butterflies are suitable for local biodiversity studies, as the taxonomy, geographic distribution and status of many species are relatively well known. Moreover, butterflies occupy a vital position in ecosystems and their occurrence and diversity are considered as good indicators of the health of any given terrestrial biotope (Kunte 2000, Aluri and Rao 2002, Thomas 2005). In addition to this, butterflies are good indicators in terms of anthropogenic disturbance and habitat quality (Kocher and Williams 2000) because they exhibit high host plant specificity (Munguira et al 2009). The study of butterfly community in relation to the human dominated landscape is very important from the ecological point of view as such type of modified habitats often negatively influence the distribution of butterfly species and their dynamics (Gascon et al 1999, Ricketts et al 2001). The developmental activities and resulting habitat fragmentation create threats to the survival of butterflies worldwide (Asher et al 2001, Tiple and Khurad 2009, Theivaprakasham 2020). Hence it requires proper exploration in various ecological pockets of primary and disturbed (human dominated) habitat of butterfly fauna. With this view, this present work was designed to know the butterfly species diversity in human dominated landscape of the CASFoS campus, Burnihat, Assam. This study is also unique because this is the first scientific documentation on the butterfly fauna from this college campus. Increase of urban features, including busy roads, buildings, and anthropogenic activities in Assam & Meghalaya posing threat to these colourful winged insects. Therefore, this checklist will help the conservationists for better management of the butterfly fauna of this degraded ecosystem.

## MATERIAL AND METHODS

**Study area:** The academy is located in between the state of Assam and Meghalaya about 21 km away from Guwahati town. The academy campus is spread over an area of about 24 hectares which is spread on either side of NH-40. The Assam side land is measuring about 19 hectares, falls in Kamrup district which is located in 26$^0$ 04'94"N to 26°03'47.47"N latitude, and 91° 52'20.54" E to 91°52'36.42" E longitude& elevation 68 m, above MSL. The study area is situated at the valley area of Assam side surrounding with mountain range of Kamrup and Khasi hill on the opposite side (Fig. 1). The climate is mostly tropical wet with hot summer and cold in winter. The average rainfall is 20 mm. The soil is clay-loom, alluvial and red-alluvial. The soil is highly porous on hilly areas and moisture retention capacity is less. The vegetation of this campus is mostly tropical. The original vegetation surrounding academy campus has been disturbed due to the development of national highway road construction, encroachment of land and construction of house. The vegetation is characterised with tree species like, *Lagersteromia spaciosa*, *Dalbergia sisso, Shorea robusta, Terminalia* spp., *Diospyros melanoxylon* and *Tectona grandis*, *Ficus religiosa, Pongamia pinnata*, *Aegle marmelos etc.,* shrubs like *Clerodendron infractunatum, Calotropis*

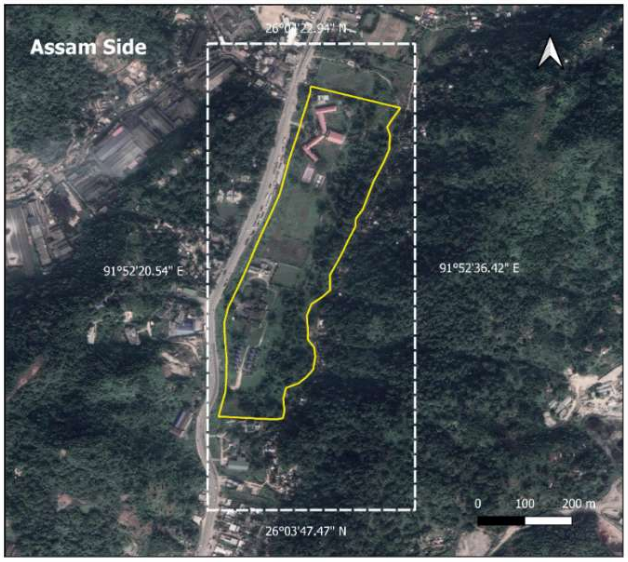


**Fig. 1.** Map of the main campus area of CASFoS Burnihat Assam

*procera, Lantana camara, Murraya koenigii, Ricinus communis and Ixora sp.,* herb like *Vinca rosea, Chromalaenao dorata,* climbers like, *Mikania micrantha.* Beside this, *Hymenocallis caroliniana* on road side blooming before rainy seasons specially attract the butterflies.

**Collection methodology**: The present study is mainly carried out on a random survey from January 2020 to December 2020 and direct observations were made once in a week. The butterflies observed during these surveys were photographed in details which were subsequently identified after consultation of works of literatures (Evans 1932, Kunte 2000, Bora et al 2014, Kehimkar 2016). The photographs for the identification of species have been taken with the Digital SLR camera (Cannon 90D). Butterfly survey was mostly made on the grassland, bushy area, adjacent to hill stream, mud puddle patches, open college campus, wildflower, and seasonal flower garden.

## RESULTS AND DISCUSSION

Present study reports 121 species under 6 families of butterflies from the CASFoS campus (Table 1). Of them, family Nymphalidae shares highest number of species (45) followed by other families as follows. Seven species of butterflies, namely, *Pelopidas sinensis* (Mabille 1877), *Baoris farri* (Moore 1878), *Castalius rosimon* (Fabricius 1775 ), *Lampides boeticus* (Linnaeus 1767), *Mahathala ameria* (Hewitson 1862), *Papilio clyita* Linnaeus1758 and *Appias libythea* (Fabricius 1775) from this study area come under Wildlife Protection Act, 1972 (Table 1, Fig. 3-9).

Among the six butterfly families reported from the campus of this academic institution, the members of the family Hesperiidae are small to medium sized butterflies characterised by the presence of hooked antenna, that is the tip of the antenna is bent or hook-like, giving this family its key feature. Only 24 (20%) species of the total butterfly fauna of CASFoS are hesperiids (Table 2). Of them, the subfamily Hesperiinae shares maximum number of species (79%) followed by Pyrginae and Coeliadinae .The members of the family Lycaenidae are also small sized butterflies and characterised by spots or freckles in the underside of their wings. Only 25 (21%) of the total butterfly fauna of CASFoS are Lycaenidae. Of them, the subfamily Polyommatinae shares maximum number of species (60%) followed by Theclinae and Lycinae. Members of the family Nymphalidae are usually medium to large sized butterflies, with bright beautifully coloured wings.Only 45 (37%) of the total butterfly fauna of CASFoS are nymphalids. Of them, the subfamily Satyrinae shares maximum number of species (31%) followed by Limenitinae, Danainae and Nymphalinae. The Papilionids are the large colourful butterflies commonly found in tropical areas. Some species possess a taillike projection in their hind wings. Only 12 (10%) species under single sub family of the total butterfly fauna of CASFoS are papilionids. Pierids are small to mediumsized, white- or yellow-coloured butterflies. The tips of the legs are forked in pierids. Only 14 (11%) of the total butterfly fauna of CASFoS are pierids (Table 2). Of them, the subfamily Pierinae shares maximum number of species (64%) followed by Coliadinae. Butterflies of the family Riodinidae have remarkable metallic spots on their wings which render them their common name 'metalmarks'. All species in this family are small or medium in size. Only 1 (1%) of the total butterfly fauna of CASFoS are riodinids.

Indian butterflies are one of the well-studied insect groups compared to any other insect groups. Van Nieukerken et al (2011) documneted about 18,732 species of butterflies are found in the entire world excluding the Hedylidae family. In

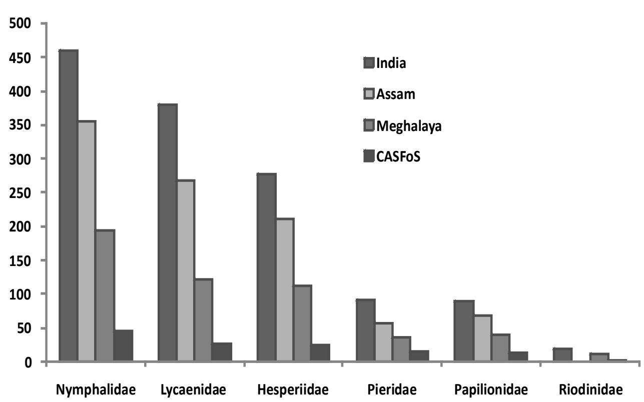


**Fig. 2.** Comparative chart on the butterfly faunal diversity of India Assam Meghalaya and CASFoS

**Table 1.** Butterfly species currently known from the campus of CASFoS

| Sr. No. | Scientific name | Common name | WPA (1972) |
|---|---|---|---|
| Family -Hesperiidae | | | |
| Sub-family- Coeliadinae | | | |
| 1 | *Burara amara* (Moore 1865) | Small Green Awlet | |
| Subfamily-Hesperiinae | | | |
| 2 | *Rapala manea* (Hewitson 1863 ) | Slate Flash | |
| 3 | *Iambrix salsala* (Moore1865) | Chestnut Bob | |
| 4 | *Potanthus Confucius* ( C & R.Felder 1862 ) | Chinese Dart | |
| 5 | *Oriens gola* (Moore1877 ) | Common Dartlet | |
| 6 | *O. goloides* (Moore 1881) | SmallerDartlet | |
| 7 | *Udaspes folus* (Cramer 1775) | Grass Demon | |
| 8 | *Notocrypt acurvifascia* (C. & R. Felder1862) | Restricted Demon | |
| 9 | *Ampittia dioscorides* (Fabricius1793 ) | Bush Hopper | |
| 10 | *Aeromachu spygmaeus* Fabricius1775 | Pygmy Scrub Hopper | |
| 11 | *Halpe zola* Evans 1937 | Long Banded Ace | |
| 12 | *Erionota torus* Evans 1941 | Rounded Palm-red Eye | |
| 13 | *Matapa aria* (Moore 1866) | Common Red Eye | |
| 14 | *M. cresta* Evans 1949 | Fringed Branded Red Eye | |
| 15 | *Pelopidas sinensis* (Mabille 1877) | Chinese Banded Swift | Sch- IV |
| 16 | *Caltoris cahira* Moore 1877 | Colon Swift | |
| 17 | *Parnara ganga* Evans 1937 | Continental Swift | |
| 18 | *Baoris farri* (Moore 1878 ) | Complete Paint Brush Swift | Sch-IV |
| 19 | *Borbo cinnara* (Wallace 1866 ) | Rice Swift | |
| 20 | *Pelopidas mathias* (Fabricius 1798 ) | Small branded Swift | |
| Subfamily Pyrginae | | | |
| 21 | *Sarangesa dasahara* (Moore 1866 ) | Common Small Flat | |
| 22 | *Tagiades japetus* (Stoll 1781 ) | Common Snow Flat | |
| 23 | *T.e smenaka* (Moore 1865) | Spotted Snow Flat | |
| 24 | *Pseudocoladenia dan* (Fabricius1787 ) | Fulvous Pied Flat | |
| Family -Lycaenidae | | | |
| Subfamily- Polyommatinae | | | |
| 25 | *Anthene emolus* (Godart 1824 ) | Common Ciliate Blue | |
| 26 | *Prosota snora* (C.Felder 1860 ) | Common Line Blue | |
| 27 | *Caleta decidia* (Hewitson 1876 ) | Angled Pierrot | |
| 28 | *Castlius rosimon* (Fabricius 1775 ) | Common Pierrot | Sch-I Part-IV |
| 29 | *Jamides celeno* (Cramer 1775 ) | Common Cerulean | |
| 30 | *J.elpis* (Godart 1824 ) | Glistening Cerculean | |
| 31 | *J. alecto* (C. Felder 1860) | Metallic Cerulean | |
| 32 | *Lampides boeticus* (Linnaeus1767 ) | Pea Blue | Sch-II Part-II |
| 33 | *Leptotes plinius*(Fabricius 1793 ) | Zebra Blue | |
| 34 | *Zizeeria karsandra* (Moore 1865 ) | Dark Grass Blue | |
| 35 | *Pseudozizeeria maha* (Kollar 1844 ) | Pale Grass Blue | |
| 36 | *Zizula hylax* (Fabricius 1775) | Tiny Grass Blue | |
| 37 | *Megisba malaya* (Horsfield1828 ) | Malayan | |

***Cont...***

**Table 1.** Butterfly species currently known from the campus of CASFoS

| Sr. No. | Scientific name | Common name | WPA (1972) |
|---|---|---|---|
| 38 | *Chilades pandava* (Horsfield 1829 ) | Plains Cupid | |
| 39 | *C. lajus* (Stoll1780 ) | Lime Blue | |
| Subfamily- Lycaeninae | | | |
| 40 | *Heliophorus epicles* (Godart 1824 ) | Purple Sapphire | |
| Subfamily- Theclinae | | | |
| 41 | *Mahathala ameria* (Hewitson 1862) | Falcate Oak Blue | Sch-II Part- II |
| 42 | *Surendra quercetorum* (Moore 1858 ) | Common Acacia Blue | |
| 43 | *Charana mandarinus* (Hewitson 1863) | Mandarin Blue | |
| 44 | *Hypolycaena erylus* (Godart 1824 ) | Common Tit | |
| 45 | *Zeltus amasa* (Hewitson 1865) | Fluffy Tit | |
| 46 | *Remelana jangala* (Horsfield 1829 ) | Choclate Royal | |
| 47 | *Loxura atymnus* (Stoll 1780 ) | Yamfly | |
| 48 | *Cheritra freja* (Fabricius 1793 ) | Common Imperial | |
| 49 | *Rapala iarbas* (Fabricius 1787 ) | Common Red Flash | |
| Family -Nymphalidae | | | |
| Subfamily- Acraeinae | | | |
| 50 | *Acraea issoria* ( Hubner1819 ) | Yellow Coster | |
| Subfamily -Apaturinae | | | |
| 51 | *Herona marathus* Doubleday 1848 | Pasha | |
| Subfamily -biblidinae | | | |
| 52 | *Ariadne merione* (Crame 1777 ) | Common Castor | |
| Subfamily -Charaxinae | | | |
| 53 | *Polyur aathamas* Drury 1770 | Common Nawab | |
| 54 | *Charaxes eudamippus* Doubleday 1843 | Great Nawab | |
| 55 | *C. spsaphon* (Butler 1870 ) | Plain Tawny Rajah | |
| Subfamily -Cyrestinae | | | |
| 56 | *Chersonesia risa* (Doubleday1848) | Common Maplet | |
| 57 | *C. intermedia* (Martin 1895 ) | Wavy Maplet | |
| Subfamily- Danainae | | | |
| 58 | *Tirumala limniace* (Cramer 1775 ) | Blue Tiger | |
| 59 | *Parantica aglea* (Stoll 1782 ) | Glassy Tiger | |
| 60 | *Danau schrysippus* (Linnaeus 1758) | Plain Tiger | |
| 61 | *D. genutia* ( Cramer 1779 ) | Stripped Tiger/ | |
| 62 | *Eupolea klugii* (Moore 1858 ) | King Crow | |
| 63 | *E. core* (Cramer 1780 ) | Common Crow | |
| 64 | *E. algea* (Godart 1819 ) | Long Branded Blue Crow | |
| Subfamily- Heliconiinae | | | |
| 65 | *Cirrochroa tyche* C. & R . Felder 1861 | Common Yeoman | |
| Subfamily -Limenitinae | | | |
| 66 | *Moduza procris* (Cramer 1777) | Commander | |
| 67 | *Pantoporia sandaka* (Eliot 1969) | Extra Lascar | |
| 68 | *Neptis clinia* Moore 1872 | SulliiedSailer | |
| 69 | *N. hylas* Linnaeus 1758 | Common Sailer | |

***Cont...***

**Table 1.** Butterfly species currently known from the campus of CASFoS

| Sr. No. | Scientific name | Common name | WPA (1972) |
|---|---|---|---|
| 70 | *Euthalia aconthea* Cramer 1777 | Common Baron | |
| 71 | *E.monina* (Fabricius 1787 ) | Powdered Baron | |
| 72 | *Tanaecia lepidea* (Butler 1868 ) | Grey Count | |
| 73 | *T. jahnu* (Moore 1858 ) | Plain Earl | |
| Subfamily Morphinae | | | |
| 74 | *Discophora sondaica* Boisduval 1836 | Common Duffer | |
| Subfamily Nymphalinae | | | |
| 75 | *Junonia iphita* (Cramer 1779 ) | Chocolate Pansy | |
| 76 | *J.atlites* (Linnaeus 1763) | Grey Pansy | |
| 77 | *J. lemonias* (Linnaeus 1758 ) | Lemon Pansy | |
| 78 | *J. almana* (Linnaeus 1758 ) | Peacock Pansy | |
| 79 | *J. hierta* (Fabricius 1798 ) | Yellow Pansy | |
| 80 | *Hypolimnas bolina* (Linnaeus 1758 ) | Great Egg Fly | |
| Subfamily Satyrinae | | | |
| 81 | *Elymnias hypermnestra* (Linnaeus 1763 ) | Common Palmfly | |
| 82 | *E. malelas* (Hewitson 1863 ) | Spotted Palmfly | |
| 83 | *Melanitis leda* (Linnaeus 1758 ) | Common Evening Brown | |
| 84 | *M. phedima* (Cramer 1780 ) | Dark Evening Brown | |
| 85 | *M.s zitenius* (Herbst 1796 ) | Great Evening Brown | |
| 86 | *Lethe rohria* (Fabricius1787 ) | Common Tree Brown | |
| 87 | *L. mekara* (Moore 1858 ) | Common Red Forester | |
| 88 | *Mycalesis gotama* (Moore 1857 ) | Chinese Bush Brown | |
| 89 | *M. mineus* (Linnaeus 1758 ) | Dark Brand Bush Brown | |
| 90 | *M. visala* Moore 1858 | Long Brand Bush Brown | |
| 91 | *Orsotrioena medus* (Fabricius1775 ) | Nigger | |
| 92 | *Loxerebia narasingha* (Moore1858 ) | Mottled Argus | |
| 93 | *Ypthima baldus* (Fabricius 1775) | Common Five Ring | |
| 94 | *Y. huebneri* Kirby 1871 | Common Four Ring | |
| Family Papilionidae | | | |
| Subfamily Papilioninae | | | |
| 95 | *Graphium sarpedon* (Linnaeus 1758 ) | Common Blue Bottle | |
| 96 | *Graphium doson* ( C & R. Felder 1864 ) | Common Jay | |
| 97 | *Graphium agamemnon* (Linnaeus1758 ) | Tailed Jay | |
| 98 | *Atrophaneu raadioneus* (Doubleday 1845) | Lesser Batwing | |
| 99 | *Pachliopta aristolochiae* (Fabricius 1775 ) | Common Rose | |
| 100 | *Troides aeacus* (C & R. Felder 1860 ) | Golden Birdwing | |
| 101 | *Papilio clyita* Linnaeus 1758 | Common Mime | Sch-I Part- IV |
| 102 | *P. polytes* Linnaeus 1758 | Common Mormon | |
| 103 | *P. helenus* Linnaeus 1758 | Red Helen | |
| 104 | *P. nephelus* Boisduval 1836 | Yellow Helen | |
| 105 | *P. memnon* Linnaeus 1758 | Great Mormon | |
| 106 | *P. demoleus* Linnaeus 1758 | Lime Butterfly | |

***Cont...***

**Table 1.** Butterfly species currently known from the campus of CASFoS

| Sr. No. | Scientific name | Common name | WPA (1972) |
|---|---|---|---|
| Family Pieridae | | | |
| Subfamily Coliadinae | | | |
| 107 | *Eurema andersonii* (Moore 1886) | One Spot Grass Yellow | |
| 108 | *E. blanda* (Boisduval 1836) | Three Spot Grass Yellow | |
| 109 | *E. simulatrix* (Staudinger 1891) | Changeable Grass Yellow | |
| 110 | *Catopsilia pomona* (Fabricius 1775) | Common Emigrant | |
| 111 | *C. pyranthe* (Linnaeus 1758) | Mottled Emigrant | |
| Subfamily Pierinae | | | |
| 112 | *Hebomoia glaucippe* (Linnaeus 1758) | Great Orange Tip | |
| 113 | *Appias olferna* Swinhoe 1890 | Eastern Striped Albatross | |
| 114 | *A. lyncida* (Cramer 1777) | Chocolate Albatross | |
| 115 | *A. libythea* (Fabricius 1775) | Western Striped Albatross | Sch-IVPart-I |
| 116 | *Pieris canidia* ( Linnaeus1768) | Indian Cabbage white | |
| 117 | *Delias eucharis* (Dury1773) | Indian Jezebel | |
| 118 | *D. pasithoe* (Linnaeus 1767) | Red Base Jezebel | |
| 119 | *D. descombesi* ( Boisduval 1836) | Red Spot Jezebel | |
| 120 | *Leptosia nina* (Fabricius 1793) | Psyche | |
| Family Riodinidae | | | |
| Subfamily Riodininae | | | |
| 121 | *Zemeros flegyas* (Cramer1780) | Punchinello | |

**Table 2.** Family-wise butterfly species currently known from the campus of CASFoS

| Family | Subfamily | No. of species | Percent |
|---|---|---|---|
| Hesperiidae | | 24 | 20 |
| | Coeliadinae | 1 | 4 |
| | Hesperiinae | 19 | 79 |
| | Pyrginae | 4 | 17 |
| Lycaenidae | | 25 | 21 |
| | Polyommatinae | 15 | 60 |
| | Lycaeninae | 1 | 4 |
| | Theclinae | 9 | 36 |
| Nymphalidae | | 45 | 37 |
| | Acraeinae | 1 | 2 |
| | Apaturinae | 1 | 2 |
| | Biblidinae | 1 | 2 |
| | Charaxinae | 3 | 7 |
| | Cyrestinae | 2 | 4 |
| | Danainae | 7 | 16 |
| | Heliconiinae | 1 | 2 |
| | Limenitinae | 8 | 18 |
| | Morphinae | 1 | 2 |
| | Nymphalinae | 6 | 14 |
| | Satyrinae | 14 | 31 |
| Papilionidae | | 12 | 10 |
| | Papilioninae | 12 | |
| Pieridae | | 14 | 11 |
| | Coliadinae | 5 | 36 |
| | Pierinae | 9 | 64 |
| Riodinidae | | 1 | 1 |
| | Riodininae | 1 | |
| Total | | 121 | 100 |

recently published work, Varshney and Smetacek (2015) stated that India hosts 1318 butterfly species (Fig. 2). Mudai et al (2015) documented 962 species of butterfly belonging to five families from Assam region. In another unpublished document, Bora (2016) reported 514 species of butterfly, of which majority are Nymphalidae (193), followed by Lycaenidae, Hesperiidae, Papilionidae, Pieridae, and Riodinidae from the state of Meghalaya. A comparative chart on butterfly faunal diversity in India, Assam, Meghalaya and CASFoS is given below (Fig. 2).

The polyphagous nature of nymphalidae, help them for their constant dominance and the abandoned availability of food source and their strong flying habit help them for this dominancy. Nymphalidae is an abundant butterfly family on the CASFoS campus. Near about 37.2% of the total butterfly diversity in CASFoS campus belongs to the Nymphalidae family. Most of the butterflies from five families are found in post monsoon as well as in winter. The reason for huge butterfly diversity in CASFoS campus is green vegetation and a pleasant, restricted environment. Moreover, *Lantana camara* is a dominant shrub in this campus, which mainly helps to attract various butterfly species as nectar plant. As mentioned before, one of sides of CASFoS is surrounded by Meghalaya and nowadays due to excessive deforestation and disturbance from scrap factories nearby, a large number of butterfly species seems to shift their habitat from Meghalaya to this campus because of its favourable environment. The conservation impact of this paper

Fig. 3. ***Pelopidas sinensis*** **(Chinese Banded Swift)**

Fig. 4. ***Baoris farri*** **(Complete Painted Brush Swift)**

Fig. 5. ***Castalius rosimon*** **(Common Pierrot)**

Fig. 6. ***Lampides boetieus*** **(Pea Blue)**

Fig. 7. ***Mathathala ameri*** **(Falcata Oak Blue)**

Fig. 8. ***Papilio clyita*** **(Common Mime)**

Fig. 9. ***Appias libythea*** **(Western Striped Albatross)**

highlights that campus of CASFoS had a very low quantity of ill effects of urbanization and if it is maintained, then this campus will be proved as a biodiversity rich area with all developmental activities.

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# Count Data Regression Models: An Application to the Major Rice Insect Pest Counts in the Terai Region of West Bengal

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***Abstract***: In spite of India's phenomenal rice production of 118.43 million tonnes in 2019-20, the potential yield and the yield realised at the farmers' fields are vastly different. Among the factors contributing towards this yield gap, the infestation of insect pests causes significant economic damage. Since these biotic menaces are largely weather-dependent, weather-based predictions of insect pests are often utilised to make economic decisions about insect pest management. Hence, an effort has been made in this study to comparatively assess the suitability of different count data regression models for weather-based prediction of three major rice insect pests (viz., gundhi bug, brown planthopper and green leafhopper) in the Terai region of West Bengal. As the input weather variables are related in a linear fashion, principal components have been obtained to be utilised subsequently in the regression analysis. Among the regression models considered, the recently developed modified Poisson quasi-Lindley regression model has empirically outperformed all of its counterparts in handling over-dispersion. However, the Poisson regression model has provided better result when no over-dispersion is evident. Outcomes emanated from the investigation have also revealed that the over-dispersion test plays a fairly good role in providing reliable guidance on the presence of over-dispersion. Hence, it is suggested that before adopting any weather-based count data regression model for predicting insect pest counts, one needs to check whether the count response variable is indeed over-dispersed.

***Keywords***: Count data regression, Insect pest count, Over-dispersion, Rice, Weather influence, Weather-based modelling

Rice (*Oryza sativa* L.) feeds more than half of the global population (Doliente and Samsatli 2021) and is the sole cereal crop grown under waterlogged conditions in irrigated as well as in rain-fed fields in India (Mishra et al 2007). In spite of India's phenomenal rice production of 118.43 million tonnes in 2019-20 (Directorate of Economics and Statistics 2021), the potential yield and the yield realised at the farmers' fields are vastly different. Among the factors contributing towards this yield gap, the infestation of insect pests causes significant economic damage. In the absence of stable, desirable and diversified sources of resistance to the biotic menaces, pesticides remain the only effective means to manage them (Kumar et al 2016, Sindhu et al 2016). Precise knowledge about the insect pest population dynamics can substantially help to formulate the necessary pesticide schedule for the region against the specific menace anticipated. Since these biotic menaces are largely weather-dependent (Kumar 2016), weather-based predictions of insect pests are often utilised to make economic decisions about insect pest management. Singh et al (2012) have investigated the incidence of insect pest damage in rice crop in Punjab in connection to meteorological parameters and also suggested that these can be used as a tool for the preparation of weather-based agro-advisory. Kaur and Bala (2014) have developed crop-weather-pest calendars for need-based spraying of the pesticides to manage the rice insect pests in Punjab. Yadav et al (2010) have employed weather-based log-linear models for agro-ecological zoning of brown planthopper incidence on rice. However, if the response variable of interest is a count (i.e., non-negative integer values), as in this case insect pest count, the applications of count data regression models are now well-recognised. Due to its increasing application in divergent disciplines such as actuarial science, biostatistics, demography, economics and so on, upsurging research interest in count data modelling has been evident in the last decade. The Poisson regression model has served well as a starting point for count data modelling. Tobías et al (2001) have employed the Poisson regression model to assess the short-term impact of environmental noise on daily emergency admissions in Madrid. Crowther et al (2012) have carried out a meta-analysis of survival data using the Poisson regression model. Li et al (2013) have achieved remarkable success in modelling county-level crashes by using the geographically weighted Poisson regression model. Despite the immense popularity and sheer power of the Poisson regression model, it suffers from the limitation of equi-dispersion (Osgood 2000). That is, the mean and variance of the count response variable are assumed to be equal in this model. In reality, many count data sets often violate this assumption because of their over-dispersed (variance>mean) or under-dispersed (variance<mean) nature (Lee et al 2021). To overcome this lacuna, several researchers have put great efforts to introduce and improve different regression models for the over-dispersed or under-dispersed count data (Cameron and Trivedi 2013, Wongrin and Bodhisuwan 2017). Among the alternatives available for accommodating over-dispersion, negative binomial regression is the most popular choice (Osgood 2000). It includes a parameter to inflate the Poisson dispersion as needed (Berk and MacDonald 2008). Another alternative model, which can capture over-dispersion or under-dispersion or no dispersion at all, is the generalised Poisson regression model given by Consul and Famoye (1992). Recently, Altun (2019) has also proposed a new regression model for over-dispersed count data via re-parametrisation of Poisson quasi-Lindley distribution.

Count data regression models have been compared in several studies, especially in presence of over-dispersion. Ismail and Jemain (2007) have compared the ability of negative binomial and generalised Poisson regression models in handling over-dispersion on three different sets of claim frequency data and obtained comparable performance. Gent et al (2012) have carried out a spatial analysis to derive an appropriate incidence-density relationship for downy mildew. Outcomes emanated from their study have revealed the advantages of employing a negative binomial regression model over a Poisson regression model. Melliana et al (2013) have compared negative binomial and generalised Poisson regression models in determining the factors responsible for cervical cancer cases in East Java and found that the former one has handled over-dispersion in a much better way. Yusuf and Ugalahi (2015) have observed the superiority generalised Poisson regression model in identifying the factors associated with the number of antenatal care visits in Nigeria. However, most of these studies are devoid of any pretesting of over-dispersion. This will enable us to assess whether the over-dispersion test (Cameron and Trivedi 1990) provides any indication to the suitability of count data regression models. Besides, the literature also suggests to consider various information criteria along with the significance of regression coefficients while evaluating the model performance. This is due to the fact that Poisson regression has the property to underestimate the standard error and consequently, to exaggerate the significance of the model coefficients in presence of over-dispersion (Sileshi 2006, Ismail and Jemain 2007). The above facts explicitly indicate that there is a lack of systematic investigation on count data regression modelling, especially in the field of weather-based prediction of insect pest counts. Since improved models have continuously been added to the model builders' arsenal, there is a necessity to investigate afresh the insect pest population dynamics concerning the weather parameters. With this backdrop, an effort has been made in this paper to comparatively assess the suitability of different count data regression models for weather-based prediction of three major rice insect pests (viz., gundhi bug, brown planthopper and green leafhopper) in the Terai region of West Bengal.

## MATERIAL AND METHODS

**Collection of data:** For the present investigation on count data regression modelling, count data of three major rice insect pests, viz. gundhi bug (GB), brown planthopper (BPH) and green leafhopper (GLH) have been obtained from the Department of Agricultural Entomology, Uttar Banga Krishi Viswavidyalaya, Pundibari. The collected data consists of insect pests counts of the seven consecutive boro seasons (from 2011 to 2017). It is noteworthy to mention that the data of a particular field, which was devoid of any insecticide application, have been considered in this study with a view to analyse the natural insect pest population build-up in relation to weather parameters. Rice variety 'Annada' has been utilised for the experimental purpose. The sampling method employed to obtain the counts from the experimental field is adapted from Daorai et al (2005) and Arbab (2014). The experimental field has been divided into four strata and from each stratum, one square metre area has been selected randomly. The total count of an insect pest from those four selected areas is noted as the count of that insect pest for that particular day. The same sampling procedure is repeated at three days' intervals during the period under observation. Table 1 briefs the basic characteristics of the insect pest counts. Daily data pertaining to five weather variables (viz. $T_{max}$, $T_{min}$, $RH_{max}$, $RH_{min}$ and Rainfall) have been obtained from Gramin Krishi Mausam Sewa (GKMS), Uttar Banga Krishi Viswavidyalaya, Pundibari for the same period (2011 to 2017).

### Count Data Regression Models

**Poisson regression model:** The Poisson regression model, which allows the intensity parameter μ to depend on the explanatory variables (regressors), is often considered as the benchmark model for modelling count data. Even though this model is constrained to the restrictive assumption of equi-dispersion, it still dominates the sphere of count data regression modelling due to its simpler form and flexibility of re-parameterisation into other forms of distributional functions. In this model, the count response variable Y follows a Poisson distribution with the probability mass function (pmf)

$$P\ (Y=y)=\frac{e^{-\mu}\mu^{y}}{y!},y=0,1,2,\ldots$$
$$=0,\text{otherwise}$$

where E(Y) = V(Y) = μ. In the log-linear version of the model, the mean parameter is parameterised as $\mu = \exp(\beta_0 + \beta_1X_1 + \beta_2X_2 + \ldots + \beta_kX_k)$ to ensure μ > 0.

**Negative binomial regression model:** The negative binomial regression model introduces a dispersion parameter to accommodate for the unobserved heterogeneity present in the count data. In literature, there exist different parameterisations leading to the generation of different types of negative binomial models. The most popular one among these can be mathematically expressed as

$$P\ (Y=y)=\frac{\Gamma(y+\alpha^{-1})}{\Gamma\,(y+1)\Gamma(\alpha^{-1})}\left(\frac{\alpha^{-1}}{\alpha^{-1}+\mu}\right)^{\alpha^{-1}}\left(\frac{\mu}{\alpha^{-1}+\mu}\right)^{y},$$
$$y=0,1,2,\ldots,\alpha\geq 0$$
$$=0,\text{otherwise}$$

where E(Y) = μ, V(Y) = μ (1+αμ) and α denotes the dispersion parameter. For α = 0, the mean and variance will be equal, i.e. E(Y) = V(Y) = μ, resulting in the distribution to be a Poisson. For α > 0, the variance will exceed the mean, i.e. E(Y) < V(Y), leading to over-dispersion.

**Generalised Poisson regression model:** The generalised Poisson regression model is a natural extension of the standard Poisson regression model. It includes a dispersion parameter, which adjusts for both under-dispersion and over-dispersion. The count response variable Y follows a generalised Poisson distribution with pmf specified as (Famoye et al 2004)

$$P\ (Y=y)=\left(\frac{\mu}{1+\alpha\mu}\right)^{y}\frac{(1+\alpha y)^{y-1}}{y!}\exp\left[\frac{\mu\,(1+\alpha y)}{(1+\alpha\mu)}\right],\quad y=0,1,2,\ldots$$
$$=0,\text{otherwise}$$

where E(Y) = μ, V(Y) = μ $(1+\alpha\mu)^2$ and α denotes the dispersion parameter. Similar to the negative binomial regression model, α = 0 reduces the distribution into Poisson. For α > 0, and α < 0, it will adjust for over-dispersion and under-dispersion, respectively. Concerning the mean-variance structure, this model possesses substantial similarity with the generalised event count ($GEC_k$) model proposed by Winkelmann and Zimmermann (1994).

**Modified Poisson quasi-Lindley regression model:** Grine and Zeghdoudi (2017) have first introduced a mixed Poisson distribution, namely Poisson quasi-Lindley distribution, by compounding the Poisson distribution with the quasi-Lindley distribution. Being motivated by the approach of the generalised linear model, Altun (2019) has further proposed a re-parametrisation of the already developed Poisson quasi-Lindley distribution by putting $\theta=\frac{(2+\alpha)}{(1+\alpha)\mu}$ in its pmf. The pmf of the modified Poisson quasi-Lindley distribution is given by

$$P\ (Y=y)=\frac{(2+\alpha)}{(1+\alpha)^2\mu}\left\{\frac{\alpha+(2+\alpha)\,(\mu+\alpha\mu)^{-1}\ (y+\alpha+1)}{[1+(2+\alpha)\,(\mu+\alpha\mu)^{-1}]^{\,y+2}}\right\}$$
$$,y=0,1,2,\ldots,\alpha>0,\mu>0$$
$$=0,\text{otherwise}$$

where E(Y) = μ and $V(Y)=\mu+\frac{\mu^2}{(2+\alpha)^2}(2+4\alpha+\alpha^2)$. As the variance of this distribution is always greater than its mean, it can be a great pick for modelling the over-dispersed data sets. However, the dispersion of this distribution, as expressed in the variance function, does not depend only on α, but also on μ.

The parameters of all the count data regression models employed in this study have been estimated by the method of maximum likelihood (Famoye et al 2004, Cameron and Trivedi 2013).

**Comparative assessment:** The performance of the count data regression models is assessed in terms of two common information criteria (Bozdogan 2000, Altun 2019), viz., the Akaike information criterion (AIC) and the Bayesian information criterion (BIC). In estimating the amount of information loss, AIC deals with the trade-off between the goodness of fit and the simplicity of the model. AIC is mathematically expressed as

$$AIC=-2\ln L\,(\hat{\theta})+2k$$

where $L(\hat{\theta})$ is the log-likelihood value and k is the number of model parameters. Similar to AIC, BIC is also a penalised-likelihood criterion and is defined as

$$BIC=-2\ln L\,(\hat{\theta})+k\ln(n)$$

where n is the number of observations. $L(\hat{\theta})$ and k have the same meanings as above. Models with the lowest AIC and BIC values are considered best.

## RESULTS AND DISCUSSION

To test for normality, the Shapiro-Wilk test (Yap and Sim 2011) has been employed. Table 2 reflects the strong rejection of normality for all three cases despite the large sample size (>30). This significant result clearly indicates the possible effective implementations of the count data regression models to these data sets.

Since the pest count of the current day depends on the weather of preceding weeks, weather variables are considered accordingly. However, these variables are usually related in a linear fashion. Hence, principal component analysis (PCA), which is basically a dimensionality reduction technique, has been employed to handle the problem of multicollinearity. As the emergence pattern of the hoppers (BPH and GLH) varies from GB, different sets of weather observations have served as inputs. Bartlett's sphericity test (Bucci et al 2018), which compares the sample correlation matrix to the identity matrix, has been applied before proceeding to PCA in order to check whether there is a redundancy between the weather variables that can be summarised with fewer factors. The results (Table 3) confirm the appropriateness of PCA application to the present data.

PCA has been carried out using the ten weather variables (five weather variables of each 31 DAT – 37 DAT and 38 DAT – 44 DAT for GB, and of each 1 DAT – 7 DAT and 8 DAT – 14 DAT for BPH and GLH) for feature extraction of the weather data. The sensitivity of weather variables is evaluated in terms of principal component loadings, which are nothing but the correlations among the PC scores and the attributing weather variables. For a better interpretation of factor loadings, principal components (PCs) are obtained by varimax rotation. As the retention criterion, PCs with Eigen values higher than one are further considered for the regression analysis (Jolliffe and Cadima 2016). Table 4 provides the loadings of the retained PCs. All the ten weather variables are included in the three selected PCs in both

**Table 2.** Results of the Shapiro-Wilk test

| Insect pest | Statistic | p-value |
|---|---|---|
| GB | 0.947 | 0.002 |
| BPH | 0.928 | <0.001 |
| GLH | 0.936 | <0.001 |

**Table 3.** Results of the Bartlett's test of sphericity

| Insect pest | Statistic | p-value |
|---|---|---|
| GB | 361.044 | <0.001 |
| BPH and GLH | 620.092 | <0.001 |

**Table 1.** Characteristics of the insect pest count

| Insect pest | Total no. of observations | Period under observation in each year | Mean | Variance |
|---|---|---|---|---|
| GB | 84 | 45 DAT – 78 DAT | 7.31 | 9.42 |
| BPH | 119 | 15 DAT – 63 DAT | 114.12 | 757.79 |
| GLH | 119 | 15 DAT – 63 DAT | 228.57 | 1861.84 |

Start year: 2011; End year: 2017; DAT: Days after transplanting

**Table 4.** Loadings of the selected principal components

| Insect pest | Period considered in each year | Variable | $PC_1$ | $PC_2$ | $PC_3$ |
|---|---|---|---|---|---|
| GB | 38 DAT – 44 DAT | $T_{max}$ | -0.722 | 0.173 | 0.450 |
| | | $T_{min}$ | -0.028 | 0.126 | 0.777 |
| | | $RH_{max}$ | 0.887 | 0.053 | 0.162 |
| | | $RH_{min}$ | 0.881 | -0.017 | 0.091 |
| | | Rainfall | 0.731 | -0.005 | 0.189 |
| | 31 DAT – 37 DAT | $T_{max}$ | 0.076 | -0.745 | 0.386 |
| | | $T_{min}$ | 0.347 | 0.029 | 0.760 |
| | | $RH_{max}$ | 0.137 | 0.834 | 0.316 |
| | | $RH_{min}$ | 0.040 | 0.827 | 0.297 |
| | | Rainfall | -0.105 | 0.589 | 0.001 |
| % of variance explained | | | 35.76 | 31.31 | 25.92 |
| BPH and GLH | 8 DAT – 14 DAT | $T_{max}$ | 0.505 | -0.662 | 0.323 |
| | | $T_{min}$ | 0.680 | 0.305 | 0.418 |
| | | $RH_{max}$ | 0.265 | 0.852 | 0.077 |
| | | $RH_{min}$ | 0.295 | 0.826 | 0.159 |
| | | Rainfall | 0.100 | 0.727 | 0.066 |
| | 1 DAT – 7 DAT | $T_{max}$ | -0.233 | 0.067 | 0.880 |
| | | $T_{min}$ | 0.636 | 0.458 | 0.397 |
| | | $RH_{max}$ | 0.837 | 0.259 | -0.155 |
| | | $RH_{min}$ | 0.853 | 0.237 | -0.107 |
| | | Rainfall | 0.635 | -0.066 | -0.147 |
| % of variance explained | | | 36.74 | 33.09 | 18.04 |

cases. Only a few variables have displayed the high loading within each PC. In the case of GB, $PC_1$ has accounted for 35.76 per cent of variations in the input data and has loadings of more than 0.7 with a combination of $T_{max}$, $RH_{max}$, $RH_{min}$ and rainfall of 38 DAT – 44 DAT. $PC_2$ on the other hand, has explained 31.31 per cent of the total variation by extracting the information from the same weather variables ($T_{max}$, $RH_{max}$, $RH_{min}$ and rainfall) but of 31 DAT – 37 DAT. $PC_3$ depends on $T_{min}$ of both 31 DAT – 37 DAT and 38 DAT – 44 DAT to explain 25.92 per cent of the variation. However, in the case of BPH and GLH, $PC_1$ has accounted for 36.74 per cent of variations by exhibiting higher loadings with $T_{min}$, $RH_{max}$, $RH_{min}$ and rainfall of 1 DAT – 7 DAT and $T_{min}$ of 8 DAT – 14 DAT. $PC_2$ has explained 33.09 per cent of variations and has higher loadings with a combination of $T_{max}$, $RH_{max}$, $RH_{min}$ and rainfall of 8 DAT – 14 DAT. $PC_3$ relies on $T_{max}$ of 1 DAT – 7 DAT to account for 18.04 per cent of variations in the input data. In both cases, the retained PCs cumulatively explain around 90 per cent of the input data variations.

In the next step, to find out the best model under each count data regression set up, the stepdown method has been employed. In our study, the stepdown regression procedure starts with considering all the retained PCs in the model, i.e. with a full model and then, variable selection and model building are carried out simultaneously. For GB and GLH count data, the final model consists of $PC_2$ and $PC_3$ as explanatory variables in all the regression set-ups under investigation. However, in the case of BPH count data, $PC_1$ and $PC_2$ comprise the final models. To examine whether the over-dispersion test provides any reliable guidance for model selection, we have applied the over-dispersion test to all the count data sets under study. Table 5 deciphers the presence of overdispersion in BPH and GLH count data sets indicating that in both these cases, the models with the ability of accommodating over-dispersion (Negative binomial regression model, Generalised Poisson regression model and Modified Poisson quasi-Lindley regression model) may perform better than the model assuming equi-dispersion (Poisson regression model ).

The parameter estimates of the Poisson regression, negative binomial regression, generalised Poisson regression and modified Poisson quasi-Lindley regression models are obtained in the next step and provided in Table 6-

**Table 5.** Results of the over-dispersion test

| Insect pest | Statistic | p-value |
|---|---|---|
| GB | 1.272 | 0.207 |
| BPH | 11.603 | <0.001 |
| GLH | 10.153 | <0.001 |

**Table 6.** Parameter estimates of the poisson regression models

| Insect pest | Parameter | Estimate | Standard error | p-value |
|---|---|---|---|---|
| GB | $\beta_0$ | 3.034 | 0.024 | <0.001 |
| | $\beta_2$ | -0.037 | 0.004 | <0.001 |
| | $\beta_3$ | 0.036 | 0.002 | <0.001 |
| BPH | $\beta_0$ | 4.737 | 0.008 | <0.001 |
| | $\beta_1$ | -0.028 | 0.001 | <0.001 |
| | $\beta_2$ | 0.013 | 0.002 | <0.001 |
| GLH | $\beta_0$ | 5.431 | 0.006 | <0.001 |
| | $\beta_2$ | 0.028 | 0.001 | <0.001 |
| | $\beta_3$ | 0.009 | 0.001 | <0.001 |

**Table 7.** Parameter estimates of the negative binomial regression models

| Insect pest | Parameter | Estimate | Standard error | p-value |
|---|---|---|---|---|
| GB | $\beta_0$ | 3.032 | 0.032 | <0.001 |
| | $\beta_2$ | -0.038 | 0.016 | 0.017 |
| | $\beta_3$ | 0.037 | 0.017 | 0.029 |
| | Dispersion | 0.039 | 0.031 | 0.208 |
| BPH | $\beta_0$ | 4.734 | 0.023 | <0.001 |
| | $\beta_1$ | -0.025 | 0.007 | <0.001 |
| | $\beta_2$ | 0.012 | 0.005 | 0.016 |
| | Dispersion | 0.049 | 0.022 | 0.026 |
| GLH | $\beta_0$ | 5.425 | 0.017 | <0.001 |
| | $\beta_2$ | 0.031 | 0.007 | <0.001 |
| | $\beta_3$ | 0.012 | 0.006 | 0.045 |
| | Dispersion | 0.031 | 0.014 | 0.031 |

**Table 8.** Parameter estimates of the generalised Poisson regression models

| Insect pest | Parameter | Estimate | Standard error | p-value |
|---|---|---|---|---|
| GB | $\beta_0$ | 3.029 | 0.026 | <0.001 |
| | $\beta_2$ | -0.036 | 0.012 | 0.003 |
| | $\beta_3$ | 0.040 | 0.014 | 0.004 |
| | Dispersion | 0.018 | 0.011 | 0.102 |
| BPH | $\beta_0$ | 4.729 | 0.020 | <0.001 |
| | $\beta_1$ | -0.023 | 0.005 | <0.001 |
| | $\beta_2$ | 0.015 | 0.003 | <0.001 |
| | Dispersion | 0.014 | 0.006 | 0.019 |
| GLH | $\beta_0$ | 5.421 | 0.011 | <0.001 |
| | $\beta_2$ | 0.034 | 0.005 | <0.001 |
| | $\beta_3$ | 0.011 | 0.004 | 0.006 |
| | Dispersion | 0.008 | 0.004 | 0.026 |

9 respectively, where $\beta_0$ denote the intercept term and $\beta_i$ (i= 1, 2, 3) represents the coefficient of the i[th] PC.

The comparative assessment (Table 10) reflects that the modified Poisson quasi-Lindley regression model has provided better results than all other count data regression models in presence of over-dispersion. The Poisson regression model has clearly failed to account for over-dispersion in the case of BPH and GLH data sets (Table 6). The significance of regression parameters has exhibited an upward bias due to the under-estimation of standard errors (Berk and MacDonald 2008). However, as no over-dispersion is evident in the GB data set, the Poisson regression model has outperformed all of its counterparts. As

**Table 9.** Parameter estimates of the modified Poisson quasi-Lindley regression models

| Insect pest | Parameter | Estimate | Standard error | p-value |
|---|---|---|---|---|
| GB | $\beta_0$ | 3.033 | 0.035 | <0.001 |
| | $\beta_2$ | -0.035 | 0.015 | 0.019 |
| | $\beta_3$ | 0.034 | 0.016 | 0.034 |
| | Dispersion | 0.446 | 0.378 | 0.238 |
| BPH | $\beta_0$ | 4.736 | 0.024 | <0.001 |
| | $\beta_1$ | -0.023 | 0.006 | <0.001 |
| | $\beta_2$ | 0.011 | 0.004 | 0.006 |
| | Dispersion | 0.028 | 0.014 | 0.046 |
| GLH | $\beta_0$ | 5.428 | 0.019 | <0.001 |
| | $\beta_2$ | 0.026 | 0.006 | <0.001 |
| | $\beta_3$ | 0.013 | 0.005 | 0.009 |
| | Dispersion | 0.014 | 0.007 | 0.049 |

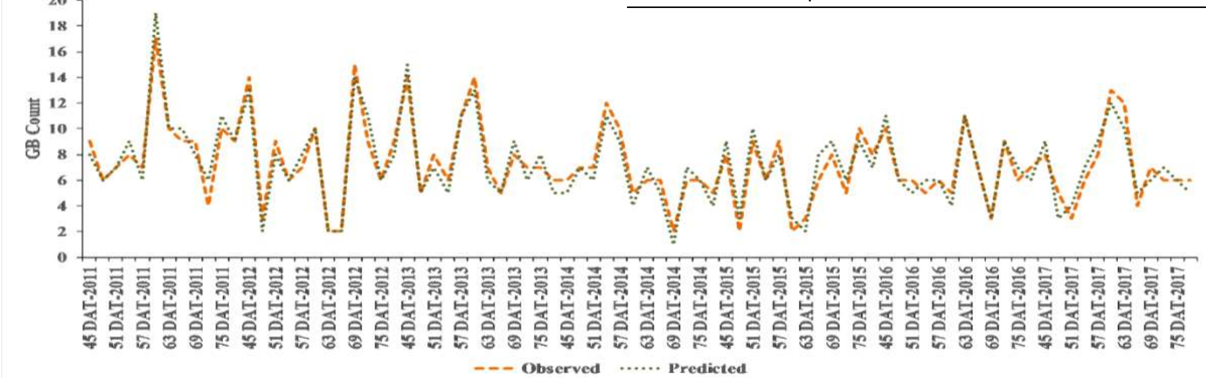


**Fig. 1.** Observed and the Poisson regression model predicted GB counts for the years under study

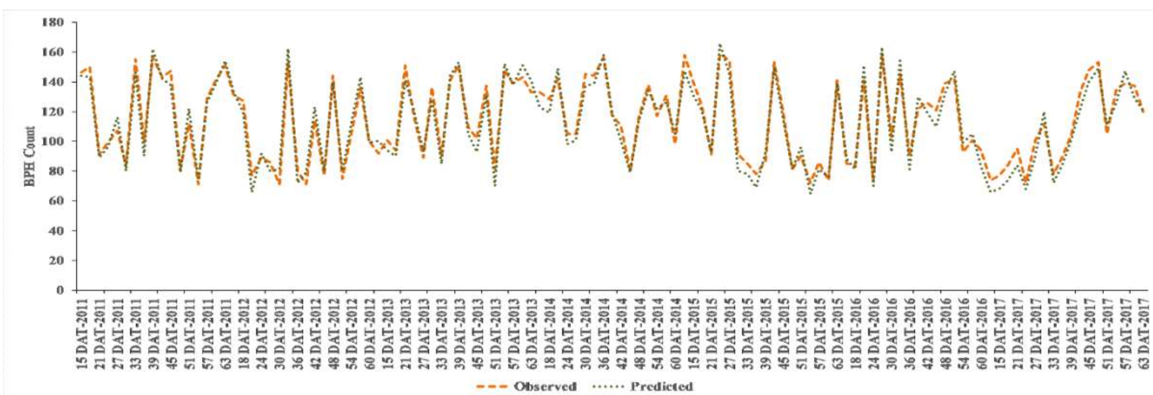


**Fig. 2.** Observed and the modified Poisson quasi-Lindley regression model predicted BPH counts for the years under study

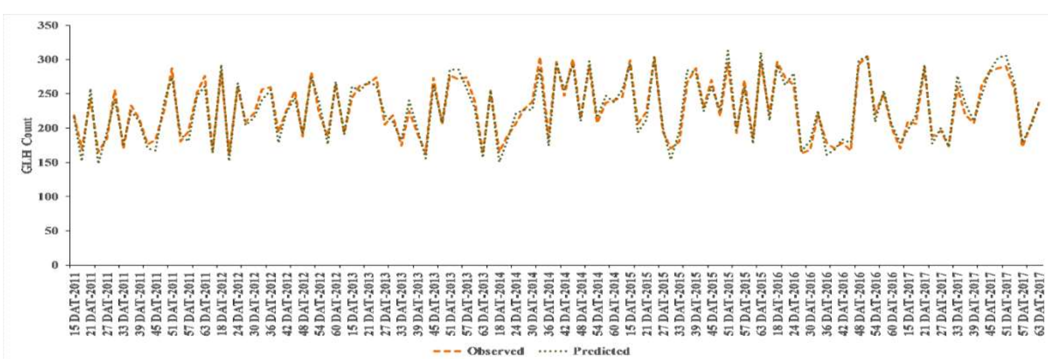


**Fig. 3.** Observed and the modified Poisson quasi-Lindley regression model predicted GLH counts for the years under study

**Table 10.** Comparative assessment of the count data regression models under study

| Model | GB | | BPH | | GLH | |
|---|---|---|---|---|---|---|
| | AIC | BIC | AIC | BIC | AIC | BIC |
| Poisson regression model | 1.90 | 9.19 | 866.40 | 874.74 | 1064.97 | 1073.31 |
| Negative binomial regression model | 7.01 | 16.73 | 492.50 | 503.62 | 575.80 | 586.92 |
| Generalised Poisson regression model | 5.73 | 15.45 | 501.05 | 512.17 | 580.94 | 592.06 |
| Modified Poisson quasi-Lindley regression model | 9.96 | 19.68 | 463.39 | 474.51 | 562.32 | 573.44 |

the estimation procedure of these models is directly linked to the existence of over-dispersion of the count response variable conditional to the explanatory variables (Cameron and Trivedi 2013), the detection of over-dispersion is of prime importance to ensure that the inferences drawn from the employed count data regression model are appropriate. The mean and variance values of GB count are somewhat comparable, whereas in case of BPH and GLH counts, there exist substantial differences indicating possible over-dispersion, which has further been confirmed from the results of the over-dispersion test. Year-wise observed and fitted counts for the three rice insect pests under study by the respective best-fitted model are graphically represented in Figure 1-3, respectively.

## CONCLUSIONS

Among the count data regression models under investigation, the recently developed modified Poisson quasi-Lindley regression model has empirically outperformed all of its counterparts in handling over-dispersion. However, the Poisson regression model has provided better result when no over-dispersion is evident. We also find that the over-dispersion test plays a fairly good role in providing reliable guidance on the presence of over-dispersion. Even though the weather-based modified Poisson quasi-Lindley regression model has satisfactorily accommodated for over-dispersion, the scope still remains for further modification and exploration to predict the over-dispersed count response variable more accurately.

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# Formulation of Abiotic Triggers for Prediction of Thrips and Whitefly Pest in Bt Cotton under Rainfed Condition of Maharashtra

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***Abstract***: Thrips and whitefly is the destructive insect of Bt. cotton worldwide. We analysed infestation dynamics of these pests in Bt. cotton during crop growing season of 2002–2018 (17 years), and predicted the factors influencing its abundance. Rainfall, maximum-minimum temperature, maximum-minimum relative humidity, bright sunshine hours and wind influencing the thrips and whitefly population build-up were predicted using MRM technique with reasonable accuracy (R square= 0.83 to 98). The results also showed that light rainfall (<13 mm/h) and medium rainy days (2-3 rainy days /week) combined with light air (WV<4-6 km/hr) and moderate to partially cloudy condition (BSS of 5-8 hrs./day) prevailing coupled with $T_{max}$ (30.0-33.0 $^{o}$C) for both pest, and $T_{min}$ (21.0-22.0 $^{o}$C), RH-I >80% and RH-II >50% for thrips and $T_{min}$ (15.0-22.0 $^{o}$C), RH-I >75% and RH-II >40% for whitefly are favourable to build up optimal population (or above ETL) during the period 34-39 SMW and 38-44 SMW respectively, in which time required management to control both pest.

***Keywords:*** Abiotic factors, Thrips, Whitefly, *Bt* cotton, MRM

India ranks first in cotton production with 38.41 and 26 % of the total world production and area, respectively (Anonymous 2017). Bt cotton was introduced during 2002 in India and currently it occupies over 93 percent of the area under cotton cultivation (Kumar et al 2018) and in general 98-99 percent in Maharashtra. Among various insect species infesting the Bt cotton crop at different growth stages, a complex of sucking pests viz., aphid, jassid, thrips and whitefly cause considerable damage and it causes 22.85% reduction in seed cotton yield under rainfed conditions (Mohapatra 2008). The insects damage cotton to the tune of 39.50 % and about 40-50 % of crop is damage due to sucking insect pests (Ali et al 2020). Though, previous field studies have investigated the higher population of whiteflies (*Bemisia tabaci*) and thrips (*Thrips tabaci*) in Bt-cotton as compared to conventional cotton crop (Naveen et al 2017). However, it is seen that any pest can only progress if the conditions provided by the host plants as well as weather are favourable, and weather is one of the major factors responsible for infestation of pests in the crop. Many earlier workers have identified the favourable ranges of weather parameters for thrips and whitefly. Findings of different researchers in the past are mostly similar with each other (Kaur et al 2009, Akaram et al 2013, Panwar et al 2015, and Badgujar et al 2018). Nevertheless, some findings are contradictory regarding relationship of weather and pest which was under taken in the study (Tomar 2010, Jaybhaye and Shinde 2020). Hence, timely forewarning of insect-pest population would certainly be useful for management of pest control, or making strategic decision. Therefore, there is a need to develop forewarning systems, which can provide advance information for outbreak of the pest. The linear regression equation based on abiotic factors for prediction of sucking pest incidence on cotton is playing important role in pest management (Kumar et al 2018, Jaybhaye and Shinde 2020). Therefore, to standardise range of abiotic factors for optimal or above ETL pest population of *Bt* cotton, under rainfed condition is an urgent need. And the present study is useful to get an idea for environment friendly and economical integrated pest management in advance by using district wise medium range weather forecast issued by IMD (Jaybhaye et al 2018, Jaybhaye and Shinde 2020). With this background present study was conducted to identifying weather triggers and forewarning of the incidence of sucking pests (thrips and whitefly) at different standard meteorological week (SMW) during Bt cotton crop growth period under rainfed climatic condition.

## MATERIAL AND METHODS

**Field experimentation:** Field experiments were carried out for the period of 17 years (2002 to 2018) at Department of Agricultural Meteorology and Department of Agricultural

Entomology, VNMKV, Parbhani, Maharasthra, India. Experiments were conducted without plant protection with a plot size of 9.6 m X 9.0. After receipt of monsoon rainfall, more than 100 mm in one meteorological week (MW), Bt cotton crop were sown at spacing 120 x 45 cm under rainfed farming, in the *kharif* seasons (25 SMW to 52 SMW). The *Bt.* cotton crop Hy. MECH-184 (2002 to 2005), Hy. Rasi-2 (2006 to 2015) and Hy. RCH-659 BG II (2016 to 2018) was taken during experimentation.

**Pest data collection:** Each experiment plot was divided in to four quarters of 4.8 m X 4.5 m to record observations. Population of thrips and whitefly were recorded before 1000 hrs at weekly intervals from three leaves (each from top, middle and bottom of crop canopy) on five randomly selected plants from each of the quadrant as per standard procedure (Jaybhaye and Shinde 2020, Pathania et al 2020). Biotic factors (i.e. thrips and whitefly population values) for the study period (2002-2018) were recorded weekly from 28 SMW to 52 SMW. Recorded weekly average pest values were converted into meteorological week wise long-term average (Fig. 1).

**Weather data collection:** Seasonal abiotic factors (RF: rainfall, RD: rainy days, $T_{max}$: maximum temperature, $T_{min}$: minimum temperature, RH-I: morning relative humidity and RH-II: afternoon relative humidity, BSS: bright sunshine hours and WV: wind velocity for the experimentation period were recorded daily from the agrometeorological observatory located at Dept. of Agril. Meteorology VNMKV, Parbhani and as per standard meteorological week (SMW), it was converted into average (Fig. 1).

**Statistical analysis:** The population occurrences of thrips and whitefly have quantified the relationship with climatic variables, including RF, RD, $T_{max}$, $T_{min}$, RH-I and RH-II, BSS, and WV, using Pearson's correlation analysis with regards to crop season from 33 SMW to 52 SMW. Significant correlation coefficient (R) values were taken as criteria to select suitable factor(s) for developing multiple linear regression (MLR) models with observed pest population. The correlation between weather factors and pest population dynamics were under taken. Correlations worked out between observed pest populations and weather factors for a SMW (Table 1).

**Development of multiple regression models (MRM):** Simple regression analysis generated in between weekly mean thrips/whitefly population and weather parameters independently. Multiple linear regression (MLR) also known simply as multiple regression (MR) and MLR equation also known multiple regression model (MRM), is a descriptive statistics analysis technique that used to for prediction of pest population were developed. The objective of MRM is the transfer of information among several abiotic factors observed simultaneously and the estimation of the dependent variable from these independent variables. MRM with a stepwise selection method was developed, considering weather variables to achieve a maximum coefficient of determination ($R^2$) for estimating the pest population. MR is a statistical method in regression for analysis of relationships between a single dependent variable and two or more independent variables (Jaybhaye and Shinde 2020) in the form (Equation (1))

$$Y = b_0 + b_1x_1 + b_2x_2 + \ldots\ldots. + b_nx_n \quad (1)$$

Where, Y is the dependent variable (predicated or expected value of pest population), $b_0$ is the y-intercept (value of y when all other parameters are set to 0) and $b_1$, $b_2$,…, $b_n$ are the regression coefficients and $x_1$, $x_2$,…, $x_n$ are the independent variables (abiotic factors). The MRM's were generated by IBM SPSS Statistic 22.0 (Anonymous 2013). The MRM's were developed based on the descriptive

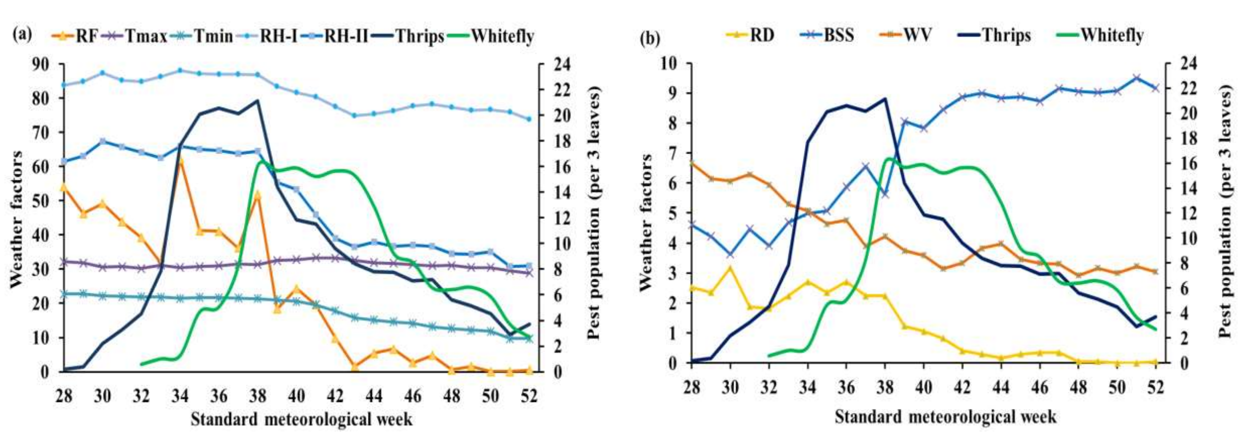


**Fig. 1.** Population dynamics of thrips and whitefly in relation to weather factors (a) rainfall, maximum and minimum temperature, morning and afternoon relative humidity (b)rainy days, bright sunshine hours, wind velocity etc. having significant relationship

statistics analysis of dependant variables (Thrips/whitefly population values) and independent variables (weather factors) of the same SMW were considered. To develop MRM's for forewarnings MRM of thrips, eight, six and three selective independent variables (i.e. abiotic factors) and for whitefly, eight, five, four and two selective independent variables (i.e. abiotic factors) were taken, respectively. And out of available 25-week data (28-52 SMW), 20 weeks data (33-52 SMW) for thrips and 15 weeks data (38-52 SMW) for whitefly is taken, during this period of thrips/whitefly population values were recorded more or at Economic Threshold Level (ETL). The ETL level of thrips and WF (30 adult/ 3 leaves) was reported by Bhede and Bhosle (2012) which is useful to decide spraying schedule. In this study Model 1, Model 2, Model 3 and Model 4 are represented by MRM-1, MRM-2, MRM-3 and MRM-4 respectively to different models (Table 2). The performance evaluations of models during development and validation period (SMW) were carried out with comparison of predicted and observed values of pest population. The performance criteria adopted here is the highest correlation coefficient ($R^2$) and the lowest values of standard error (SE) and lower error % in observed-estimated values by MRM. The error % in pest population based on multiple regressions models were worked out as per Jaybhaye and Shinde (2020).

## RESULTS AND DISCUSSION

The weekly mean data on population dynamics of thrips and whitefly infesting *Bt* cotton showed highly significant differences among the years (2002 to 2018) and week to week may be due to the variation in year to year climatic and week to week weather condition i.e. abiotic factors (*viz.,* RF, RD, $T_{max}$, $T_{min}$, RH-I, RH-II, BSS and WV etc.). The changes in the abiotic factor (independent factor) forced to changes in the thrips and whitefly incidence i.e. biotic stress (dependent factor) during the crop growing period. The insects in nature are not under the influence of one single factor but are subjected to abiotic factor and availability of food (i.e. change in the crop growth stage and crop condition) which plays a role in the distribution and abundance of pest (Jaybhaye and Shinde 2020). The microclimatic conditions largely influence the pest number and activity either directly or indirectly (Kaur et al 2009, Pathania et al 2020). Consequently, it is evident that all the abiotic factors either significant or highly significant correlation with the thrips/whitefly population or these correlations can be used to predict the population or its trends. Nevertheless, forewarning needs to be made in advance at least one week, which has considerable worth for thrips and whitefly infestation management and this statement is assenting with Jaybhaye and Shinde (2020) developed regression models to predict aphids and jassid population based on abiotic factors.

**Thrips (*Thrips tabaci* Lindeman)**

**Population dynamics:** The present results revealed that thrips builds up its population for 28th SMW after sowing and it was ranged in between 4 to 21 thrips/three leaves. Thereafter, it increased gradually and reaches at the peak during 38th SMW and after that decreased sharply (Fig. 1).

**Table 1.** Correlation matrix of weekly average thrips and whitefly population with weather factors under Bt cotton at Parbhani (2002-2018)

| Pest | RF (mm) | RD (days) | Tmax (°C) | Tmin (°C) | RH-I (%) | RH-II (%) | BSS (hrs) | WV kmhr$^{-1}$ |
|---|---|---|---|---|---|---|---|---|
| Thrips | 0.89** | 0.89** | 0.23 | 0.87** | 0.88** | 0.90** | -0.78* | 0.64* |
| Whitefly | 0.66* | 0.69* | 0.90** | 0.94** | 0.60 | 0.75* | -0.61 | 0.70* |

* Significant at 5% level** Significant at 1% level

**Table 2.** Correlation coefficient and regression equations of thrips and whitefly with respect to weather parameters

| Weather parameters | Regression equation | Correlation coefficient |
|---|---|---|
| (a) Thrips | | |
| Rainfall (mm) | $Y= -0.0085RF^2 + 0.8154RF$ | 0.56 |
| Rainy days (Numbers) | $Y= -4.3425RD^2 + 18.07 RD$ | 0.61 |
| Minimum temperature (°C) | $Y= 0.0384Tmin^2 -0.0536Tmin$ | 0.76 |
| Morning relative humidity (%) | $Y= 0.0114RH\text{-}I^2 -0.788RH\text{-}I$ | 0.77 |
| Afternoon relative humidity (%) | $Y= 0.0036RH\text{-}II^2 +0.0511RH\text{-}II$ | 0.81 |
| Bright sunshine hours (hrs) | $Y= -0.7261BSS^2 + 7.3022BSS$ | 0.75 |
| (b) Whitefly | | |
| Rainfall (mm) | $Y= -0.0141RF^2 + 0.8592RF$ | 0.72 |
| Maximum temperature (°C) | $Y= -0.1141Tmax^2 – 3.3005Tmax$ | 0.70 |

Zanwar et al (2014) reported thrips population was observed during early growth stage and continued till the end of crop growth in Bt cotton. This study has shown that the favourable weather conditions for development and progression of thrips population was light rainfall (<13 mm/h) and medium rainy days (2-3 rainy days /week) combined with light air (WV<4-5 km/h), and moderate to partially cloudy condition (BSS of 5-8 h/day) prevailing coupled with $T_{max}$ (30.0-33.0 $^{0}$C) ($T_{min}$ (21.0-22.0 $^{0}$C), RH-I >80% and RH-II >50%, respectively to build up optimal population (above ETL) of thrips during the 34-39 SMW period (Fig. 1). Kudale (2000) observed maximum population of thrips in 39$^{th}$ MW when temperature and RH were 31.0 $^{0}$C and 83 %, respectively and these results were assenting with Ali et al (2020). However, inverse condition was determined; moderate to heavy rainfall (>13 mm/hr) and more number of rainy days (>2), moderate to heavy winds (> 5-6 km/hr.), clear weather (>8 hrs/day of BSS) were not favourable weather condition. These results are in agreement with Shivanna et al (2011) who stated that more precipitation was negative effect on the thrips and whitefly pest of cotton**.**

In general, year to year variation in first incidence of thrips was observed by 4-5 weeks (w.e.f. 28$^{th}$ to 32$^{nd}$ SMW) and it might be because of variation in date of monsoon initiation, which are influenced on sowing dates of Bt. cotton, and more or less similar trend was observed in peak incidence and completely cessation period. The large variation observed in numbers of count (11.9 to 75.6 thrips /three leaves) at peak incidence of thrips. These fluctuations in population build up were prominently due to variation in weather factors. It could be due to a reason stated earlier (Kaur et al 2009, Jaybhaye and Shinde 2020, Pathania et al 2020).

**Correlation:** The correlation between weather parameter and thrips population, and their significance is presented in Table 1. The analysis showed that cumulative RF, RD, Tmin, RH-I and RH-II was significantly and highly positive correlated and WV was significantly and positively correlated, while BSS was significantly and negatively correlated with thrips population. Positive and significant correlation between temperatures with population of thrips is also seen in other studies (Arif et al 2006, Akram et al 2013). Unlike these observations, thrips population was reported to be positively and significantly correlated with Tmax and significantly negative with BSS (Babu and Meghwa 2014). Similar positively significant correlation between RD, Tmin and RH-I was observed by Panwar et al (2015).

**Regression models:** Simple regresson models based on individual abiotic factor, which can be predicted population fluctuation of thrips and coefficent of determination is given in Table 2a and Figure 2 Simple regression study indicated that thrips population increases with increasing amount of rainfall (up to 50 mm/week) and rainy days (up to 2.5 i.e. 3 rainy days/week) and thereafter decreasing thrips population (Fig. 2a, b). Shivanna et al (2011 reported that more precipitation was negative effect population. The very good significant positive relationship of thrips population was established with $T_{min}$, Rh-I, RH-II and WV, and it was increased, increases thrips population (Fig. 2d-f and 2h). The negative significant relationship was observe with RF, RD and BSS (Fig. 2a, 2b and 2g), which indicate that as increase in these factors beyond certain range decreased population. Similar results were reported by Arif et al (2006), Akaram et al (2013), Pawar et al (2015).

The regression equation for the prediction of infestation of thrips in Bt. cotton computed by multiple linear regression analysis using data on thrips population dynamics and weather parameters. The computed regression equations were given in Table 3 (a), the coefficient of determination ($R^2$) was tested for significance at both 5% and 1% level of probability. The $R^2$ value indicated that how much % variation in thrips population is explained by the weather parameters involved in equation, but as seen by the regression equation,

**Table 3.** Multiple regression models for forewarning of thrips and whitefly

| Model No. | Equation | R Square | Std. Error |
|---|---|---|---|
| (a) Thrips | | | |
| MRM-1 | Y= -19.97+0.08 (RF)+9.34(RD)+3.22($T_{max}$)-1.94($T_{min}$)-1.12(RH-I)+0.88(RH-II)+1.58(BSS)-2.99(WV) | 0.93 | 2.16 |
| MRM-2 | Y= -9.0 +0.14 (RF)+5.08(RD)-0.01($T_{min}$)-0.48(RH-I)+0.46(RH-II)+3.84(BSS) | 0.91 | 2.24 |
| MRM-3 | Y= -0.962 +0.132 (RF)+0.963(RD)+0.496($T_{min}$) | 0.83 | 2.73 |
| (b) Whitefly | | | |
| MRM-1 | Y= -7.31+0.02 (RF)-0.27(RD)+1.12($T_{max}$)+1.01($T_{min}$)-0.42(RH-I)-0.05(RH-II)-0.71(BSS)+2.33(WV) | 0.98 | 0.99 |
| MRM-2 | Y= -14.97+0.05 (RF)+0.40(RD)+0.42($T_{max}$)+1.58($_{Tmin}$)-0.31(RH-II) | 0.94 | 1.50 |
| MRM-3 | Y= -16.61 +1.58 (RD)+0.49($T_{max}$)+1.53($T_{min}$)-0.31(RH-II) | 0.94 | 1.43 |
| MRM-4 | Y= -5.82+1.80 ($T_{min}$)-0.28(RH-II) | 0.94 | 1.32 |

RF in all three model, RH-I in first two model and WV in first model had a negative influence on thrips population, while other all the weather parameters had a positive influence in respective models.

On the basis of descriptive statistics analysis, generated MRM's and evaluated of all three MRM (Table 3a) were accepted and validated for forewarning of thrips population in *Bt* cotton. The comparison in between predicted and observed thrips population values shows very good agreement for the seasonal comparison and slope of the regression line (regression coefficient- $R^2$) for predicated vs observed thrips population values was significantly <1 (Figure 3-1 to 3). Separate regression for the three different models indicates accuracy of models and linear regressions are (1) y=0.986x, $R^2$=0.97; (2) y=1.0x, $R^2$=0.95 and (3) y=0.947x, $R^2$=0.93 whereas, x= observed thrips population values. The $R^2$ value indicated that 93 to 97 % accuracy of forewarned model with observed thrips population.

The observed mean error percentage of MRM 1, MRM 2 and MRM 3 was quite low (1.0, 3.0 and 1.4 % respectively). The seasonal prediction error of the model below 10-15% is acceptable error, considering the criteria for ETL of thrips (Jaybhaye and Shinde 2020). The present investigation of SMW wise seasonal prediction error was shown by MRM 1 to MRM 3 is 11-14 % except 34, 35, 37, 51 and 52 SMW. The error % observed more in the estimated values of models may be due to error in the data which could be caused due to error induced by human beings or by instruments during collection of data/processing of data, and similar observations were reported by Pathania et al (2020). Thus, all models (MRM 1 to 3) (Table 3a) can be used in the field of Bt. cotton to forewarning of thrips infestation under given environmental conditions for one week in advance.

**Whitefly (*Bemisia tabaci* Genn)**

**Population dynamics:** The whitefly builds up its population for 31$^{st}$ SMW after sowing and it was ranged in between 3 to

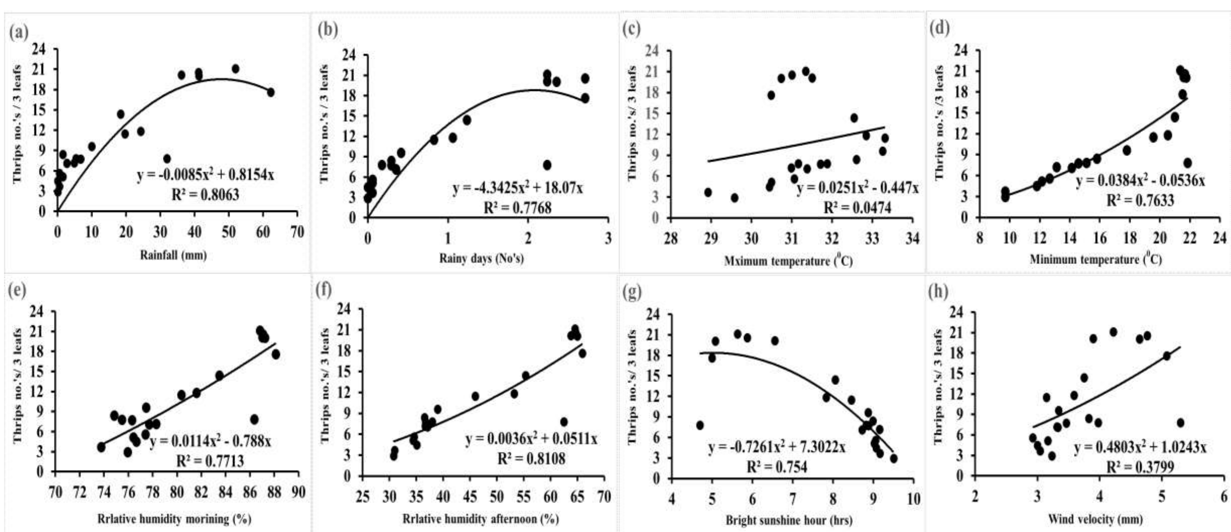


**Fig. 2.** Relation between thrips population and weather factors (a-rainfall; b- rainy days; c-maximum temperature; d-minimum temperature; e-morning relative humidity; f-afternoon relative humidity; g-bright sunshine hours and f-wind velocity)

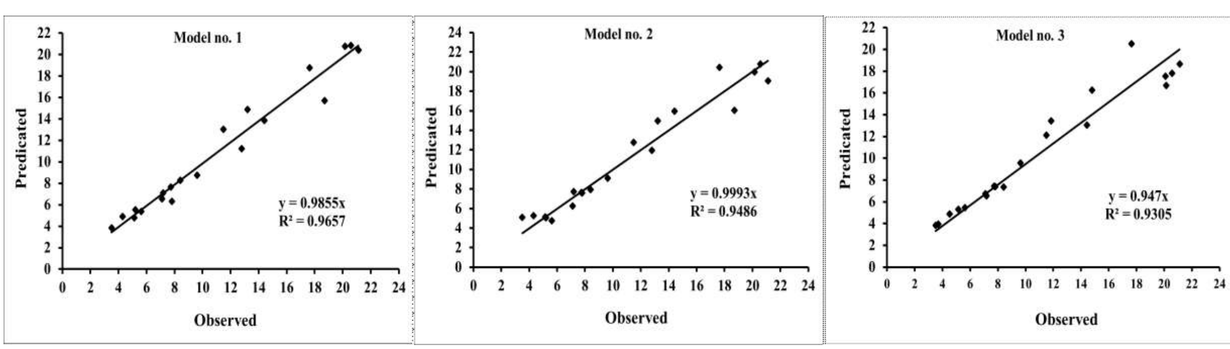


**Fig. 3.** Relation between observed and predicated thrips population

16 whitefly/three leaves. Thereafter, it increased gradually and reaches at the peak during 38th SMW and after that more or less constant up to 43rd SMW and decreased sharply thereafter (Fig. 1). The light rainfall (<13 mm/hr) and medium rainy days (2-3 rainy days /week) combined with light air (<5-6 km/hr) and moderate to partially cloudy condition (BSS of 5-8 hrs/day) prevailing, coupled with $T_{max}$ (30.0-33.0 $^0$C) ($T_{min}$ (15.0-22.0 °C), RH-I >75% and RH-II >40% were congenial to build up optimal population (or above ETL) of whitefly (which have need to control through management) and which was observed during the 38-44 SMW period. Though, opposite condition was determined, weekly mean moderate to heavy RF (>13 mm/hr.) and a greater number of rainy days (>2/week) to moderate heavy winds (>5-6 km/hr), clear weather (>8 hrs./day of BSS) weather condition are not favourable for development and growth in population of whitefly under rainfed Bt. cotton.

The present findings on the activity, peak incidence and impact of abiotic factor on the whitefly are in agreement with the findings of Badgujar *et al.* (2018) who reported the population fluctuation of whitefly during *kharif* 2008-2010 on BG-I Bt cotton ranged from 0.2 to 61.0 whiteflies/3leaves, incidence started at 35th SMW and peak activity was observed during 41st to 45th SMW and thereafter decreased suddenly. Similar to present findings Ali *et al*. (2020) reported that they were reported that the population density of white fly was gradually increases by increase in temperature up to 35°C but decreasing the population size above 35°C. The population size was increased with the increase of humidity level but above 60% of humidity level it was highest. The fluctuation of population size was observed with the increase of wind speed which has no significant effect on population density of this pest. These findings are also supported with those of Sharma et al (2004), Mohapatra (2008), Pawar et al (2015), Parsai and Shastry (2009). Similarly, Selvaraj and Ramesh (2012) reported that maximum population (7.99/3 leaves) was build up at temperature ranged from 26.0 °C to 35.0 °C, relative humidity ranges from 84 and 67 per cent, wind velocity 6.30 km/hr, total shine hours (9.4 hrs), evaporation (52.20 mm), dewfall (0.708 mm) coupled with no rains weather condition. Similar results were reported by Shivanna et al (2011) where more precipitation was negative effect on whitefly. In general, year to year variation in first incidence of whitefly was observed by 2-5 weeks (w.e.f. 31st to 35th SMW) and more or less similar trend was observed in peak incidence and completely cessation period as mentioned above in mean population dynamics; it is because of earlier stated reason under thrips. Large variation observed in numbers of count (1 to 38 whitefly /three leaves) at peak incidence of thrips. These fluctuations in population build up were prominently due to variation in weather factors (Jaybhaye and Shinde 2020, Pathania et al 2020).

**Correlation:** Figure 1 clarifying the relationship in between weather parameters and whitefly population dynamics and the correlation study revealed that the whitefly population was significantly and highly positive correlated with $T_{max}$ and $T_{min}$; significantly and positively correlated with RF, RD, RH-II and WV (Table 1).

Shivanna et al (2011) observed that whitefly population in range of 3.9 to 42.0 per 3 leaves and rainy days and relative

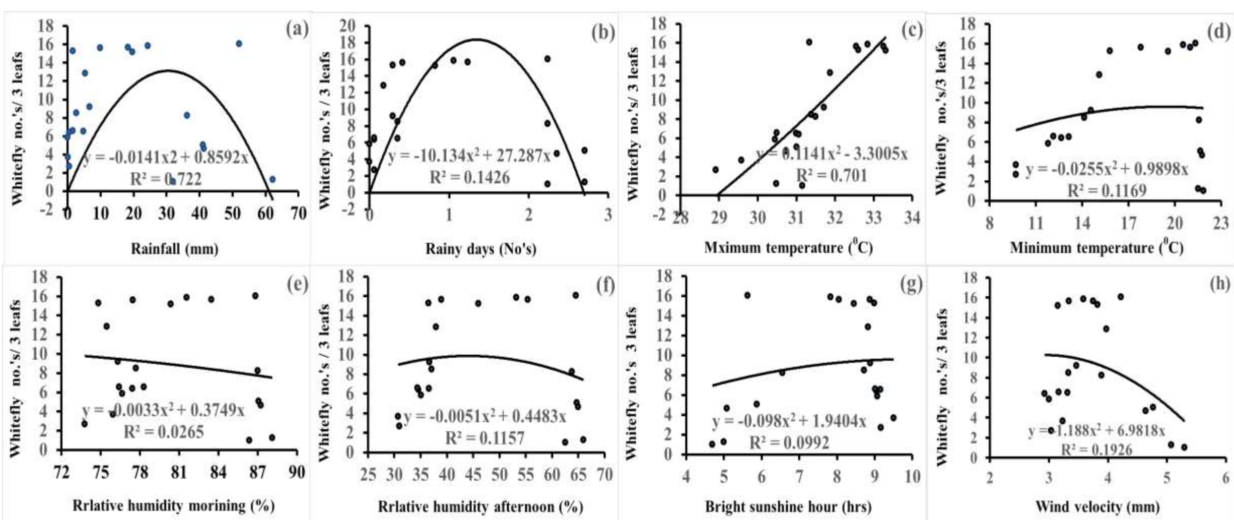


**Fig. 4.** Relation between whitefly population and weather factors (a-rainfall; b- rainy days; c-maximum temperature; d-minimum temperature; e-morning relative humidity; f-afternoon relative humidity; g-bright sunshine hours and f-wind velocity)

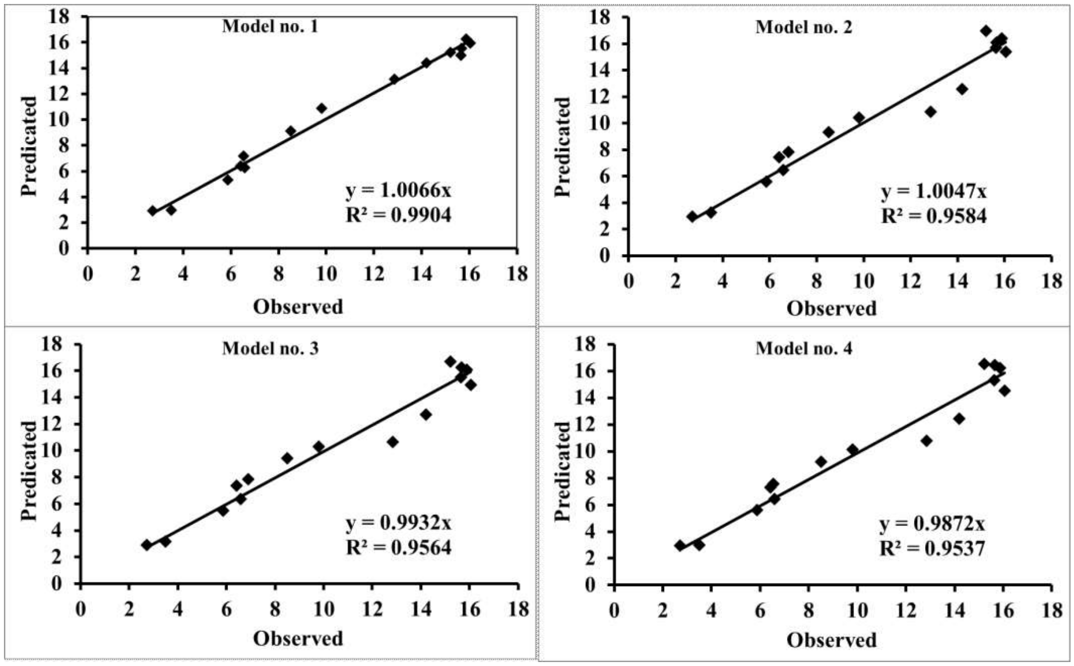


**Fig. 5.** Relation between observed and predicated whitefly population

humidity were the main significant contributing factors for maximum occurrence of whitefly in Bt cotton. Present results are in conformity with Ashfaq et al (2010) who reported that whitefly population to be positively correlated with the temperature and rainfall and the present findings is more or less agreeing with the results of Patel et al (2013), Akram et al (2013), Zanwar et al (2014), Babu and Meghwa (2014).

**Regression models:** The relationship between the recorded weekly mean abiotic factors independently and whitefly population (Fig. 4) and simple regression study indicated that population increases with increasing amount of rainfall (up to 40 mm/week) and rainy days (up to 2 rainy days/week) and thereafter decreasing population (Fig. 4a,b). The very good significant positive relationship of whitefly population was established with $T_{max}$ and it was increased, increases population of whitefly (Figure 4c). The negative significant relationship with remaining abiotic factors (Fig. 4a-b and 4d-h), which indicate that as increase in above mentioned abiotic factors beyond certain range decreases population. These results are also assenting with Muchhadiya et al (2014) where that RF, $T_{min}$, RH-I and RH-II are significantly negatively associated with the whitefly incidence. Simple regression models based on individual abiotic factor, which can be predicated population fluctuation of whitefly, along with coefficient of determination is given in Table 2b. On the basis of descriptive statistics analysis, generated MRM's and evaluated of all four MRM (Table 3b) were accepted and validated for forewarning of whitefly population in *Bt* cotton. The comparison in between predicted and observed whitefly population values shows very good agreement for the seasonal comparison and slope of the regression line (regression coefficient) for predicated vs observed whitefly population values was significantly <1 (Fig. 5, 1-4). Separate regression for the four different models indicates accuracy of models and linear regressions are (1) y=1.007x, $R^2$=0.99; (2) y=1.005x, $R^2$=0.96 and (3) y=0.993x, $R^2$=0.96 and (4) y=0.987x, $R^2$=0.95; whereas, x= observed whitefly population values.

All models (MRM 1 to 4) (Table 3b) were accurate and acceptable to forewarning of whitefly infestation for one week in advance. This may be beneficial to management of in Bt cotton, because the observed mean error percentage in MRM 1, MRM 2, MRM 3 and MRM 4 was quite low (-0.4, -0.8 , -2.0 and -0.4 % respectively). In the present investigation of SMW wise seasonal prediction error was shown by MRM 1 to MRM 4 is 11-15 % except for 44 and 45 SMW. The error % observed more in the estimated values of models may be due to reason stated above (Pathania et al 2020). Therefore, statistical weather based thrips and whitefly pest models are required to continue verification and validation under filed condition for specific geographical location.

## CONCLUSION

It can be concluded from the present study that thrips and whitefly are destructive pests up to some extent of the Bt. cotton crop and it will be more destructive in future with changing climate, and its population build-up and dynamics is greatly influenced by abiotic factors viz. rainfall, temperature, relative humidity and radiations which primarily affected the seasonal fluctuations and incidence thrips and whitefly in Bt. cotton under rainfed condition. August to October for thrips and September to November for whitefly are most crucial for population build up and further spread. Thus, planning and implementing management strategies against this pest under semi-arid climatic conditions during this time plays important role in sustainable rainfed Bt. cotton cultivation. Prediction or development of a Decision Support System for infestation and dynamics of a particular insect-pests involving the abiotic factors is of great significance in pest management. In general, the study warrants the adoption of pest monitoring for timely decision making in formulating pest management strategies. Need-based and timely Integrated Pest Management strategies are effective against thrips and whitefly under field conditions.

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# Non-Preference Mechanism of Resistance in Rice Germplasm Accessions to Whitebacked Planthopper *Sogatella furcifera* (Horvath)

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***Abstract*:** A total of 1010 germplasm accessions collected from different parts of India were mass screened for their reaction to Whitebacked planthopper, *Sogatella furcifera* (Horvath) by standard seedbox screening technique during 2016-2018 at ICAR-Indian Institute of Rice Research, Hyderabad. 43 accessions exhibited a damage score (DS) ranging from 1.39 to 5.0 and were designated as resistant and moderately resistant to WBPH, and 967 accessions were susceptible (DS 5.1 to 9.0). Two germplasm accessions *viz.,* IC 75864 (DS-1.39), IC 215295 (DS-2.65) were resistant and 41 accessions were moderately resistant (DS 3.1 to 5.0). The selected resistant accessions were assessed for their feeding preference by WBPH by measuring feeding/probing marks and honeydew excretion area. The resistant accessions exhibited more number of probing marks ranging from 4.6 to 24.0/seedling indicating the non-suitability of the accessions for feeding by WBPH. Resistant check MO1 recorded 31.6, PTB33 recorded 17.8 probing marks and susceptible check TN1 recorded 8.2 probing marks/seedling. WBPH fed less and excreted less honeydew on the resistant germplasm accessions indicating their non-preference. Negative correlation existed between resistance and probing marks whereas it is positively correlated with honeydew excretion. The identified resistant germplasm accessions can be used in the breeding programmes to develop WBPH resistant varieties.

***Keywords***: Germplasm accessions, Honeydew excretion, Host plant resistance, Mass screening, Probing marks, *Sogatella furcifera*, Whitebacked planthopper

Rice is one of the world's most important staple food crops. There are many constrains in rice production among which insect pests remain a constant problem in all rice growing areas. One of the most economically important insects is the Whitebacked planthopper, *Sogatella furcifera* (Horvath) (Hemiptera: Delphacidae) which is a migratory insect which can cause huge damage where both the nymphs and adults suck the plant sap directly and results in loss of water and nutrients (Park et al 2008) and indirectly transmits viral diseases such as black-streaked dwarf virus (Pie et al 2016). The control of WBPH with chemical insecticides results in insecticide resistance development, detrimental impact on natural enemies and environmental pollution (Jhansi Lakshmi et al 2010a,b,c, Dhawan et al 2013, Kamala 2020, Vijay Kumar Yadav et al 2021). Host plant resistance is the most important measure to keep the insect pests under control. A resistant plant variety that reduces the insect population by 50 per cent in each generation is sufficient to eliminate an insect of economic importance within few generations. The necessity to identify suitable new resistant donors for whitebacked planthopper from different sources is important in order to combat the pest and develop resistant varieties. It is also necessary to understand the mechanisms responsible for manifesting resistance into the selected cultures with desirable characters, so that these can be utilized effectively in the breeding programme. Measurement of honeydew excretion and number of feeding marks made by WBPH are used as tools to assess the resistance and susceptibility of a genotype. Keeping this in view, present investigation was planned to evaluate the germplasm accessions for their resistance to Whitebacked planthopper and to study the antixenosis mechanism of resistance for feeding.

## MATERIAL AND METHODS

**Mass rearing of whitebacked planthopper:** WBPH was mass reared on the susceptible rice variety TN1 (Jhansi Lakshmi et al 2010c). WBPH population was initially collected from rice fields and pure culture was maintained in the greenhouse at a temperature of 30±5°C with a relative humidity of 70±5% on 60 day old potted rice plants. Mass rearing was done in the cages of 70 cm x 62 cm x 75 cm dimension with glass panels on one side and wire mesh on all other sides. Adult gravid female hoppers were collected and released on pre-cleaned potted plants and were placed in oviposition cages. After four days of egg laying, the gravid females were collected and released on fresh batch of TN1 plants for further egg laying. Plants with eggs were taken out of cages and placed in separate cages for the nymphs to hatch. Fresh plants were placed in the cages with nymphs as and when required. The hatched nymphs were utilized for experiments as and when they attained the desired age. Using this technique, a continuous pure culture of WBPH was maintained during the period of study.

**Mass screening of germplasm accessions:** In order to identify the sources of resistance to WBPH, 1010 germplasm accessions were mass screened under controlled greenhouse conditions as per the technique described by (Nagendra Reddy et al 2016). The entries were pre-germinated in petridish and sown individually in screening trays filled with fertilizer enriched puddled soil. Each screening tray contained 20 test lines with about 15 -20 seedlings per line, one row of resistant check (MO1) in the middle and two rows of susceptible check (TN1) in the border. When the seedlings are 12 days old, first and second instar nymphs of WBPH were released on the seedlings ensuring that each test seedling was infested with at least 6-8 nymphs. The infested trays were monitored regularly for plant damage. When TN1 plants on one side showed damage, the tray was rotated by 180° for even reaction on both the sides. When more than 90 per cent plants in the susceptible check were killed, the test entries were scored for the damage reaction, based on the 0-9 scale of International Standard Evaluation System (IRRI 2013) (Table 1). All the 1010 germplasm entries were screened in two replications and the identified resistant accessions were further screened in 5-7 replications.

**Feeding behaviour of whitebacked planthopper based on probing marks:** The resistant and moderately resistant entries along with some susceptible accessions, susceptible and resistant checks were selected to find out the feeding behaviour of one day old adults and third instar nymphs of whitebacked planthopper expressed in terms of feeding marks or probing marks on the leaves and stems of the rice entries (Ponnada et al 2011). For this purpose, a single one-day old adult female and third instar nymph were separately confined for 24 hours on seven-day old test entry in a test tube and this was replicated five times. After 24 hours, the insect was removed and the test plant was stained by dipping for one hour in one per cent aqueous erythrosine solution to distinguish the feeding marks from the test entries. The feeding marks were counted and the data were analyzed statistically in Completely Randomized Design (CRD) and the means were separated using DMRT.

**Table 1.** Criteria for WBPH damage score in greenhouse screening

| Resistance score | Plant state | Rating |
|---|---|---|
| 0 | No damage | Highly resistant |
| 1 | Very slight damage | |
| 3 | Lower leaf wilted with two green upper leaves | Resistant |
| 5 | Two lower leaves wilted with one green upper leaf | Moderately resistant |
| 7 | All three leaves wilted but stem still green | Moderately susceptible |
| 9 | All plants dead | Susceptible |

**Honeydew excretion**: This parameter was used to know about non-preference mechanism for feeding. The amount of honeydew excreted by the insects was measured which was an indication of the feeding preference and efficiency of WBPH to feed on a rice variety. Whatman No.-1 filter paper was dipped in ethanol solution dissolved with 0.02% Bromocresol green powder, allowed to dry for 1 hour and dipped again till the filter paper turned yellowish orange (Nanthakumar et al 2012). The treated filter paper was placed at the bottom of 30 days-old plants, planted in small plastic pots. A small plastic cup with a hole was placed over the filter paper and five pre-starved adult insects/3$^{rd}$ instar nymphs were released into the cup. The hole was plugged with cotton to prevent the escape of the insects. The adults were allowed to feed for 24 h at the base of the stem of the plant. The honeydew droplets excreted by the adults/nymphs turn into blue spots when come in contact with the filter paper. The relative area of the spots produced by honeydew excreted on bromocresol green treated filter paper were traced on tracing paper and placed on millimeter square graph paper and the squares were counted and expressed in mm$^2$. The germplasm accessions were statistically compared on the basis of mean value obtained from 3 replications each.

**Correlation and regression analysis**: Pearson correlation analysis and linear regression analysis among the damage score, probing marks and honeydew excretion was done using OP Stat software to understand their relationship and interdependence.

## RESULTS AND DISCUSSION

**Germplasm accessions resistant to WBPH:** Out of these 1010 germplasm accessions, 43 accessions exhibited a damage score (DS) ranging from 1.39 to 5.0 and were designated as resistant and moderately resistant to WBPH, and the remaining 967 accessions were susceptible with a damage score of 5.1 to 9.0 (Table 2). Out of 43 germplasm accessions, two accessions *viz.,* IC 75864 (DS-1.39), IC 215298 (DS-2.65) were resistant and rest 41 accessions were moderately resistant (DS-3.1 to 5.0) (Fig. 1a and 1b). The frequency distribution graph (Fig. 2) shows that in the remaining 967 germplasm accessions, 204 accessions were

**Table 2.** Damage score, probing marks and honeydew excretion of WBPH in the germplasm accessions

| Germplasm accessions | Damage score | Probing marks | | Honeydew excretion ($mm^2$) | |
|---|---|---|---|---|---|
| | | Adults | Nymphs | Adults | Nymphs |
| IC75864 | 1.4 (R) | 16.6 (4.07)$^{c-f}$ | 12.6 (3.52)$^{c-e}$ | 23.6$^{o}$ | 6$^{o}$ |
| IC215298 | 2.7 (R) | 18.8 (4.28)$^{cd}$ | 10.4 (3.22)$^{d-g}$ | 63.3 $^{j-n}$ | 18.7 $^{i-m}$ |
| IC216620 | 3.2 (MR) | 13.8 (3.69)$^{e-i}$ | 13.8 (3.69)$^{c}$ | 72.6$^{g-n}$ | 31$^{e-i}$ |
| IC75877 | 3.5(MR) | 12.4 (3.49)$^{g-k}$ | 10.8 (3.28)$^{c-f}$ | 121.6$^{b-f}$ | 28$^{g-k}$ |
| IC216897 | 3.9 (MR) | 15.0 (3.80)$^{d-i}$ | 7.0 (2.62)$^{j-m}$ | - | - |
| IC216632 | 4.0 (MR) | 14.2 (3.73)$^{e-i}$ | 13.2 (3.58)$^{cd}$ | 68.3$^{h-n}$ | 32.3$^{e-i}$ |
| IC216901 | 4.0 (MR) | 16.6 (4.07)$^{c-f}$ | 10.2 (3.11)$^{e-h}$ | 76.3$^{f-n}$ | 44$^{b-f}$ |
| IC210765 | 4.1 (MR) | 12.0 (3.43)$^{g-k}$ | 7.0 (2.64)$^{i-m}$ | 109.3$^{b-h}$ | 15.7$^{k-n}$ |
| IC216856 | 4.1 (MR) | 15.2 (3.87)$^{d-h}$ | 7.0 (2.64)$^{i-m}$ | - | - |
| IC216563 | 4.2 (MR) | 13.4 (3.65)$^{f-j}$ | 4.2 (2.04)$^{o-s}$ | 66.3$^{i-n}$ | 17.3$^{j-n}$ |
| IC216710 | 4.3 (MR) | 11.4 (3.37)$^{h-l}$ | 5.4 (2.30)$^{l-p}$ | 98$^{c-k}$ | 15.7$^{k-n}$ |
| IC216612 | 4.3 (MR) | 11.4 (3.37)$^{h-l}$ | 2.2 (1.47)$^{uv}$ | 129.6$^{b-d}$ | 48.7$^{b-e}$ |
| IC540676 | 4.3 (MR) | 12.4 (3.49)$^{g-k}$ | 9.2 (3.03)$^{f-j}$ | 74.6$^{g-n}$ | 36$^{d-h}$ |
| IC216944 | 4.3 (MR) | 24.5 (4.91)$^{b}$ | 10.0 (3.09)$^{e-i}$ | 84.3$^{e-l}$ | 11.3$^{m-o}$ |
| IC540644 | 4.4 (MR) | 20.2 (4.42)$^{bc}$ | 2.6 (1.60)$^{r-v}$ | 64.3$^{j-n}$ | 15.7$^{k-n}$ |
| IC216628 | 4.4 (MR) | 11.6 (3.39)$^{g-k}$ | 5.0 (2.2)$^{l-p}$ | 101$^{b-j}$ | 25$^{h-l}$ |
| IC211233 | 4.4 (MR) | 15.6 (3.90)$^{c-g}$ | 2.4 (1.52)$^{uv}$ | 85$^{e-m}$ | 54.7$^{bc}$ |
| IC75735 | 4.5 (MR) | 18.2 (4.21)$^{c-e}$ | 7.8 (2.78)$^{g-k}$ | 53.3$^{l-n}$ | 23.7$^{h-l}$ |
| IC216678 | 4.5 (MR) | 13.8 (3.69)$^{e-i}$ | 4.2 (2.04)$^{o-s}$ | 45.3$^{no}$ | 16.3$^{j-n}$ |
| IC75747 | 4.5 (MR) | 14.4 (3.78)$^{d-i}$ | 2.0 (1.37)$^{v}$ | - | - |
| IC216640 | 4.6 (MR) | 7.4 (2.71)$^{n-p}$ | 4.8 (2.18)$^{m-q}$ | 61$^{k-n}$ | 26.7$^{g-k}$ |
| IC215276 | 4.6 (MR) | 7.2 (2.65)$^{n-q}$ | 2.0 (1.37)$^{v}$ | 49$^{n}$ | 13$^{l-o}$ |
| IC216874 | 4.7 (MR) | 6.6 (2.56)$^{o-q}$ | 3.8 (1.94)$^{p-u}$ | - | - |
| IC216566 | 4.8 (MR) | 14.0 (3.70)$^{e-i}$ | 4.0 (1.98)$^{p-t}$ | 105.6$^{b-i}$ | 42.7$^{b-g}$ |
| IC216479 | 4.8 (MR) | 7.2 (2.67)$^{n-p}$ | 1.8 (1.31)$^{v}$ | 50.3$^{n}$ | 8.7$^{no}$ |
| IC216525 | 4.9 (MR) | 11.0 (3.31)$^{i-m}$ | 6.8 (2.59)$^{k-m}$ | 88$^{d-l}$ | 31.3$^{e-i}$ |
| IC17045X | 4.9 (MR) | 10.0 (3.13)$^{j-n}$ | 3.0 (1.72)$^{q-v}$ | - | - |
| IC216596 | 4.9 (MR) | 6.4 (2.52)$^{pq}$ | 2.4 (1.54)$^{t-v}$ | 76$^{g-n}$ | 41.7$^{d-g}$ |
| IC17037X | 4.9 (MR) | 9.4 (3.06)$^{k-o}$ | 2.6 (1.60)$^{r-v}$ | - | - |
| IC75955 | 4.9 (MR) | - | - | 90.3$^{c-k}$ | 15.7$^{k-n}$ |
| IC216693 | 5.0 (MR) | 8.4 (2.89)$^{l-p}$ | 5.0 (2.22)$^{l-p}$ | 136$^{a-c}$ | 29.3$^{f-j}$ |
| IC458401X | 5.0(MR) | 12.0 (3.45)$^{g-k}$ | 6.6 (2.54)$^{k-m}$ | 78.3$^{e-n}$ | 51.3$^{b-d}$ |
| IC75958 | 5.0 (MR) | 6.8 (2.60)$^{o-q}$ | 6.8 (2.59)$^{k-m}$ | 76.6$^{g-n}$ | 55.3$^{bc}$ |
| IC75748 | 5.0 (MR) | 4.6 (2.14)$^{q}$ | 6.4 (2.52)$^{k-n}$ | 123.3$^{b-e}$ | 55$^{bc}$ |
| IC75800 | 5.1 (MS) | 6.2 (2.46)$^{pq}$ | 7.4 (2.66)$^{h-l}$ | 104.6$^{b-i}$ | 43.3$^{b-f}$ |
| IC540720 | 5.1 (MS) | 7.0 (2.64)$^{n-q}$ | 6.2 (2.47)$^{k-o}$ | 110.3$^{b-g}$ | 32.7$^{e-h}$ |
| IC216609 | 5.1 (MS) | 7.8 (2.78)$^{m-p}$ | 5.0 (2.22)$^{l-p}$ | 144.3$^{ab}$ | 62$^{ab}$ |
| IC75737 | 5.2 (MS) | 9.6 (3.06)$^{k-o}$ | 6.8 (2.59)$^{j-m}$ | - | - |
| MO1 | 1.4 (R) | 31.6 (5.55)$^{a}$ | 31.0 (5.51)$^{a}$ | 28.7$^{g-k}$ | 21.6$^{o}$ |
| PTB 33 | 3.4 (MR) | 17.8 (4.20)$^{c-e}$ | 19.4 (4.37)$^{b}$ | 25.3$^{o}$ | 10$^{m-o}$ |
| TN1 | 9.0 (HS) | 8.2 (2.83)$^{m-p}$ | 4.4 (2.06)$^{n-r}$ | 185$^{a}$ | 82$^{a}$ |
| CD | | 0.4665 | 0.6157 | 46.985 | 28.42 |
| CV(%) | | 10.94 | 37.11 | 32.99 | 5.7123 |

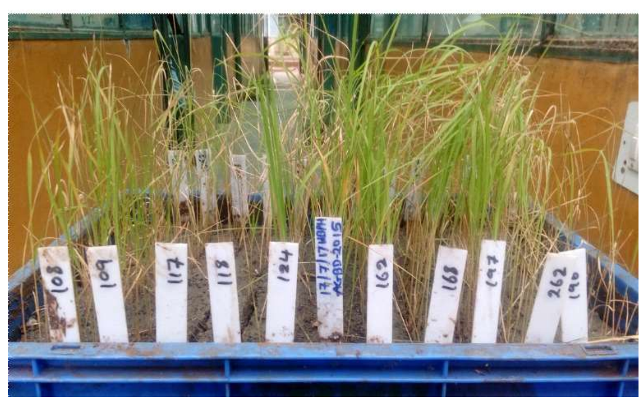
**Note:** Means in a column followed by same letter are not significantly different from each other by LSD (P=0.05). Figures in parenthesis are square root transformed values moderately susceptible with a damage score of 5.1 to 7.0, 329 accessions were susceptible with a damage score of 7.1 to 8.9 and the remaining 434 accessions were highly susceptible with a damage score of 9.0. The resistant check MO-1 recorded a damage score of 1.4, PTB 33 recorded a damage score of 3.4 and the susceptible check TN1 recorded a damage score of 9.0. Host plant resistance is the most economical and desirable method for the management of crop pests (Horgan et al 2015). Screening for resistance to whitebacked planthopper is a continuous process to identify new sources of resistance. In India, host plant resistance to WBPH is being exploited in several research centres and very important sources of resistance have been identified. Beant Singh and Shukla (2007) screened 1224 rice accessions out of which 57 accessions were resistant, 370 were moderately resistant to WBPH. Three lines, viz., RIC 06-0305, RP 4334-TSH-41-8-1-1-2-6 and MO1 were resistant and 28 were moderately resistant out of fifty-eight rice lines (Sarao and Mahal 2007). Sarao and Mahal 2012 screened 66 rice germplasm lines out of which two lines, *viz*., IR 59 547-235-3-3 and SPR 85 163-5-1-2-4 were resistant, 20 lines were moderately resistant and the remaining lines were susceptible to WBPH. Zhu et al 2016 evaluated 218 common wild rice materials out of which one was highly resistant and twenty-one were moderately resistant to WBPH. Out of seventy-four rice landraces, eight landraces *viz*., Kudai Vazhai, Karthi Samba, Vadivel, Ponmani Samba, Kallimadayan, Panamara Samba, Kodaivilayan and Kalyani were resistant and 18 landraces were moderately resistant to WBPH (Venkatesh et al 2019). Four varieties viz., Pathara, Pratap, Tejaswini and Santpheal were resistant and fifteen were moderately resistant out of ninety-four released varieties (Meher et al 2020). The results are in conformity with the findings of Sarao and Mahal 2007, Kumar et al 2018 and Meher et al 2020, where TN1 was highly susceptible, MO1 was resistant and PTB33 was moderately resistant to WBPH.

**Probing marks:** A total number of 37 resistant, moderately resistant and susceptible germplasm accessions along with susceptible check TN1 and resistant checks *viz*., MO1 and PTB33 were selected to find out the feeding behaviour of third instar nymphs and one-day old adult WBPH expressed in terms of feeding marks or probing marks on the stems of rice plants (Table 2).

**WBPH Adults:** There was a significant difference among the germplasm accessions with regard to probing marks. The resistant accession IC 216944 had maximum number of probing marks (24.5) while susceptible check TN1 recorded lowest number of marks (8.2) by adult whitebacked planthopper. The resistant entries recorded more number of probing marks compared to susceptible entries. Maximum number of probing marks were recorded in the resistant accession; IC 216944 (24.5) followed by IC 540644 (20.2), IC215298 (18.8), IC75735 (18.2), IC 75864 (16.6), and IC 216693 (16.6). The resistant check MO1 had more number of probing marks (31.6). The susceptible entries were probed less number of times (average 7.9 probing marks/seedling) compared to resistant germplasm accessions (13.2 marks/seedling) (Table 2).

**WBPH nymphs**: WBPH nymphs probed more number of times on the resistant germplasm accessions compared to susceptible accessions. The resistant germplasm accession IC216620 was probed more number (13.8) of times followed by IC216632 (13.2), IC75864 (12.6) and IC75877 (10.8). The resistant check MO1 received maximum number of probing marks (31.0) and PTB33 was probed 19.4 times. However, the susceptible germplasm accessions recorded less number of probing marks (5.0-7.4). The susceptible check TN1 had 4.4 probing marks. The susceptible germplasm accessions were probed less number of times (average 5.4 probing marks/seedling) compared to resistant accessions (7.2 marks/seedling). The nymphs probed less number of times (7.1) than the adults (12.5). The present study on


a




b

**Fig. 1a and 1b.** Mass screening of the germplasm accessions probing marks indicated that the presence of non-preference mechanism for feeding in the case of resistant checks and resistant germplasm accessions. Prior to insertion of the stylets, the planthopper secretes a small amount of coagulable saliva while pushing the labial tip onto the plant epidermis. This makes a tight connection between them, leaving characteristic circular marks at the point of stylet insertion. The salivary deposit on the plant epidermis is called a "feeding mark" (Ponnada et al 2011). The feeding mark is a spherical protrusion, 15-17 p.m. in height, with a circular flange. It is possible to ascertain the probing frequency in a given period on different plant materials by counting the number of feeding marks.

**Honeydew excretion:** The honeydew excretion in one-day old WBPH female adult in the germplasm accessions ranged from 23.6 $mm^2$ (IC75864) to 185.0 $mm^2$ (TN1) (Table 2). The feeding and honeydew excretion in the resistant germplasm accessions was less (38.5$mm^2$) compared to moderately resistant germplasm accessions (82.7$mm^2$) and in the susceptible germplasm accessions the honeydew excretion was high (136 $mm^2$). In the case of WBPH nymphs, the honeydew excretion ranged from 6 $mm^2$ (IC75864) to 82 $mm^2$ (TN1). The honeydew excretion in the susceptible accessions including check TN1 was highest and ranged from 32.7 to 82.0 $mm^2$ with a mean of 55.0 $mm^2$. In the resistant entries the honeydew excretion was less (15.4$mm^2$) compared to moderately resistant accessions (28.9 $mm^2$). In general, the adults fed more and excreted more honeydew (83.4$mm^2$) compared to nymphs (30.7$mm^2$). This revealed that difference in the amount of honeydew excretion is mainly attributed to the difference in the relative amount of sap intake. Less intake of sap on resistant varieties, despite successful stylet penetration into the vascular bundles indicates the occurrence of certain undesirable gustatory factors that governed sustained sucking by the insect. It is further considered that this gustatory reaction is responsible for the abnormally high frequency of stylet probing, lack of satisfactory intake of nutrients, and subsequent reduction in fecundity or non-preference response. Therefore, the amount of honeydew excreted by the insect in unit time when fed on different rice cultures could be considered as an index for its feeding preference. WBPH has copiously excreted honeydew on the susceptible TN1.

**Correlation and regression between damage score, probing marks and honeydew excretion:** Correlation analysis between damage score and probing marks of adults ($R^2$ = -0.605) and nymphs ($R^2$ = - 0.624) indicated negative correlation which is significant. More number of probing marks were observed on the germplasm accessions which are resistant and vice versa (Table 3 and Fig. 3). There is a significant and positive correlation between the damage score and honeydew excretion of the whitebacked planthopper (adults $R^2$ =0.684 and nymphs $R^2$ =0.631). The honeydew excretion was less in the resistant germplasm accessions and vice versa. There was a significant and negative correlation between probing marks and honeydew excretion by the adults (-0.483) and nymphs (-0.410) (Table 3 and Fig. 4). The negative relation between probing marks and feeding/honeydew excretion tells that WBPH was a phloem feeder, probed readily and fed longer on the susceptible accessions. In contrast, the insect made brief and repeated probes on the resistant germplasm accessions, consequently reducing the effective ingestion period. Ramesh et al (2014) also suggested a positive correlation between damage score and honeydew excretion area in whitebacked planthopper in the mapping population

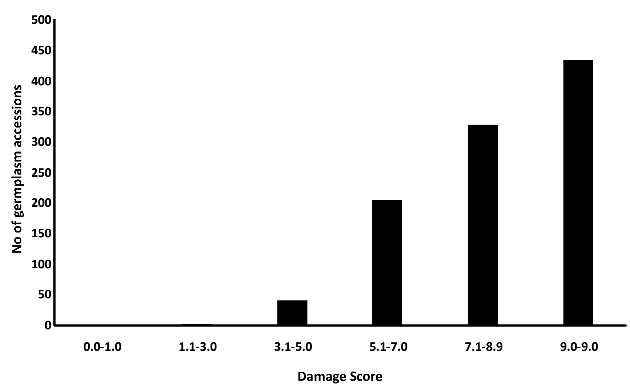



**Fig. 2.** Frequency distribution of damage score in germplasm accessions

**Table 3.** Correlation matrix among damage score, probing marks and honeydew excretion of WBPH

| Components of resistance | Damage score | Probing marks (Adults) | Probing marks (Nymphs) | Honeydew excretion (Adult) | Honeydew excretion (Nymphs) |
|---|---|---|---|---|---|
| Damage score | | | | | |
| Probing marks- adults | -0.605$^{**}$ | | | | |
| Probing marks- nymphs | -0.624$^{**}$ | 0.670$^{**}$ | | | |
| Honeydew excretion- adult | 0.684$^{**}$ | -0.483$^{**}$ | -0.412$^{*}$ | | |
| Honeydew excretion- nymphs | 0.631$^{**}$ | -0.410$^{*}$ | -0.238$^{NS}$ | 0.686$^{**}$ | 1 |

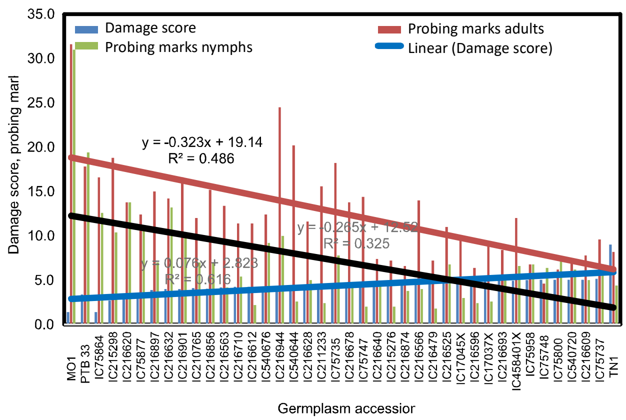



**Fig. 3.** Damage score, probing marks in the WBPH adults and nymphs in the germplasm accessions

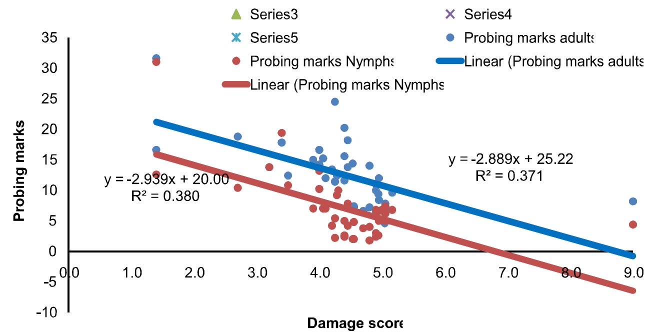



**Fig. 5**. Regression analysis between damage score and probing marks

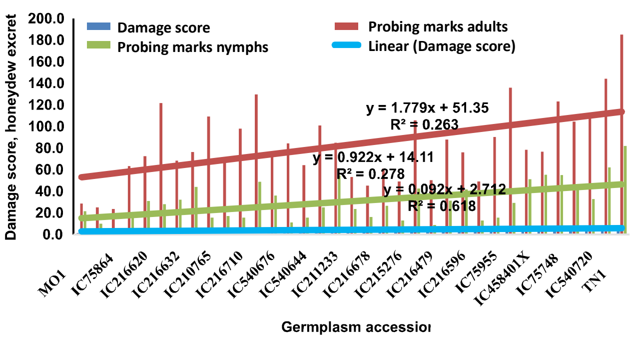



**Fig. 4.** Damage score, honeydew excretion in the WBPH adults and nymphs in germplasm accessions

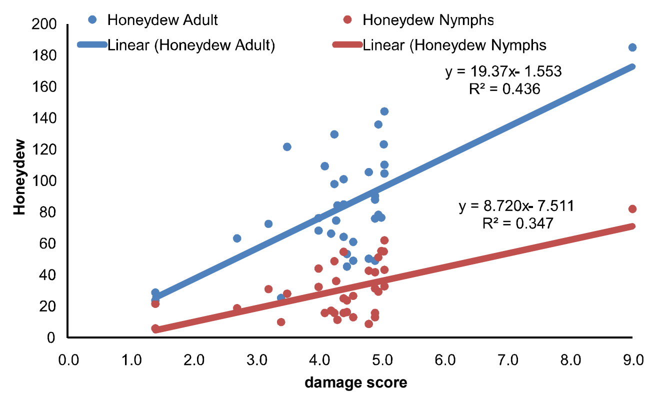



**Fig. 6.** Regression between damage score and honeydew excretion

**Table 4.** Linear regression analysis among different components of resistance

| Component | No of observations | Regression equation | Standard error | $R^2$ |
|---|---|---|---|---|
| Probing marks- adults | 40 | y = -2.8896x + 25.222 | 4.3526 | 0.3714 |
| Probing marks- nymphs | 40 | y = -2.9396x + 20.004 | 4.344366 | 0.3807 |
| Honeydew excretion-adults | 35 | y = 19.37x - 1.5534 | 0.922515 | 0.4363 |
| Honeydew excretion-nymphs | 35 | y = 8.7202x - 7.511 | 0.9928 | 0.3472 |

of TN1 X Sinasivappu. There was a negative relation between damage score and probing marks and the probing marks could explain 75% variation in the damage score and for each unit increase in the probing marks, the damage score is decreased by 5.8 units (Table 4 and Fig. 5). A positive relation was observed between damage score and honeydew excreted (feeding) by both nymphs and adults. The honeydew excretion (feeding) by the nymphs and adults together explains 78.4% variation in the damage score and for each unit increase in the honeydew excretion/feeding, the damage score is increased by 28.1 units (Table 4 and Fig. 6).

## CONCLUSIONS

Two germplasm accessions *viz.*, IC 75864 (DS-1.39), IC 215295 (DS-2.65) and MO1 were resistant to whitebacked planthopper and the insect exhibited non-preference for feeding with more number of probing (feeding) marks and less feeding and honeydew excretion on resistant accessions. The identified resistant germplasm accessions with known resistant mechanisms can be used as donors in the breeding programmes to develop WBPH resistant varieties.

## ACKNOWLEDGEMENT

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# Effect of Different Dates of Transplanting of Brinjal on Shoot and Fruit Borer *Leucinodes orbonalis* (Guenee) in Hill Region of North Western Himalayas, India

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***Abstract***: The incidence of *L. orbonalis* on brinjal was noticed in different dates. The result obtained from the present study revealed that among the three different dates of transplanting of brinjal, the crop transplanted 15$^{th}$ of May recorded the lowest mean shoot infestation (9.87 per cent) and fruit infestation on number (9.66 per cent) as well as on weight basis (8.83 percent) as compared to the crop transplanted on 15$^{th}$ of June, which recorded mean shoot infestation of 13.33 per cent and mean fruit infestation of 21.70 per cent on number basis and 19.91 percent on weight basis. This could be attributed to the less population build up of *L. orbonalis* on the crop transplanted on 15$^{th}$ of May as compared to the crop transplanted on 15$^{th}$ of June.

***Keywords***: *L. orbonalis*, Different dates, Transplanting, Shoot/fruit damage, Incidence

Brinjal (*Solanum melongena* Linnaeus) also known as egg plant, is an important solanaceous plant originated from India and now grown as a vegetable throughout the tropical, sub-tropical and warm temperate regions of the world. Brinjal is referred as “King of Vegetables”. In India, brinjal is extensively grown under diverse agro climatic conditions throughout the year (Nayak et al 2014). It is grown in almost all the states, with an area of 730.35 thousand hectares under cultivation and with total production of about 12,801 thousand metric tons (Indian Horticultural database, 2019). Different insect pests attack brinjal right from seedling stage to final harvesting stage. Some important insect pests of brinjal, which cause enormous damage to this crop are brinjal shoot and fruit borer (*Leucinodes orbonalis*), hadda beetle (*Epilachna* spp), jassid (*Amrasca bigutella bigutella*), aphid (*Aphis gossyppii*) and white fly (*Bemisia tabaci*) (Latif et al 2009). Among these major insect pests, brinjal shoot & fruit borer *Leucinodes orbonalis* is considered to be the most destructive pest of brinjal (Latif et al 2010, Chakraborti and Sarkar 2011, Saimander and Gopal 2012) and is found in all brinjal growing countries (Dutta et al 2011). In India, the yield reduction by this pest has been reported to be around 20-30 per cent (Bhargava et al 2008) and as high as 70 per cent (Dhandapani et al 2003) or 70-92 per cent (Chakraborti and Sarkar 2011). The pest poses serious problem because of its high reproductive potential, rapid turnover of generations and intensive cultivation of brinjal both in wet and dry seasons of the year. Brinjal shoot and fruit borer is practically monophagous but attacks other plants which belong to solanaceae family and has attained global importance in recent years. The caterpillars bore into tender shoots at vegetative stage, flower and fruit (CABI 2007). The higher percentage of larvae has been reported in fruits followed by shoots, flowers, flower buds and mid-rib of leaves (Alpurutto 1994).

The larvae feed on the mesocarp of fruit and feeding and excretion result in fruit rotting (Neupane 2001), making it unfit for human consumption (Baral et al 2006). On an average a larva can infest 4-7 fruits during its lifespan (Jayaraj and Manisegaran 2010). Larval feeding in flower has been reported to be rare, if it happens, there will be no fruit formation from damaged flowers (Alam et al 2006). Once the fruit setting has been initiated, shoot infestation becomes negligible (Kumar and Dharmendra 2013) or completely disappear (Naqvi et al 2009). The infestation by this pest results in lowering the vitamin C content up to 80 per cent in infested brinjal fruits (Sharma 2002).

The time of transplanting is an important cultural practice having a bearing on the population build up of the associated pest complex in brinjal. Pest attack can be suppressed or escaped by altering the transplanting dates. In this way most vulnerable period of crop growth may not synchronize with peak activity of the pest organism. Thus manipulation of the date of transplanting of this crop may reduce the incidence of this pest and indirectly it may lessen the number of spray applications for its management. Keeping in view the economic importance of the crop, quantum of damage caused by the shoot and fruit borer, the present study regarding the effect of different dates of transplanting on the incidence of brinjal shoot and fruit borer was carried out.

## MATERIAL AND METHODS

The experiment was laid out in RBD in uniformly sized plots measuring 3.60x3.15m at spacing of 60x45 cm. The brinjal variety Nisha was used for the experiment. Seedlings of brinjal (Nisha) were raised in three different nursery beds for different dates of transplanting. There were six replications and three treatments in the trial. Ten plants were randomly selected and tagged in each plot. The first transplanting was done on May 15, 2020 and subsequently another two transplanting were done at 15 and 30 days after the first transplanting. Weekly observations were taken from ten randomly selected plants/plot for brinjal shoot and fruit borer infestation on shoot from each planting. For fruit infestation, total number of fruits and infested fruits were recorded per plot during each harvesting from each replication. The per cent age of infested shoot/fruit was recorded and data recorded were analyzed by using OPSTAT online software and two factor ANOVA was performed in Randomised Block Design to compute CD value. The treatments with significant difference were also separated using Tukey's honestly significant difference post Hoc test using IBM SPSS software.

## RESULTS AND DISCUSSION

**Shoot infestation**: The weekly data on shoot infestation (per cent) by *Leucinodes orbonalis* at three different dates of transplanting viz. 15$^{th}$ May, 30$^{th}$ May and 15$^{th}$ June, 2020 are presented in Table 1. During the first week after transplanting there was no shoot infestation (%) in all the treatments and it started after the second week of transplanting and the crop transplanted on 15$^{th}$ June recorded the highest shoot infestation of 4.19 per cent. The present investigations on the initiation of shoot infestation by brinjal shoot and fruit borer is in close agreement with that of Jat et al (2002) who reported that the infestation of brinjal shoot borer commenced on shoots one week after transplantation. Salve et al (2021) reported that the infestation of *L. orbonalis* on developing shoots commenced from four weeks after transplantation and ranged from 2.25 (31$^{st}$ SMW) to 0.45 per cent (43$^{th}$ SMW) with peak being 10 per cent at 37$^{th}$ SMW.

From the second week onwards, the shoot infestation in all the three treatments showed an increasing trend. In case of the crop transplanted on 15$^{th}$ of May ($T_1$), the peak (highest) shoot infestation of 24.85 per cent was observed on the 8$^{th}$ week after transplanting whereas in case of crop transplanted on 30$^{th}$ of May ($T_2$), the highest shoot infestation of 39.66 per cent was observed on 9$^{th}$ week after transplanting. Treatment ($T_3$) recorded the peak (highest) shoot infestation of 43.80 per cent on the 7$^{th}$ week after the transplanting. After attaining a peak, shoot infestation showed a decreasing trend in all the treatments. No shoot infestation due to *L. orbonalis* attack was observed after 17$^{th}$ weeks after transplanting in $T_1$ and 16$^{th}$ weeks after transplanting in $T_2$, respectively. However, shoot infestation ceased at 15$^{th}$ weeks after transplanting in $T_3$. Infestation in shoots decreased after fruit setting. On comparing the mean shoot infestation observed in the three treatments, the highest mean shoot infestation was observed in $T_3$ (13.33 per cent) followed by $T_2$ (12.78 per cent) and then $T_1$ (9.87%). The treatments $T_3$ and $T_2$ were statistically at par ($p > 0.05$), however, $T_1$ was found to be statistically different from $T_2$ and $T_3$ ($p < 0.05$) at 0.05 significance level. Interaction between the transplanting date and the duration of crop was significant at 0.05 level of significance. The results thus revealed that among the three different dates of transplanting, the brinjal crop transplanted on 15$^{th}$ of May ($T_1$) showed the lowest shoot infestation, while the crop transplanted on 15$^{th}$ of June ($T_3$) recorded the highest shoot infestation.

The finding on peak infestation of brinjal shoot and fruit borer are in conformity to those of Nandi et al (2017) who reported that peak shoot infestation by *L. orbonalis* was around 8 weeks after transplantation during *Kharif* season. Singh et al (2000) reported that shoot infestation was started at the end of August and reached peak in the third week of September. Bharadiya and Patel (2005) also reported that the damage of shoot & fruit borer on shoot was the highest during fourth week of September.

**Fruit infestation (on number basis):** The weekly data on fruit infestation on number basis (per cent) by *L. orbonalis* at three different dates of transplanting viz. 15$^{th}$ May, 30$^{th}$ May and 15$^{th}$ June are presented in Table 2. It is evident from the table 2 that in the initial days of the crop growth i.e. from the first to fifth weeks after transplanting, only vegetative phase of crop is there and no fruit was formed. After the initiation of reproductive phase, the fruit infestation (per cent) in all the treatments started on 6$^{th}$ week after transplanting, highest number of fruits infestation (28.13%) were observed in $T_3$ however, a very less number of infested fruits were recorded in $T_1$ (3.0%) and $T_2$ (2.5%). Similar to the trend followed in shoot infestation, fruits infestation also showed an increasing trend. The peak fruit infestation of 26.17 per cent was observed on 12$^{th}$ week after transplanting in $T_1$, however peak number of fruits infestation of 36.61 and 53.36 per cent was observed in 11[th] and 10[th] week after transplanting in $T_2$ and $T_3$, respectively. After attaining a peak, a reduction in fruit infestation was observed. The fruit infestation was observed till the 19[th] week after transplanting in all the treatments. The mean number of fruits infested was highest in $T_3$ (21.71 per cent), however, in $T_1$ and $T_2$, fruit infestation was 9.66 and 10.21 per cent, respectively. All the mean number of fruit infested were statistically different at 0.05 level of significance ($p<0.05$). Interaction between the date of transplanting and duration of crop growth was found to be significant 0.05 level of significance.

**Fruit infestation (weight basis):** The data on fruit infestation on weight basis (%) by *L. orbonalis* at three different dates of transplanting viz. 15[th] May, 30[th] May and 15[th] June are presented in table 2. As reported earlier also there was no fruit infestation up to 5 weeks after each transplanting and the fruit infestation started in the later stage. The fruit infestation commenced from 6[th] week after the transplanting of the crop and the highest fruit infestation of 25.37 per cent (on weight basis) was observed in $T_3$, however, a very less infested fruits on weight basis were recorded in $T_1$ (2.3 per cent) and $T_2$ (2.65 per cent). Similar to the trend followed in

**Table 1.** Shoot Infestation level of *L. orbonalis at* different date of transplanting

| Crop duration (WAT) | Shoot infestation (%) | | | |
|---|---|---|---|---|
| | $T_1$ (TD=15[th] May) | $T_2$ (TD=30[th] May) | $T_3$ (TD=15[th] June) | Mean |
| 1 | 0±0* (0) | 0±0 (0) | 0±0 (0) | 0 (0) |
| 2 | 1.12±1.28 (4.195 ) | 1.80±1.98 (5.401 ) | 4.19±0.97 (11.73) | 2.37 (7.11) |
| 3 | 2.48±1.17 (8.39) | 5.91±0.93 (14.02) | 9.47±0.84 (17.90) | 5.95 (13.44) |
| 4 | 7.49±1.11 (15.83) | 9.09±0.90 (17.52) | 14.29±1.00 (22.19) | 10.29 18.51) |
| 5 | 19.2±2.55 (25.93) | 14.59±0.72 (22.44) | 18.83±1.01 (25.70) | 17.54 (24.69) |
| 6 | 20.50±1.63 (26.89) | 19.68±1.38 (26.31) | 26.27±1.39 (30.81) | 22.15 (28.00) |
| 7 | 22.51±2.31 (28.28) | 25.60±1.06 (30.38) | 43.80±1.09 (41.42) | 30.64 (33.36) |
| 8 | 24.85±2.13 (29.87) | 35.86±1.47 (36.77) | 42.10±11.45 (40.15) | 34.27 (35.60) |
| 9 | 21.14±0.78 (27.36) | 39.66±21.72 (39.28) | 40.40±1.45 (39.44) | 33.73 (35.36) |
| 10 | 16.42±1.08 (23.88) | 25.96±2.92 (30.58) | 22.58±1.30 (28.35)) | 21.65 (27.61) |
| 11 | 11.63±1.49 (19.89) | 21.06±2.16 (27.28) | 17.49±0.74 (24.71) | 16.72 (23.96) |
| 12 | 11.63±0.91 (19.92) | 17.67±2.19 (24.81) | 11.78±1.75 (21.58) | 13.69 (21.58) |
| 13 | 9.44±0.59 (17.88) | 12.07±0.69 (20.31) | 9.33±0.74 (17.76) | 10.28 (18.65) |
| 14 | 9.37±0.50 (17.81) | 10.92±1.36 (19.26) | 6.04±4.22 (13.57) | 8.78 (16.88) |
| 15 | 8.71±0.77 (17.14) | 9±0.76 (17.44) | 0±0 (0) | 5.90 (11.53) |
| 16 | 7.39±0.76 (15.75) | 6.65±0.95 (14.90) | 0±0 (0) | 4.68 (10.22) |
| 17 | 3.43±1.04 (10.55) | 0±0 (0) | 0±0 (0) | 1.14 (3.52) |
| 18 | 0±0 (0) | 0±0 (0) | 0±0 (0) | 0 (0) |
| Mean | 9.87[a] | 12.78[b] | 13.33[b] | |

*Mean ± SE (value in the parentheses are arc sin transformation values); WAT = Week after transplanting, TD=Transplanting date
Mean followed by different letters are significantly different at α = 0.05 (p-value < 0.05) according to Tukey HSD
CD (α = 0.05)
Date of transplanting (Factor A) = 0.94 (0.69)
Crop Duration (Factor B) = 2.43 (1.77)
Factor A X B = 4.22 (3.07)

shoot infestation, fruit infestation on weight basis also showed an increasing trend. The peak fruit infestation on weight basis (24.13%) was observed in 12th week after the transplanting in $T_1$, however peak fruits infested on weight basis (32.57 and 50.01 per cent) were observed in 11th and 10th week after the transplanting in $T_2$ and $T_3$, respectively. After attaining a peak, a reduction in fruit infestation was observed. The fruit infestation was observed till the 19th week after the transplanting in all the treatments. The mean fruits infested on weight basis was highest in $T_3$ (19.91 per cent) which was statistically different from $T_1$ and $T_2$, with the fruit infestation of 8.83 and 9.01 per cent, respectively, at 0.05 level of significance ($p<0.05$). Interaction between the date of transplanting and duration of crop growth was found to be significant 0.05 level of significance.

The results thus revealed that among the three different dates of transplanting, the brinjal crop transplanted on 15th of May ($T_1$) showed the lowest fruit infestation (both number and weight basis) while the crop transplanted on 15th of June ($T_3$) recorded the highest fruit infestation (both number and

**Table 2.** Fruit Infestation level of *L. orbonalis* at different date of transplanting (on number and weight basis)

| Crop duration (WAT) | Transplanting date = 15th May ($T_1$) | | Transplanting date = 30th May ($T_2$) | | Transplanting date = 15th June ($T_3$) | | Mean (on number basis) | Mean (on weight basis) |
|---|---|---|---|---|---|---|---|---|
| | FI on number basis (%) | FI on weight basis (%) | FI on number basis (%) | FI on weight basis (%) | FI on number basis (%) | FI on weight basis (%) | | |
| 5 | 0±0 (0) | 0±0 (0) | 0±0 (0) | 0±0 (0) | 0±0 (0) | 0±0 (0) | 0 (0) | 0 (0) |
| 6 | 3±2.37 (8.15) | 2.3±0.34 (8.70) | 2.5±2.74 (6.46) | 2.65±0.45 (9.34) | 28.13±1.34 (32.01) | 25.37±1.44 (30.23) | 11.21 (15.54) | 10.11 (16.09) |
| 7 | 10.11±0.75 (18.52) | 8.7±0.60 (17.14) | 6.58±2.01 (14.73) | 4.34±0.60 (12.00) | 32.42±1.33 (34.69) | 29.7±1.82 (33.00) | 16.37 (22.65) | 14.25 (20.72) |
| 8 | 13.89±1.39 (21.85) | 13.48±0.84 (21.52) | 9.98±1.16 (18.38) | 8.04±1.46 (16.41) | 39.38±1.24 (38.85) | 37.614.40 (37.79) | 21.08 (26.36) | 19.71 (25.24) |
| 9 | 16.28±1.16 (23.77) | 15.21±0.64 (22.94) | 14.41±2.99 (22.21) | 12.05±1.52 (20.28) | 46.5±0.99 (42.98) | 43.19±1.69 (41.07) | 25.73 (29.65) | 23.49 (28.10) |
| 10 | 19.9±1.05 (26.47) | 18.01±0.82 (25.10) | 18.67±0.75 (25.58) | 16.56±0.84 (24.00) | 53.36±1.70 (46.91) | 50.01±1.76 (44.99) | 30.64 (32.99) | 28.19 (31.36) |
| 11 | 23.41±1.32 (28.92) | 22.96±1.17 (28.62) | 36.61±1.51 (37.22) | 32.57±1.92 (34.78) | 46.33±0.76 (42.88) | 45.1±1.68 (42.17) | 35.46 (36.34) | 33.54 (35.19) |
| 12 | 26.17±1.81 (30.74) | 24.13±1.35 (29.40) | 28.67±1.33 (32.35) | 26.4±0.75 (30.90) | 42.99±0.96 (40.95) | 40.03±1.79 (39.23) | 32.6 (34.68) | 30.19 (33.18) |
| 13 | 20.89±0.95 (27.18) | 19.34±1.02 (26.08) | 23.65±1.64 (29.08) | 22.7±1.54 (28.43) | 38.74±1.43 (38.48) | 35.01±1.87 (36.26) | 27.76 (31.58) | 25.69 (30.26) |
| 14 | 19±0.92 (25.83) | 17.72±1.10 (24.88) | 21.67±2.52 (27.67) | 20.08±2.15 (26.59) | 36.21±3.39 (36.16) | 31.23±1.64 (33.96) | 25.63 (30.17) | 23.01 (28.47) |
| 15 | 15.53±0.40 (23.02) | 13.27±0.94 (21.34) | 17.08±2.38 (24.36) | 14.16±0.96 (22.08) | 24.62±1.10 (29.73) | 22.68±1.39 (28.42) | 19.08 (25.76) | 16.7 (23.95) |
| 16 | 11.63±0.77 (19.92) | 11.03±0.71 (19.38) | 12.28±1.97 (20.45) | 10.83±1.36 (19.18) | 20.9±0.91 (27.15) | 18.36±0.98 (25.36) | 14.92 (22.51) | 13.41 (21.30) |
| 17 | 8.58±0.80 (17.01) | 8.46±0.73 (16.89) | 8.3±0.42 (16.68) | 6.98±0.81 (15.29) | 13±1.55 (21.10) | 11.88±1.33 (20.13) | 9.94 (18.27) | 9.1 (17.44) |
| 18 | 4±0.89 (11.47) | 1.59±1.39 (5.86) | 3.17±1.17 (10.11) | 2.49±1.56 (8.17) | 8.2±0.69 (16.62) | 6.2±0.78 (14.39) | 5.12 (12.73) | 3.43 (9.47) |
| 19 | 0.83±0.98 (3.67) | 0.35±0.65 (1.89) | 0.67±0.82 (3.27) | 0.43±0.52 (2.63) | 3.42±1.02 (10.55) | 1.73±1.25 (6.73) | 1.64 (5.83) | 0.84 (3.75) |
| 20 | 0±0 (0) | 0±0 (0) | 0±0 (0) | 0±0 (0) | 0±0 (0) | 0±0 (0) | 0 (0) | 0 (0) |
| Mean | 9.661[a] | 8.83[a] | 10.21[b] | 9.01[a] | 21.708[c] | 19.91[b] | | |

*Mean ± SE (value in the parentheses are arc sin transformation values); WAT = Weeks after transplanting, FI= Fruit infestation
Mean followed by different letters are significantly different at α = 0.05 (p-value < 0.05) according to Tukey HSD
CD (α = 0.05)
For fruit infestation on number basis
Date of transplanting (Factor A) = 0.32 (0.42)
Crop duration (Factor B) = 0.83 (1.09)
Factor A X B = 1.43 (1.89)
For fruit infestation on weight basis
Date of transplanting (Factor A) = 0.28 (0.33)
Crop duration (Factor B) = 0.72 (0.85)
Factor A X B = 1.25 (1.47)

weight basis). The present finding are in agreement to those of Nandi et al (2017) who reported that fruit infestation reached its maximum at 12 weeks after transplantation during *Kharif* season. These findings also in agreement to those of Tripura et al (2017) who reported that peak infestation of shoot & fruit borer on shoot and fruits were in the first week of August (34.20 per cent) and in the third week of August (46.75 per cent ), respectively.

The result obtained from the present study thus revealed that among the three different dates of transplanting of brinjal, the crop transplanted $15^{th}$ of May recorded the lowest mean shoot infestation (9.87 per cent) and fruit infestation on number (9.66 per cent) and weight basis (8.83 per cent) as compared to the crop transplanted on $15^{th}$ of June which recorded mean shoot infestation of 13.33 per cent and mean fruit infestation of 21.70 per cent on number basis and 19.91 per cent on weight basis. This can be attributed to the less population build up of L. *orbonalis* on the crop transplanted on $15^{th}$ of May as compared to the crop transplanted on 15th of June.

The present results find support from the studies of Tripura et al (2017) carried out at Meghalaya who reported that first transplanting (done on $15^{th}$ of April, 2015) showed lowest shoots and fruit damage followed by the second transplanting (done on $30^{th}$ April, 2015). They further reported that the third transplanting (done on $15^{th}$ of May) showed the highest shoot and fruit infestation. The peak shoot infestation was 25.25, 32.60 and 34.20 per cent in the first, second and third transplanting, respectively. Whereas the peak fruit infestations were recorded to be 16.25, 44.75 and 46.75 per cent in the respective transplanting. However, Singh et al (2017) on the basis of the experiments conducted during *Kharif* (July 2016 to February, 2017) reported that brinjal crop transplanted during August 2016 (third transplanting) recorded relatively higher shoot damage with a mean of 18.01 per cent followed by that in first and second transplanted crop (crop transplanted during July, 2016) with a mean of 16.07 and 16.17 per cent shoot damage. Similarly the third transplantation crop recorded the highest mean fruit damage (17.65 per cent) on number basis and 15.70 percent on weight basis followed by first and second transplanted crop with a mean fruit damage of 15.95 per cent on number basis and 14.64 per cent on weight basis and 17.62 per cent on number basis and 14.97 per cent on weight basis, respectively.

The present findings are in partial agreement with reports of Rashid et al (2003) who revealed that the highest level of shoot & fruit infestation was found from June to September. Radhakishore et al (2009) observed that infestation of *L. orbonalis* on brinjal crop started from early vegetative stage and continued up to crop maturity. First infestation appeared on shoots from the second week of April and peaked in the second week of June and third week of May during two consecutive years.

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# Impact of Different Crop Geometry in Maize on Fall Armyworm, *Spodoptera frugiperda* Infestation

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***Abstract***: A field study was designed to investigate the impact of crop spacing and hybrids on the incidence of Fall armyworm in maize CoH(M)-6 and NK-6240 during *Rabi* season (2019) and the observations were made at fortnight intervals. The results revealed that NK-6240 hybrid maize sown at conventional sowing (dibbling method) showed maximum larval population ranged from 1.71 to 3.05 larvae/plant, infestation ranged from 56.73 to 74.21 % and leaf damage score was 6.6. The lowest larval population was observed on CoH(M)-6 maize plots sown at 60x25cm spacing, which ranged from 0.52 to 1.09 larvae/plant and per cent infestation was ranging from 23.14 to 53.32% and the mean damage score was significantly low (3.5) and resulted in significantly higher yield. However, in NK-6240 the grain yield was higher at 60x25cm spacing (10525 kg/ha) as compared to conventional sowing (6196 kg/ha). The different crop spacing had an impact on the fall armyworm incidence, leaf damage, plant infestation and yield loss. The hybrid CoH(M)-6 at 60x25cm spacing recorded minimum larval population, infestation and leaf damage score and yield loss.

***Keywords***: Maize, Fall armyworm, *Rabi*, Spacing, Larval population, Per cent infestation, Leaf damage, Yield

Fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) native to America is a key pest of maize, found in several countries including Mexico, Brazil, Argentina and USA (Clark *et al* 2007) and causes severe economic losses in variety of crops such as maize, soybean, cotton, rice and other grasses and feeds on number of weeds (Nabity et al 2011). Severe incidence of fall armyworm was reported from African countries such as Nigeria, Benin and Togo in 2016. The incursion of FAW as an invasive pest into Asia was reported for the first time from India on maize during May 2018. Since then, it has spread to different states cultivating maize (Sharanbasappa et al 2018). The spread of this pest to other Asian countries including Thailand, Sri Lanka, Bangladesh, Myanmar, Vietnam, Laos and China has occurred quickly (Wu et al 2019). Maize, *Zea mays* L. (Poaceae) is one of the most important staple crops in India, grown in an area of 9.2 million ha with the production of 27.8 million metric tonnes per year and productivity of 2965 kg/ha. In India, about 15 million farmers are engaged in maize cultivation and it generates employment for more than 650-million-person at farming and its related business ecosystem levels (FICCI 2018). Kharif maize represents around 80% of maize area while *rabi* maize represent 19% of area. Summer maize occupies 1-2% of total maize area in India. Out of three maize seasons nearly 80% of kharif maize is cultivated under rainfed condition, while *rabi* and summer maize is cultivated under assured irrigated ecosystem. In India, maize is cultivated throughout the year as grain, feed, fodder, green cobs, sweet corn, baby corn, popcorn and industrial products. The recent invasion of fall armyworm is a threat to the food security of India. The FAW larvae usually feed on the developing leaves in the funnel, creating a characteristic windowing effect and bore into the developing reproductive structures such as maize cobs, reducing yield quality and quantity (Bateman et al 2018).

Farmers have resorted to 4-5 sprays of different insecticides at high doses without the knowledge of their efficacy leads to quick development of resistance, negative impact on natural enemies and also causing accumulation of pesticides in the environment (Gutierrez et al 2019). t. Due to monoculture of maize, the fall armyworm infestation causes more and high pest buildup. This leads to chemical intensive agriculture is so much, that farmers resort to a minimum of 5 to 6 chemical sprays on maize, making cultivation of maize highly risky and non-profitable. In addition to this, overuse of pesticides has leads to resurgence of pests and ill effects on natural enemy fauna. Pesticide residues in maize are also of great concern from the point of domestic consumption and exports as well. It is therefore, imperative to find out a better spacing from the point of pest debilitation so that the crop can escape the pest attack or receives less pest ravage ultimately leading to reduced pesticide consumption and to become viable components of a sound IPM programme. In present study the management option for FAW is ecological pest management based on the utilization of crop spacing, which is sustainable, cost- effective and causes minimum risk to the humans and the environment.

## MATERIAL AND METHODS

The present investigation to determine the effect of different plant spacings against fall armyworm and yield of maize was conducted at Experimental farm, Agricultural College and Research Institute, Madurai situated between latitude 9.54º N and longitude 78.54º E. The area is semiarid with a mean annual rainfall of 890 mm and 147 meters from above mean sea level. Field trial was carried out during the year *rabi*, 2019 and 2020. Three different crop spacing were evaluated under three two hybrid maize varieties. Three crop spacings were selected based on (i) Precision farming (75x20 cm), (ii) TNAU recommended spacing (60x25cm) and Farmer's practice (45x30cm) was maintained by hand dibbler having a net plot size was 7m x 2m were evaluated against fall armyworm incidence and damage in comparison with check. Check was maintained by dibbling method using NK- 6240 irregular spacing. Each treatment was replicated four and each replication data was the mean of data obtained from 20 plants. The sowing was done with two region popular maize hybrids *viz.,* COH (M)-6 (TNAU) and NK – 6240 (Syngenta private ltd, India). All common standard agronomic cultural practices were followed in the experimental field except plant protection measures (Table 1).

The observations on larval population (Number of larvae /plant), leaf damage (damage severity) and per cent plant infestation along with yield were recorded. Larval population was observed by counting on number of larvae present per plant at fortnight intervals. The per cent plant infestation and leaf damage described by Davis and Williams (1992) was followed for this study; leaf damage was assessed based on scale rating 0 = no visible leaf damage, 1 = only pin-hole damage to the leaves, 2 = pinhole and shot-hole damage to leaves, 3 = small elongated lesions (5-10 mm) on 1-3 leaves, 4 = mid-sized lesions (10-30 mm) on 4-7 leaves, 5 = large elongated lesions (>30 mm) or small portions eaten on 3-5 leaves, 6 = elongated lesions (>30 mm) and large portions eaten on 3-5 leaves, 7 = elongated lesions (>30 cm) and 50% of leaf eaten, 8 = elongated lesions (30 cm) and large portions eaten on 70% of leaves, 9 = most leaves have long lesions and complete defoliation. The summary classification of leaf damage rating 0-4 = minimal visible leaf damage (low), 5-7= marginal leaf damage (medium) and 8-9= extensive leaf damage (high). The yield data were recorded for each treatment separately and grain yield was expressed in kg/ha. The data collected were subjected to statistical analysis of variance by SPSS software and means were compared with Tukey's test at $P \leq 0.05$.

**Table 1.** Treatments details

| Treatments | Spacing adopted | Hybrid used | Rows |
|---|---|---|---|
| $T_1$ | 75x20 cm | CoH(M)-6 | 9 rows |
| $T_2$ | 60x25 cm | CoH(M)-6 | 12 rows |
| $T_3$ | 45x30 cm | CoH(M)-6 | 15 rows |
| $T_4$ | 75x20 cm | NK-6240 | 9 rows |
| $T_5$ | 60x25 cm | NK-6240 | 12 rows |
| $T_6$ | 45x30 cm | NK-6240 | 15 rows |
| $T_7$ | Irregular spacing | NK-6240 | 10 rows |

## RESULTS AND DISCUSSION

The descending order of best spacing against *S. frugiperda* infestation were 60 x 25 cm followed by 75x20 and 45x30 cm. Between the two hybrids, COH(M)-6 hybrid performed better than NK- 6240. All the treatments were superior over the check in reducing larval population (Table 2). On 15 DAS, treatment COH(M)-6 at 60 x25cm recorded minimum larval population of 0.52 number per plant. The treatment with COH(M)-6 at 75x20 cm and NK- 6240 at 60x 25 cm recorded 0.70 larvae per plant which were statistically on par with conventional sowing (check) recorded maximum larval population (1.71 larvae/plant). On 30 DAS, the treatment COH(M)-6 at 60 x25cm recorded minimum population 0.63 larvae per plant followed by NK -6240 at 60 x25 cm and maximum larval population in conventional sowing (check) was 1.82 larvae per plant. On 45 DAS, the conventional sowing (check) recorded maximum larval population (2.70 larvae / plant). And in treatment COH(M)-6 at 60 x 25cm larval population was minimum (0.97 larvae/ plant). On 60 DAS and 75 DAS, the same trend was observed in various treatments. Akinkunmi et al (2012) recorded at high population in sunflower in the lowest spacing of 65cm x75. However, at wider spacing especially 100cm x 75cm there was a reduction in larval population. The mean larval population recorded on COH(M)-6 at 60x25 cm was minimum (0.72larvae/plant). NK-6240 at 60 x25 cm (1.03 larvae/plant) was on par with COH(M)-6 at 75x20 cm (1.05 larvae/ plant) followed by NK -6240 at 75 x20 cm , COH(M)-6 at 45x30 and NK -6240 at 45x30 cm . The larval population was the highest in check (conventional sowing) (2.27 larvae/plant). Warkad et al (2021) indicated that spacing at 60x25 cm recorded 0.99 fall armyworm larvae per plant in maize. All the treatments were superior over the check in reducing the infestation level (Table 3). On 15 DAS, treatment COH(M)-6 at 60x25cm (23.14%) recorded minimum infestation followed by NK -6240 at 60 x25 cm . followed by

COH(M)-6 at 75x20 cm, NK -6240 at 75 x20 cm. Conventional sowing (check) recorded maximum infestation (56.73%). The present findings were confirmed with the results of Phani Kumar et al (2021) where plant infestation at spacing 75 x 20 cm was 44.07 per cent by *S. frugiperda* on maize.

On 30 DAS, the treatment COH(M)-6 at 60 x 25 cm recorded minimum infestation of 34.31% and maximum infestation recorded in conventional sowing (61.82 %). On 45 DAS, the conventional sowing recorded peak infestation (72.62%) and the treatment COH(M)-6 at 60 x25cm recorded minimum infestation (50.16%). On 60 DAS and 75 DAS, the same trend was observed in different treatments. On 15 DAS, treatment COH(M)-6 at 60 x25cm recorded minimum leaf damage score (3.0) followed by NK -6240 at 60 x25 cm (3.6) (Table 3). The treatment with COH(M)-6 at 75x20 cm recorded a score of 4.5 followed by NK -6240 at 75 x20 cm (4.8), COH(M)-6 at 45x30 cm (4.9) and NK -6240 at 45x30 cm (5). Conventional sowing (check) recorded maximum leaf damage score (5.3). On 30 DAS, the treatment COH(M)-6 at 60 x25cm recorded the lowest leaf damage score of 3.4 and leaf damage recorded on conventional sowing (check) showed the highest leaf damage (6.0) and at 45, 60 and 75 DAS the conventional sowing recorded maximum leaf damage score varying from 7.2 to 8.0.The average mean leaf damage score in the conventional sowing (check) was (7.4). Among the other treatments, COH(M)-6 at 60 x25cm recorded the lowest leaf damage score (3.5) and other treatments in order of efficacy were COH(M)-6 at 60 x25 cm, COH(M)-6 at 75x20 cm, NK -6240 at75x20 cm, COH(M)-6 at 45x30 cm and NK -6240 at 45x30 cm Phani Kumar et al (2021). also reported that fall armyworm leaf damage score was 6.6 at 75x20 cm spacing in maize. Akinkunmi et al (2012) reported that the highest damaged leaves (48.60%, 51.25%),

**Table 2.** Impact of crop geometry and hybrid against fall armyworm larval population in maize, during *rabi* season (September-December 2019)

| Treatments | Larval population (No. of larvae/plant)$^{\#}$ | | | | | Average mean |
|---|---|---|---|---|---|---|
| | 1 DAS | 30 DAS | 45 DAS | 60 DAS | 75 DAS | |
| $T_1$ - CoH(M)-6 at 75 x 20 cm | 0.70$^{ab}$ | 0.85$^{ab}$ | 1.25$^{ab}$ | 1.39$^{ab}$ | 1.03$^{b}$ | 1.05$^{b}$ |
| $T_2$ - CoH(M)-6 at 60 x 25 cm | 0.52$^{a}$ | 0.63$^{a}$ | 0.97$^{a}$ | 0.89$^{a}$ | 0.55$^{a}$ | 0.72$^{a}$ |
| $T_3$ - CoH(M)-6 at 45 x 30 cm | 1.02$^{b}$c | 1.37$^{cd}$ | 2.16$^{cd}$ | 2.23$^{cd}$ | 1.82$^{d}$ | 1.72$^{d}$ |
| $T_4$ - NK-6240 at 75 x 20 cm | 0.80$^{ab}$ | 0.99$^{a}$ | 1.69$^{bc}$ | 1.86$^{bc}$ | 1.36$^{c}$ | 1.34$^{c}$ |
| $T_5$ - NK-6240 at 60 x 25 cm | 0.70$^{ab}$ | 0.78$^{a}$ | 1.50$^{ab}$ | 1.24$^{ab}$ | 0.93$^{d}$ | 1.03$^{b}$ |
| $T_6$ - NK-6240 at 45 x 30 cm | 1.27$^{c}$ | 1.51$^{ef}$ | 2.25$^{cd}$ | 2.26$^{e}$ | 1.91$^{e}$ | 1.84$^{d}$ |
| $T_7$- Conventional sowing | 1.71$^{d}$ | 1.82$^{f}$ | 2.70$^{e}$ | 2.54$^{f}$ | 2.56$^{f}$ | 2.27$^{e}$ |

\# Mean values of four replications; Means followed by the same letter (s) are not significantly different at p≤ 0.05 by Tukey's test; DAS – Days after sowing

**Table 3**. Impact of crop geometry and hybrid against fall armyworm infestation in maize, during *rabi* season (September-December 2019)

| Treatments | Per cent infestation on plant # | | | | | Average mean | Leaf damage score on infestation # | | | | | Average score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 15 DAS | 30 DAS | 45 DAS | 60 DAS | 75 DAS | | 15 DAS | 30 DAS | 45 DAS | 60 DAS | 75 DAS | |
| $T_1$ | 36.87$^{bc}$ | 42.40 | 57.90$^{abc}$ | 55.22$^{abc}$ | 38.94$^{ab}$ | 44.92$^{ab}$ | 4.5 (M) | 5.2 (M) | 5.8 (M) | 6.0 (M) | 4.9 (M) | 5.4 (M) |
| $T_2$ | 23.14$^{a}$ | 34.31$^{a}$ | 50.16$^{a}$ | 46.95$^{a}$ | 30.24$^{a}$ | 39.10$^{a}$ | 3.0 (L) | 3.4 (L) | 4.3 (M) | 4.1 (M) | 2.8 (L) | 3.5 (L) |
| $T_3$ | 46.17$^{de}$ | 51.78$^{cd}$ | 66.38$^{cde}$ | 61.80$^{bc}$ | 46.75$^{bc}$ | 53.84$^{cd}$ | 4.9 (M) | 5.8 (M) | 6.8 (M) | 7.0 (M) | 5.5 (M) | 6.0 (M) |
| $T_4$ | 39.75$^{cd}$ | 45.13$^{bc}$ | 61.81$^{bcd}$ | 58.04$^{abc}$ | 42.32$^{bc}$ | 48.30$^{bc}$ | 4.8 (M) | 5.4 (M) | 6.0 (M) | 6.5 (M) | 5.2 (M) | 5.6 (M) |
| $T_5$ | 29.81$^{ab}$ | 39.83$^{ab}$ | 54.98$^{ab}$ | 51.30$^{ab}$ | 33.39$^{a}$ | 44.20$^{ab}$ | 3.6 (L) | 4.7 (M) | 5.0 (M) | 5.2 (M) | 4.2 (M) | 4.5 (M) |
| $T_6$ | 50.46$^{ef}$ | 56.69$^{ef}$ | 69.03$^{de}$ | 64.47$^{e}$ | 50.88$^{cd}$ | 59.06$^{de}$ | 4.8 (M) | 5.9 (M) | 7.7 (M) | 7.6 (M) | 6.1 (M) | 6.6 (M) |
| $T_7$ | 56.73$^{f}$ | 61.82$^{f}$ | 72.62$^{f}$ | 66.44$^{e}$ | 55.87$^{d}$ | 62.70$^{e}$ | 5.3 (M) | 6.6 (M) | 8.2 (M) | 8.0 (M) | 7.2 (M) | 7.4 (M) |

See Table 1 for details

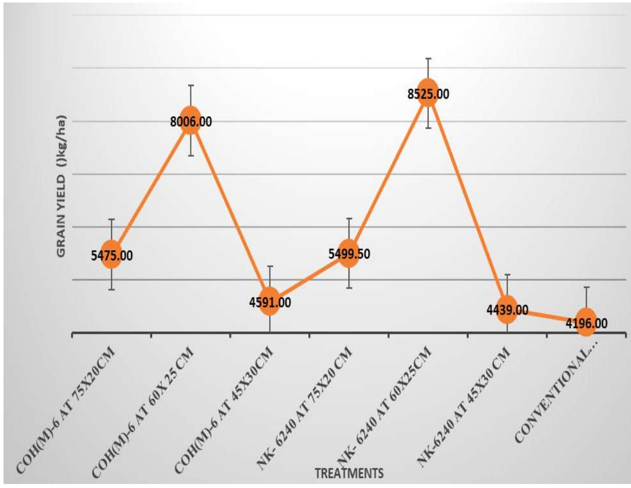


**Fig. 1.** Impact of crop geometry and hybrid on yield of maize during *Rabi* season (September 2020-December 2020)

stems (22.25%, 25.10%), and flower heads (23.50% and 27.20%) in 2009 and 2010 respectively in sunflower plants with 65 cm x 75 cm (high density) spacing while at low density spacing of 100cm x 75cm, the damage on the leaves, stem and flower head were significantly reduced.

The highest grain yield was in NK -6240 at 60 x25 cm (8525 kg/ha) which was on par with COH(M)-6 at 60 x25cm followed by NK -6240 at 75 x20 cm and COH(M)-6 at 75x20 cm The lowest grain yield was recorded in conventional sowing (4196 kg/ha). Moro et al (2016) reported higher grain yields under wider spacing (20 cm x 25 cm; 20 cm x 20 cm) than closer (20 cm x 15 cm; 15 cm x 15 cm, 30 cm x 10 cm) spacing in rice. Shranabasappa et al (2020) revealed that maize spacing of 45x30 cm (3,246 kg/ha) recorded lowest grain yield.

## CONCLUSION

This study provides valuable information about the impact of different crop geometry against fall armyworm and its infestation levels. CoH(M)-6 recorded minimum fall armyworm infestation and significantly higher yield at 60x 25 cm spacing. The FAW incidence is more in high plant density. During the *Rabi* season, the sowing of COH(M)-6 hybrid at 60x 25 cm can be included as one of the cultural components for integrated pest management of *S. frugiperda* in maize.

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# Laboratory Screening of Different Nutrient Media for Mycelial Growth and Cultural Characteristics of Blue Oyster Mushroom [*Hypsizygus ulmarius* (Bull.: Fr.) Redhead]

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***Abstract*:** Study was conducted to observe the effect of different solid and liquid nutrient media on mycelial growth, cultural characteristics and growth rate of *Hypsizygus ulmarius*. Five different solid media *viz.,* Potato dextrose agar (PDA), Czapek's Dox agar (CDA), Malt extract agar (MEA), Carrot extract agar (CEA) and Asthana and Hawker's agar (A&HA) and their respective broths were evaluated under laboratory conditions to find out the best physiological conditions for the growth of *H. ulmarius*. Potato dextrose agar medium was found to be the best medium (76.20 mm) followed by malt extract agar medium (59.40 mm) and Czapek's Dox agar medium (57.00 mm). In liquid media, highest biomass was in carrot extract broth (0.52 g). However, minimum dry weight was in Asthana and Hawkers medium (0.04 g) broth. The mycelial growth in different media showed absolutely white, cottony and fluffy growth with circinate pattern but in Czapek's Dox agar and Asthana & Hawker's medium it was light thin transparent white and become visible only when seen under light.

***Keywords*:** *Hypsizygus ulmarius*, Mushroom, Mycelial growth, Nutrient media, Cultural characters

The elm oyster or blue oyster mushroom [*Hypsizygus ulmarius* (Bull.: Fr.) Redhead]; (Lyophyllaceae, Agromycetes) grows in clusters on elm trees. This mushroom is widely distributed in the temperate forests of North America, Japan, Europe and other countries. *H. ulmarius* is not only considered as food but also rich in bioactive compounds of high medicinal value (Chioza and Ohga 2014). Blue oyster mushroom being saprophytic can easily be introduced in any part of the world. Its fast growth and high resistance against competitive microorganisms is likely to make its cultivation more economical and less tedious. For successful introduction and cultivation its physiological studies are pre-requisite. Since nutrition is required by each and every living organisms for their growth and development. The physiological and nutritional studies become more vital factor in case of mushroom as success or failure in their cultivation is mainly dependent on the clear and correct understanding of nutritional and environmental needs. Oyster mushrooms are not an exception to it. It is therefore becomes necessary to add those compounds which are required for its growth and to accomplish other life processes. But the data pertaining to influence of physiological and nutritional aspects on the mycelial growth and cultural characteristics of test fungus is very meager. Hence in the present investigation, the study was conducted on the above mentioned aspects.

## MATERIAL AND METHODS

The present investigation was carried out at Dr. Y S Parmar University of Horticulture and Forestry, College of Horticulture and Forestry, Neri, Hamirpur, Himachal Pradesh, India during the year 2019-21.

**Procurement, maintenance and preservation of culture**: The pure culture of blue oyster mushroom (*Hypsizygus ulmarius*) was procured from Directorate of Mushroom Research, ICAR complex, Chambhaghat, Solan (H.P). The culture, thus obtained was maintained on potato dextrose agar (PDA) medium (sub cultured periodically at an interval of 30-45 days). Full grown culture was stored at 2-4$^0$C in the refrigerator until used further for the entire work (Plate 1).

**Sterilization:** All media were sterilized at 15 psi pressure for 20 min. in an autoclave. All glassware were sterilized in hot air oven at 180$^0$C for 2 h. However, the spawn substrates were sterilized in the autoclave at 22 psi pressure for 2 h and 20 min. The cork borer and inoculating needle were initially dipped in ethyl alcohol, finally flame sterilized and used only after complete cooling.

**Cultural Studies:** Cultural studies were conducted under *in vitro* conditions to find out the best physiological conditions for the growth of *H. ulmarius* with the standard procedure laid down by Lilly and Barnett (1951) and Tuite (1969) with some modifications, wherever necessary.

**Screening of basal media:** Five different media *viz.,* potato dextrose agar (PDA), Czapek's Dox agar (CDA), malt extract agar (MEA), carrot extract agar (CEA) and Asthana and Hawker's agar (A&HA) were evaluated to find out the best suitable nutrient medium for diametric growth of *H. ulmarius.* Forty mililitre of each medium was poured in each sterilized Petri plate. After solidification of media, Petri plates were inoculated with culture disc (5.0 mm dia.) of actively growing mycelium of *H. ulmarius.* These Petri plates were then incubated at 25$\pm$1$^0$C for 5 days and the observations on diametric growth (mm) and growth characteristics of the test fungus were recorded at 24 h interval up to 120 h of incubation.

Growth rate (mm/h):

$r_g$= $dgt_2$-$dgt_1$/$t_2$-$t_1$

Where, $dgt_2$ = Diametric growth (mm) at time $t_2$; $dgt_1$ = Diametric growth (mm) at time $t_1$.

**Screening of liquid medium:** Seventy five ml broth of each of above media was taken in 250 ml Erlenmeyer flasks. These flasks were inoculated with 5.0 mm disc of actively growing mycelium of *H. ulmarius.* The inoculated flasks were incubated at 25$\pm$1 $^0$C for 5, 10 and 15 days. Thereafter, dry mycelial weight of the test fungus was recorded after each interval. The broths were filtered through Whatmann's No. 1 filter paper and fresh mycelial mat was collected and weighted on electric top pan balance with sensitivity of 0.01 g. For dry weight of mycelium, mat was continuously dried in an oven at 60$^0$C overnight and the dry weight of the test fungus was calculated.

**Data analysis*:*** The experiments were conducted in completely randomized design having four replications in each treatment. The observations were recorded in *in vitro* conditions by culturing the fungus in Petri plates. The average diametric growth (mm/day) was recorded after 24 h of interval up to five days of incubation. The data thus obtained were statistically analysed by using statistically package of program OPSTAT (Sheoran 2006).

## RESULTS AND DISCUSSION

### Physiological Studies

**Effect of different solid nutrient media on the growth of *H. ulmarius*:** PDA exhibited significantly mean maximum (41.44 mm) mycelial growth, followed by MEA (32.63 mm) and CDA (32.32 mm, Table 1). However, latter two treatments were statistically at par with each other. Significantly mean minimum diametric growth was in A&HA (27.04 mm) followed by CEA medium, irrespective of different durations of incubation. However, irrespective of the nutrient media under study, average mean diametric growth was maximum (56.24 mm) after 120 h of incubation followed by that after 96 h. Minimum growth was after 24 h (11.60 mm) followed by 48 and 72 h. Significantly higher diametric growth (76.20 mm) was in PDA after 120 h of incubation, which was followed by growth in MEA after same duration of incubation. Minimum diametric growth (11.00 mm) was in A&HA after 24 h of incubation which was statistically at par with the diametric growth in CDA (11.40 mm) after same duration of incubation. An intermediate range of diametric growth was in rest of the test media after varying duration of incubation. Mycelial characteristics of *H. ulmarius* were also recorded in different media (Table 1). The colour of the mycelium was white in PDA, MEA and CEA, while it was transparent in CDA and A&HA media. The growth in PDA was observed to be cottony white but having suppressed ray pattern while, in case of MEA it was cottony and fluffy ray with circinate pattern. Cottony compact growth was noticed in CEA while, thin and transparent growth was observed in CDA and A&HA media which was visible only when seen under light (Plate 2). The maximum mean growth rate of *H. ulmarius* was recorded in

**Table 1.** Evaluation of different solid nutrient media and cultural characteristics for the growth of *Hypsizygus ulmarius*

| Nutrient medium | Average diametric growth (mm) after different incubation duration (h) | | | | | Overall Mean | Colour of mycelium | Type of growth |
|---|---|---|---|---|---|---|---|---|
| | 24 | 48 | 72 | 96 | 120 | | | |
| Potato dextrose agar | 12.60 | 23.60 | 38.20 | 56.62 | 76.20 | 41.44 | White | Cottony but suppressed, ray pattern |
| Malt extract agar | 11.80 | 20.35 | 29.00 | 42.60 | 59.40 | 32.63 | White | Cottony and fluffy, ray with circinate pattern |
| Carrot extract agar | 11.20 | 17.50 | 25.20 | 33.40 | 42.60 | 25.98 | White | Cottony and compact |
| Czapex's Dox agar | 11.40 | 19.20 | 30.60 | 43.40 | 57.00 | 32.32 | Transparent | Thin and transparent |
| Asthana and Hawker's agar | 11.00 | 17.60 | 25.40 | 35.20 | 46.02 | 27.04 | Transparent | Thin and transparent |
| Overall Mean | 11.60 | 19.65 | 29.68 | 42.24 | 56.24 | | | |
| | Nutrient medium | | Duration | | Interaction | | | |
| CD (p=0.05) | 0.19 | | 0.19 | | 0.42 | | | |

PDA (0.58 mm) followed by MEA and CDA which differ significantly with each other (Table 2). Least growth rate was in CEA (0.31 mm) and A&HA (0.33 mm) media between 0-24 h of incubation. Irrespective of different nutrient media under study, growth rate of *H. ulmarius* was minimum (0.27 mm) between 0-24 h of incubation which increased significantly after each 24 h of incubation and reached its maximum (0.58 mm) between 96-120 h of incubation. Fungus attained maximum growth rate in PDA (0.81 mm) between 96-120 h of incubation, which was followed by PDA between 72-96 h of incubation. Minimum growth rate was recorded in A&HA (0.24 mm) medium between 0-24 h of incubation. Rest of all the treatments exhibited intermediate range of growth rate.

**Effect of different liquid nutrient media on the growth of *H. ulmarius:*** The mean maximum biomass of *H. ulmarius* was in CEB (0.52 g) which was statistically at par with the biomass in PDB irrespective of different days of incubation

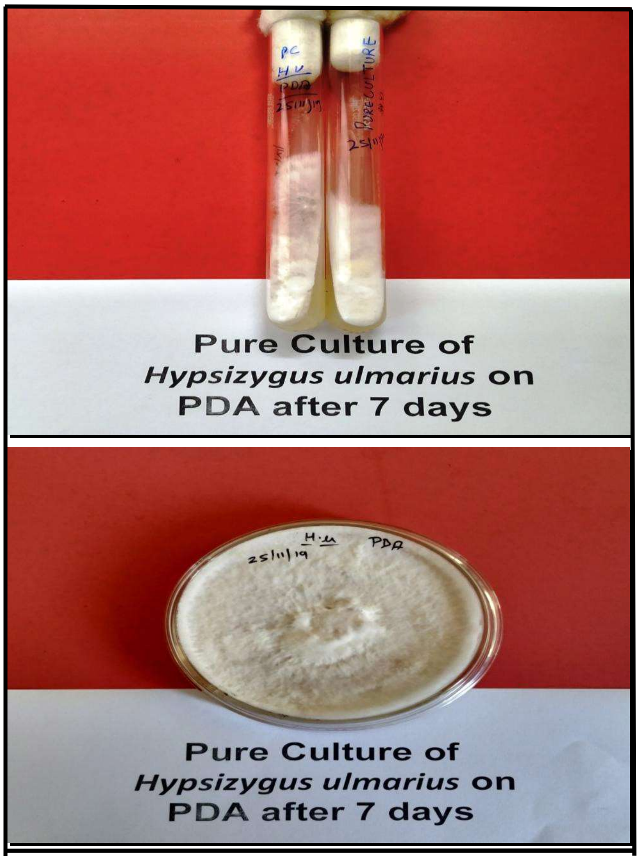


**Plate 1.** Pure culture of *Hypsizygus ulmarius*


**Plate 2.** Petri plates exhibiting mycelial growth of *Hypsizygus ulmarius* on different soild media

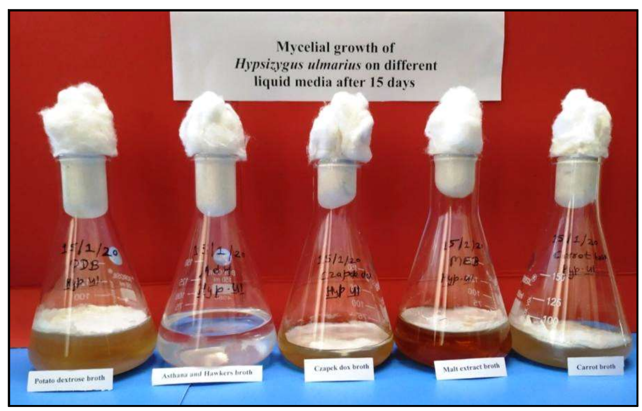


**Plate 3.** Erlenmeyer's flasks exhibiting biomass production of *Hypsizygus ulmarius* on different liquid media

**Table 2.** Effect of different nutrient media on the growth rate of *Hypsizygus ulmarius*

| Nutrient medium | Average growth rate (mm/h) between duration of incubation (h) | | | | | Overall Mean |
|---|---|---|---|---|---|---|
| | 0-24 | 24-48 | 48-72 | 72-96 | 96-120 | |
| Potato dextrose agar | 0.31 | 0.45 | 0.60 | 0.76 | 0.81 | 0.58 |
| Malt extract agar | 0.28 | 0.35 | 0.35 | 0.56 | 0.69 | 0.45 |
| Carrot extract agar | 0.25 | 0.27 | 0.32 | 0.34 | 0.38 | 0.31 |
| Czapex's Dox agar | 0.26 | 0.32 | 0.47 | 0.53 | 0.56 | 0.43 |
| Asthana and Hawker's agar | 0.24 | 0.27 | 0.32 | 0.40 | 0.44 | 0.33 |
| Overall Mean | 0.27 | 0.33 | 0.41 | 0.52 | 0.58 | |
| | Nutrient medium | | Duration | | Interaction | |
| CD (p=0.05) | 0.01 | | 0.01 | | 0.02 | |

**Table 3.** Effect of different liquid media on biomass production and cultural characteristics of *Hypsizygus ulmarius*

| Nutrient medium | Average biomass (g) after incubation duration (days) | | | Overall mean | Colour of mycelium | Type of growth |
|---|---|---|---|---|---|---|
| | 5 | 10 | 15 | | | |
| Potato dextrose broth | 0.23 | 0.49 | 0.77 | 0.50 | Absolutely white | Thick and Cottony |
| Malt extract broth | 0.16 | 0.24 | 0.41 | 0.25 | White | Cottony and fluffy |
| Carrot extract broth | 0.24 | 0.52 | 0.79 | 0.52 | Dull white | Thick, compact and |
| Czapex's Dox broth | 0.04 | 0.09 | 0.16 | 0.09 | White | Thin |
| Asthana and Hawker's broth | 0.02 | 0.03 | 0.07 | 0.04 | Light white translucent | Very thin and transparent |
| Overall Mean | 0.13 | 0.27 | 0.44 | | | |
| | Nutrient medium | | Duration | Interaction | | |
| CD (p=0.05) | 0.03 | | 0.04 | 0.06 | | |

(Table 3). However, significantly minimum biomass was in A&HB (0.04 g) followed by CDB and MEB. Significantly mean maximum biomass was after 15 days of incubation (0.44 g) followed by 10 days and 5 days of incubation, irrespective of different liquid media investigated (Plate 3). The maximum biomass of *H. ulmarius* (0.79 g) was recorded in CEB after 15 days of inoculation which was statistically at par with the biomass in PDB (0.77 g) after same interval of inoculation followed by 10 days after inoculation in CEB (0.52 g) and PDB (0.49 g). However, mean minimum dry weight of the test fungus was recorded in A&HB (0.02 g) after 5 days of incubation. The colour of the mycelium was absolutely white to white in PDB, MEB and CDB while, it was dull white in CEB (Table 3). Light translucent colour of the mycelium was in AH&B. The growth was observed to be thick cottony in PDB, cottony and fluffy in MEB, thick, compact and cottony in CEB while, thin to very thin in CDB and AH&B respectively after 15 days of incubation was observed.

The results obtained in present study are in consonance with the results of Jatav et al (2013), Sumi and Geetha (2016) and Baghel et al (2019) where PDA as the best and most suitable medium for the growth of *H. ulmarius*. In the present investigations, maximum mean biomass of the test fungus was in CEB which was statistically at par with PDB. The present findings are also in agreement with the findings of Shendge (2018) where PDA was most suitable medium for growth and biomass production of *H. ulmarius*. PDA, MEA, CDA, A&HA, oat meal agar and yeast extract agar have also been tried by different workers (Krasnopolskaya *et al* 2008, Rawte and Diwan 2011, Sardar et al 2017) for culturing of *Pleurotus* spp. and *H. ulmarius* (Mishra et al 2015, Sumi and Geetha 2016 , Kumar and Eswaran, 2016).

## CONCLUSION

Potato dextrose agar medium exhibited mean maximum diametric growth followed by malt extract agar medium. Minimum growth was observed in carrot extract agar. Growth rate was maximum in potato dextrose agar medium followed by malt extract agar medium while it was least in carrot extract agar medium after 120 h of incubation. Mean maximum biomass was observed in carrot extract broth which was statistically at par with potato dextrose broth. However, mean minimum dry weight of the test fungus was in Asthana and Hawker's broth medium after 15 days of incubation. In all the treatments colour of the mycelium varied from white to transparent white and type of growth observed as cottony, fluffy, compact, thin and transparent having ray and circinate patterns.

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# Feasibility of Aqua Crop Model for Predicting Yield and Biomass of Wheat Crop

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***Abstract***: The study was carried out to investigate the effect of different level and method of irrigation on yield and yield contribution parameters of wheat crop. The results obtained under drip irrigation treatments were compared with the surface irrigation treatments. Crop yield and yield contributing characters for wheat crop were maximum in the subsurface drip irrigated treatments. Water supply to the wheat crop was significantly higher in the conventional irrigation as compared to other treatments. The AquaCrop model was calibrated for simulation of yield and biomass of wheat crop for all treatments with the prediction error statistics $0.96 < E < 0.99$, $0.15 < RMSE < 1.10$, $.90 < R^2 < 0.94$ and $0.59 < MAE < 0.87$ t ha$^{-1}$. The model was validated for wheat crop yield and biomass with all treatment combinations with prediction error statistics values $0.96 < E < 0.99$, $0.28 < RMSE < 1.1$, $0.90 < R^2 < 0.96$ and $0.38 < MAE < 1$ t ha$^{-1}$.

***Keywords***: AquaCrop model, Calibration, Validation, Subsurface drip irrigation, Crop yield and biomass

The available fresh water resources in the world are constant and the population is continually increasing, this available water per capita will continue to decrease resulting in stress or water scarcity in some areas. In present era, fresh water resources are limited and depleted day by day which creates problem of water scarcity (Vikas 2020). Wheat (*Triticum aestivum L.*) is an important cereal crop of the world. Due to its high demand as well as adaptability, wheat crop is grown on a large area of the world all round the year. Right amount and frequency of irrigation is vital for optimum use of limited water resources for crop production and management (Sharma et al 2017). The main causes for the low coverage of irrigation is the commonly use of flood (conventional) method of irrigation (FMI), where water use efficiency is significantly low due to various reasons. Drip irrigation &Sprinkler irrigation and mini sprinkler irrigation are the different types of irrigation methods commonly adopted by the Indian farmers (Sharma and Yadav 2021). Drip irrigation is a most efficient method of supplying irrigation water to plants. Most of the simulation models require a very high number of input parameters to overcome these difficulties, in 2009 the Food and Agriculture Organization (FAO) developed a water-driven crop growth simulation model (Steduto et al 2009), named AquaCrop, from the basic crop yield response to water theorem in Doorenbos and Kassam (1979). It uses small number of explicit and mostly intuitive parameters and some input variables, requiring simple methods for their derivation (FAO 2009). Objective of study- is to assess the yield and biomass of wheat crop at different level and method of irrigation and to evaluate FAO-AquaCrop Model for wheat crop at different level of irrigation grown under surface and subsurface drip irrigation.

## MATERIAL AND METHODS

**General description of study area, climate and soil characteristics:** The present study was conducted at G.B. Pant University of Agriculture and Technology, Pantnagar (29˚N latitude, 79˚30´E longitude and 243.83 m above mean sea level) in Uttarakhand state of India which comes under *Tarai* region, located in foothills of the great Himalayas. The meteorological data such as temperature, relative humidity, wind speed, rainfall, pan evaporation and sunshine hours during the crop period was acquired from the meteorological observatory.

**Drip irrigation scheduling of wheat crop:** The estimation of crop water requirement/volume of water to be applied daily was done using the following relationship as given in INCID, (1994).The total water applied to the wheat crop is calculated as:

$$V = \sum(E_p \times K_p \times K_c \times S_p \times S_r \times WP + ER)$$

Where,

V = estimated crop water requirement at 100% water use level, litre/day/plant

Epan = Pan Evaporation, mm/day

Kp = Pan coefficient

Kc = Crop coefficient

Sp = Plant to plant spacing, m

Sr = Row to row spacing, m

Wp = Percentage wetted area, 90%

ER = Effective rainfall, mm

The crop coefficient value for initial stage $K_{cinit}$ was taken as 0.7, for mid stage $K_{cmid}$ was taken as 1.15 and for end stage it was taken as $K_{cend}$ as 0.40.

Based on USDA. S.C.S method the effective rainfall (ER) is calculated on monthly basis as:

$$ER = P_t\left[\frac{125 - 0.2 \times Pt}{125}\right] for\ Pt < 250\ mm$$

Where, $P_t$- total rainfall, mm

The drip irrigation system with a mainline of a PVC pipe of 40 mm diameter having wall thickness of 1.8 mm and pressure rating up to 4 kg/cm$^2$ was laid. The lateral turbo line having 16 mm diameter was provided with drippers of 1.3 litre per hour discharge capacity with minimum pressure of 1 kg/cm$^2$ spaced at 30 cm. In this study drip lines (turbo line) were laid parallel to the crop rows and one drip line served two rows of crop.

**Experimental details**

T1: V - Volume of water application under surface drip irrigation planted at 20 cm row spacing

T2: 1.2V - Volume of water application under surface drip irrigation planted at 20 cm row spacing

T3: 1.2V - Volume of water application under subsurface drip irrigation planted at 20 cm row spacing

T4: V - Volume of water application under surface drip irrigation planted at 15 cm row spacing

T5: 1.2V - Volume of water application under surface drip irrigation planted at 15 cm row spacing

T6: 1.2V - Volume of water application under subsurface drip irrigation planted at 15 cm row spacing

T7: Surface irrigation (At 50% level of available water depletion) planted at 20 cm row spacing

Wheat (*Tritium aestivum*), variety UP-2572 was selected as the test crop for study.. Deep ploughing (20-25 cm) of field was done with soil turning plough. Thereafter two ploughing with rotavator was done. In subsurface drip irrigation treatments, lateral (turbo line) were laid at 20 cm below ground surface**.** At the inlet of drip line (turbo line) lateral valve were provided to start and stop the irrigation. The seeds were directly sown in all treatments with the row spacing of 20 cm and 15 cm on 22$^{th}$ of November 2015. Randomly five plants were selected from each replication and selected plants were tagged by aluminium tag for identification. Yield and yield contributing characters (Harvesting index (HI), Water productivity) were recorded at 30, 60, 90, 120 DAS and at harvest. Harvesting of the crop was started on 18$^{th}$ April 2016. The harvesting was finished by 22$^{th}$ of April 2015. From each plot, the crop and straw yield was recorded separately and then converted to per hectare basis.

**Fao-Aquacrop model:** AquaCrop is a water driven crop simulation model which mainly focused on simulating the attainable crop yield and biomass in response to the water available (Steduto et al 2009). It has achieved significant modification in accuracy over Doorenbos and Kassam (1979) while maintaining significant simplicity and robustness of model.

**Governing equations and concepts of FAO aquacrop model:** AquaCrop model is based on the crop growth engine which is inherently water driven, in which, the crop growth and crop production (crop yield as well as biomass) are driven by the amount of water efficiently used through consumptive use of the plant.

$$\frac{Y_X - Y}{Y_X} = K_X\left[\frac{ET_X - ET}{ET_X}\right]$$

where, Yx and Y are the maximum yield and actual yield respectively, ETx and ET are the maximum evapotranspiration and actual evapotranspiration respectively, and Kx is the proportionality factor between relative loss in yield and relative reduction in evapotranspiration. The some changes led to the following equation for the AquaCrop model

$$B = WP \times \Sigma T_R$$

Where, Tr is the crop transpiration (mm) and WP is the crop water productivity parameter (kg of biomass per square meter and per mm of cumulated water transpired during the time period in which the biomass is produced).

**Input data requirement of aquacrop model:** The model was calibrated and validated using the data acquired from field experiments for its further use. Climatic data (daily / monthly rainfall, daily / monthly $ET_{0,}$ daily / monthly temperature, $CO_2$ concentration), crop data (limited set (crop development and production parameters)**,** calendar of growing cycle), management practices (irrigation method and amount, field data, soil fertility, mulches, field surface practice, ground water (constant and varying water depth).

Criteria of model evaluation: In this study prediction error statistics were used to corroborated the goodness of fit between the simulated and observed values.

$$Pe = \frac{(Si - Oi)}{Oi} \times 100$$

$$E = 1 - \frac{\sum_{i=1}^{N}(Oi - Si)^2}{\sum_{i=1}^{N}(Oi - \overline{O\,i})^2}$$

Where $S_i$ and $O_i$ are predicted and actual (observed) data, $O_i$ is mean value of $O_i$ and N is the number of observations.

$$RMSE = \sqrt{\frac{1}{(N)}\sum_{i=1}^{N}(Si - Oi)^2}$$

$$MAE = \frac{1}{(N)}\sum_{i=1}^{N}\left|Si - Oi\right|$$

Model efficiency (E) and $R^2$ approaching one and $P_e$, MAE and RMSE nearby to zero were indicators for better model performance.

**Statistical analysis:** The analysis of variance technique was used to analyse the experimental data to randomized block design with the help of Microsoft excel.

## RESULTS AND DISCUSSION

### Effect of different level and methods of irrigation on biometric parameters of wheat crop

**Plant height:** The maximum average plant height at 30 and 60 DAS was in $T_3$ (1.2V - Volume of water application under subsurface drip irrigation planted at 20 cm row spacing) with value of 36 cm and 55.1 cm, respectively while the average plant height at 90,120 DAS and at harvest was maximum in $T_2$, $T_3$ and $T_3$, (102.6 cm, 110 cm and 144 cm). The result revealed that the significant influence of sub surface drip irrigation with 20 cm row spacing over surface irrigated treatment.

**Number of tillers per plant:** The number of tiller per plant at 30 DAS the number of tillers per plant was maximum in $T_3$(5). At 60, 90, 120 DAS and at harvest the highest number of tillers per plant was again for $T_3$ being 7, 8, 9, and 10 respectively. The irrigation through subsurface drip was significantly superior to surface drip and conventional method of irrigation.

**Leaf area index (LAI):** Effect of different level of irrigation was significant on LAI all different days after sowing. The highest leaf area index at 30 DAS was for $T_7$ (1.3m$^2$ m$^{-2}$) followed by treatment $T_3$. AT 60, 90 DAS the highest LAI was again in $T_7$ followed by $T_3$. But at 120 DAS the maximum leaf area index was for $T_3$. This result revealed that the plant leaf growth was affected by water and moisture availability. The result observed in this work suggests that the crop that received more water had the maximum leaf area index.

**Plant dry matter:** Effect of different level of irrigation was found to be significant on plant dry matter at different DAS. At 30, 60, 90 and 120 DAS the highest plant dry matter was for $T_7$ with value of (150.6, 388, 772, 998.4 g m$^{-2}$). The plant dry matter under surface irrigation and subsurface drip irrigation was significantly superior to plant dry matter under surface drip irrigation. Similarly, at harvest the plant dry matter was also maximum for the treatment $T_7$ followed by $T_3$.

**Other factors:** The numbers of productive tillers/plant were similar in all treatment except treatment $T_3$. In wheat the maximum number of tillers/plant was recorded as 8 (Table 1). The maximum number of grains per ear was for treatment $T_3$ (68) followed by $T_5$. Similarly, the maximum ear length was in $T_2$ (58 cm) followed by treatment $T_1$. The weight of 1000 grains was maximum for the $T_3$ (67.8 gm) followed by $T_1$ and $T_2$. Thus, result showed that the treatment under subsurface drip irrigation with 20 cm spacing significantly influenced the crop yield and all yield contribute character. Similar result was also reported by *Ayars* et al (1999) based on his study on subsurface drip irrigation of row crops.

The effect of irrigation regimes and methods of irrigation on water use efficiency was significant in $T_1$ to $T_7$ with 0.19 to 0.44 t/ha-cm (Table 2). The amount of water needed to grow one kg of wheat was lowest for treatment $T_4$ with a value of 225 litres of water and highest for treatment $T_7$ (504.4 litres). Thus, the overall result showed that the effective use of water as well as effective water management under surface and subsurface drip irrigation over surface irrigation significantly improved the water use efficiency. Similar finding was reported by Sharma et al (2019) for rice crop and reported maximum water use efficiency under subsurface drip

**Table 1.** Effect of various treatments on yield contributing characters of wheat at harvest

| Treatment | No. of productive tillers plant$^{-1}$ | No. of grains ear$^{-1}$ | Ear length (cm) | 1000 grain weight (g) | Grain yield (t ha$^{-1}$) | Straw yield (t ha$^{-1}$) | Harvesting Index (%) |
|---|---|---|---|---|---|---|---|
| $T_1$ | 5 | 57 | 57 | 67.2 | 4.9 | 9.2 | 34.8 |
| $T_2$ | 5 | 56 | 58 | 67.1 | 4.6 | 9.5 | 33 |
| $T_3$ | 8 | 68 | 55.6 | 67.8 | 5 | 10.2 | 32.8 |
| $T_4$ | 6 | 62 | 53.8 | 64.2 | 4.6 | 9.4 | 32.8 |
| $T_5$ | 6 | 63 | 54.1 | 66 | 4.4 | 7.5 | 37 |
| $T_6$ | 6 | 61 | 55.1 | 62.8 | 4.7 | 9.6 | 32.9 |
| $T_7$ | 6 | 59 | 55.2 | 63.4 | 4.7 | 10.3 | 31.2 |
| CD (P<0.5) | 2.4 | 3.7 | 4.8 | 3.5 | 0.43 | 0.72 | 8.2 |
| CV (%) | 17 | 8.9 | 3.6 | 4.3 | 7.5 | 10.6 | 7.1 |

irrigation over surface drip irrigation method.

**Aquacrop Model Calibration and Validation for Wheat Crop**

The crop file in AquaCrop contained crop-specific parameters pertaining to 19 phenological crop growth stages with canopy and root development, evapotranspiration, water, fertility, and temperature stress parameters (Table 3). The calibrated values of CGC and CDC for the experiment were 11% $day^{-1}$ and 8.5% $day^{-1}$, respectively.

The calibrated maximum canopy cover was 85%. The days to emergence, sowing to flowering, senescence and maturity were 7, 70, 120 and 150 days, respectively. The reproductive growth period consists of flowering, yield formation, and harvest index (HI) development stages. The duration of flowering was 17 days while initial canopy cover ($CC_0$) was1.06. The flowering stage was triggered to start as the crop attains full canopy cover. The maximum CC is reached by the middle of the flowering stage. In this study the base temperature and cut off temperature were set as 3 $^0$C to 32 $^0$C respectively. The maximum effective rooting depth was iteratively set at 1 m with maximum root depth achieved during the flowering period. The calibrated value of WP was obtained as 15 g $m^{-2}$, which was in the range suggested for the AquaCrop for $C_3$ crops (i.e. crops that produces the 3-carbon compound oxalocethanoic (oxaloacetic) acid as the first stage of photosynthesis). The harvest index was s 33%. Subsequently, under the crop water stress category, factors pertaining to expansion stress were calibrated to have the upper threshold, lower threshold, and shape factor to be 0.25, 0.55, and 3, respectively.

**Calibration of aqaucrop model:** The model shows a good correlation between observed and simulated yield. The highest yield and biomass were 5.1 and 15.3 t $ha^{-1}$, respectively for $T_3$ under subsurface drip irrigation. Similarly, minimum yield and biomass were 4.4 and 11.8 t $ha^{-1}$ for $T_5$ under surface drip irrigation**.** The highest grain yield and biomass were be 5.3 and 15.9 t $ha^{-1}$ for the treatment $T_3$under subsurface drip irrigation method and minimum yield and biomass were found to be 4.5 and 12.1 t $ha^{-1}$ for $T_5$ under surface drip irrigation (Table 4). The model was calibrated for crop yield with model efficiency (E) and $R^2$ of 0.99 and 0.90, respectively (Table 5). The maximum and minimum errors in crop yield prediction were 3.9 and 2% for $T_3$ and $T_{1,}$ respectively. The model was calibrated for biomass with model efficiency (E) of 0.96 and $R^2$ value of 0.94.

**Validation of aquacrop model:** The highest yield and

**Table 3.** Water use efficiency of wheat under different level of irrigation

| Crop parameters | Value | |
|---|---|---|
| Base temperature | 3$^0$C | |
| Cutoff temperature | 32 | $^0$C |
| Initial canopy cover ($CC_0$) | 1.06 | % |
| Canopy growth coefficient (CGC) | 11 | % $day^{-1}$ |
| Canopy decline Coefficient at Senescence (CDC) | 8.5 | % $day^{-1}$ |
| Water productivity (WP) | 15 | g $m^{-2}$ |
| Reference Harvesting Index ($HI_0$) | 33 | % |
| Upper threshold for canopy expansion | 0.25 | - |
| Lower threshold for canopy expansion | 0.55 | - |
| Leaf expansion stress coefficient curve shape | 3.0 | - |
| Upper threshold for stomatal closure | 0.5 | - |
| Stomata stress coefficient curve shape | 3.0 | - |
| Time from sowing to emergence | 7 | Days |
| Time from sowing to start flowering | 70 | Days |
| Time from sowing to start senescence | 120 | Days |
| Time from sowing to maturity | 150 | Days |
| Duration of flowering | 17 | Days |
| Maximum effective rooting depth | 1.0 | M |

**Table 2.** Water use efficiency of wheat under different level of irrigation

| Treatment | Total irrigation water applied (mm) | Effective rainfall (mm) | Total amount of water applied (mm) | Total Water saving (%) | Water use efficiency (t $ha^{-1}$-cm) | Amount of water to produce unit yield (l $kg^{-1}$) |
|---|---|---|---|---|---|---|
| $T_1$ | 130.5 | 5.28 | 135.7 | 42.7 | 0.36 | 277 |
| $T_2$ | 156.6 | 5.28 | 161.8 | 31.7 | 0.28 | 352 |
| $T_3$ | 156.6 | 5.28 | 161.8 | 31.7 | 0.30 | 324 |
| $T_4$ | 98.2 | 5.28 | 103.4 | 6.3 | 0.44 | 225 |
| $T_5$ | 117.8 | 5.28 | 123.0 | 48.0 | 0.35 | 280 |
| $T_6$ | 117.8 | 5.28 | 123.0 | 48.0 | 0.38 | 262 |
| $T_7$ | 231.8 | 5.28 | 237.0 | | 0.19 | 504 |
| CD (P<0.5) | | | | | 0.84 | |
| CV (%) | | | | | 41.6 | |

**Table 4.** Calibration results of crop yield and biomass of wheat under different level of irrigation

| Treatments | Yield (t ha$^{-1}$) | | $P_e$ (± %) | Biomass (t ha$^{-1}$) | | $P_e$ (± %) |
|---|---|---|---|---|---|---|
| | Observed | Simulated | | Observed | Simulated | |
| $T_1$ | 4.9 | 5 | 2.0 | 14.1 | 14.2 | 0.7 |
| $T_2$ | 4.6 | 4.7 | 2.2 | 14.1 | 14.2 | 0.7 |
| $T_3$ | 5.1 | 5.3 | 3.9 | 15.3 | 15.9 | 3.9 |
| $T_4$ | 4.6 | 4.7 | 2.2 | 14 | 14.3 | 2.1 |
| $T_5$ | 4.4 | 4.5 | 2.3 | 11.8 | 12.1 | 2.5 |
| $T_6$ | 4.7 | 4.6 | 2.1 | 14.6 | 15.4 | 5.5 |
| $T_7$ | 4.7 | 4.9 | 4.3 | 15 | 15.8 | 5.3 |

**Table 5.** Calibration results of crop yield and biomass of wheat under different level of irrigation

| Model output parameters | Mean | | RMSE | MAE | E | $R^2$ |
|---|---|---|---|---|---|---|
| | Measured | Simulated | | | | |
| Crop yield (t ha$^{-1}$) | 4.71 | 4.78 | 1.1 | 0.59 | 0.99 | 0.90 |
| Biomass (t ha$^{-1}$) | 14.1 | 14.9 | 0.15 | 0.87 | 0.96 | 0.94 |

**Table 6.** Validation results of crop yield and biomass of wheat under different level of irrigation

| Treatments | Yield (t ha$^{-1}$) | | $P_e$ (± %) | Biomass (t ha$^{-1}$) | | $P_e$ (± %) |
|---|---|---|---|---|---|---|
| | Observed | Simulated | | Observed | Simulated | |
| $T_1$ | 5 | 5.1 | 2.0 | 15.1 | 15.4 | 2.0 |
| $T_2$ | 4.5 | 4.6 | 2.2 | 14 | 14.3 | 2.1 |
| $T_3$ | 5.4 | 5.3 | 1.9 | 15.1 | 15.5 | 2.6 |
| $T_4$ | 4.6 | 4.7 | 2.2 | 13.7 | 14.5 | 5.8 |
| $T_5$ | 5.2 | 5.3 | 1.9 | 12.5 | 13.3 | 6.4 |
| $T_6$ | 4.5 | 4.6 | 2.2 | 13.9 | 14.1 | 1.4 |
| $T_7$ | 5.2 | 5 | 3.8 | 15.9 | 16.1 | 1.3 |

**Table 7** Prediction error statistics of validated AquaCrop model for wheat

| Model output parameters | Mean | | RMSE | MAE | E | $R^2$ |
|---|---|---|---|---|---|---|
| | Measured | Simulated | | | | |
| Crop yield (t ha$^{-1}$) | 4.9 | 4.94 | 1.1 | 0.38 | 0.99 | 0.90 |
| Biomass (t ha$^{-1}$) | 14.3 | 14.7 | 0.28 | 1 | 0.96 | 0.96 |

biomass were 5.4 and 15.9 t ha$^{-1}$, respectively for $T_3$ and $T_7$ with subsurface drip irrigation and surface irrigation method, respectively. Similarly, minimum yield and biomass were 4.5 and 12.5 t ha$^{-1}$ for $T_2$ or $T_6$ and $T_5$ under drip irrigation respectively**.** The highest simulated grain yield and biomass were 5.3 and 16.1 t ha$^{-1}$ for $T_3$ or $T_5$ and $T_7$, respectively and, minimum yield and biomass were 4.6 and 14.1 t ha$^{-1}$ for $T_2$ and $T_6$, respectively (Table 6).

The model was validated for crop yield with model efficiency (E) and $R^2$ of 0.99 and 0.90, respectively. The maximum and minimum errors in crop yield prediction were 3.8 and 1.9 % for $T_7$ and $T_3$ or $T_5$ respectively. The model was validated for biomass with model efficiency (E) of 0.96 and $R^2$ of 0.96 (Table 7). The maximum and minimum errors in biomass prediction were 6.4 and 1.3 % for $T_5$ and $T_7$.

## CONCLUSION

The biometric parameters, crop yield and yield contributing characters for wheat crop were maximum in the treatment $T_3$ (subsurface drip irrigation) and treatment $T_7$ (conventional irrigation). Water supply to the wheat crop was significantly higher in the treatment $T_7$ as compared to other treatments. The water use efficiency for treatments under drip irrigation was significantly superior to the treatment under surface irrigation The FAO- AquaCrop model was tested for wheat crop grown under surface, subsurface drip irrigation and surface method of irrigation. Crop yield and biomass were considered for model evaluation. Observed and simulated crop yield and biomass values were compared. Wheat crop under different level of irrigation at harvest. The model evaluation was done for different level of irrigation. Using the prediction error statistics the goodness of fit between the simulated and observed values was corroborated. The model was calibrated for simulation of yield and biomass of wheat crop for all treatments with the prediction error statistics 0.96 < E < 0.99, 0.15 < RMSE < 1.10, .90 < $R^2$< 0.94 and 0.59 < MAE < 0.87 t $ha^{-1}$. AquaCrop model predictions for yield and biomass of wheat crop were in line with the observed data corroborated with E and $R^2$ values approaching one. The model was validated for wheat crop yield and biomass with all treatment combinations with prediction error statistics values 0.96 < E < 0.99, 0.28 < RMSE <1.1, 0.90 < $R^2$< 0.96 and 0.38 < MAE <1 t $ha^{-1}$.

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# Quantitative Morphometric Analysis of Dzumah Watershed of Upper Dhansiri, Nagaland, India

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***Abstract***: In the present study, an attempt was made to quantify the morphometric characteristics of Dzumah watershed located in Nagaland, India. The Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) of 30 m spatial resolution was used in ArcGIS environment for evaluating the morphometric parameters and generation of maps. The Dzumah watershed is a fifth order drainage basin with an area of 65.55 $km^2$ with 228 stream segments (total stream number) with a total stream length of 130.71 km. A low drainage density of 1.99 $km/km^2$ indicates coarse drainage texture revealing that the watershed has good infiltration/permeability and vegetation cover. The analysis of various aerial aspects such as form factor, circularity ratio and elongation ratio revealed that the watershed is elongated in shape. The analysis of relief aspects revealed that the lowest and highest elevation in the watershed was 328 m and 2345 m above mean sea level, respectively. The observed values for relief ratio and ruggedness number are 0.14 and 4.02, respectively, indicating that the watershed has rough, steep and uneven topography. The high permeability as inferred by low values of drainage density could be negated by high rainfall and steep uneven terrain characteristics of the watershed which would not only decrease the absorption time but also increase the velocity of accumulated surface run off. The overall results from the study showed that the watershed is characterized by rugged uneven terrain with steep slopes which would favour a considerable increase in flow velocity, thus increasing the risk of soil erosion.

***Keywords***: Morphometric analysis, DEM, Dzumah watershed, Soil erosion

Characterization based on analysis of morphometric aspects is a relatively simple procedure to understand the landform, hydrological response and erosion characteristics of a watershed. Quantitative morphometric analysis includes calculation of linear, aerial and relief aspects of a drainage basin. The advances in remote sensing and geospatial technologies has greatly simplified the process of computation and analysis of morphometric parameters and are capable of generating accurate and reliable results. A geospatial approach for morphometric analysis is desirable since manual on-site efforts for characterization is tedious, expensive and laborious (Harinath and Raghu 2013). Various researchers have consistently validated the use of geospatial approach for effective analysis of morphometric parameters of watersheds (Kulkarni 2015, Aparna et al 2015, Ayele et al 2017, Pande and Moharir 2017. Gizachew and Berhan 2018). For a state like Nagaland, which is characterized by steep, uneven and hilly terrain, the need for conservation of soil and water resources is of paramount importance as these are basic and critical resources where majority of the society and the overall economy rely on agricultural production and forest resources. Moreover, owing to its steep and rugged topography, the state acts as a runoff zone. Soil and water conservation projects require a comprehensive understanding of its hydrological and physical characteristics (Gutema et al 2017, Gezahegn et al 2018, Gizachew and Berhan 2018, Asfaw and Workineh 2019). Therefore, the present study was undertaken to quantify the morphometric characters of the Dzumah watershed using GIS techniques which can serve as decision-making and planning inputs for soil and water conservation and related activities.

## MATERIAL AND METHODS

**Study area:** The Dzumah watershed selected for the study is located in Medziphema, under Dimapur district of Nagaland. The watershed is located between 93° 51' 33" to 94° 00' 16" E longitude and 25° 40' 45" to 25° 47' 01" N latitude occupying an area of 6555 ha (65.55 sq km). The elevation of the watershed is at a height of 328 m above mean sea level at the confluence and increases up to a height of 2345 m above mean sea level. The watershed area has a typical humid sub-tropical and associated agro-ecological setup. The watershed exhibits a dendritic drainage pattern (Fig. 1).

**Data source and analytical approach:** The extraction of drainage, delineation of watershed and determination of elevation ranges was done using Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) of 30 m spatial resolution in ArcGIS environment. The automated method for generation of drainage network, delineating the watershed and deriving basic parameters followed a series of steps (Fig. 2). Thereafter, morphometric parameters for the watershed were computed based on this dataset (Table 1).

## RESULTS AND DISCUSSION

**Stream order (Su):** The Dzumah watershed is a 5$^{th}$ order watershed (Fig. 3) consisting of 184, 36, 5, 2 and 1 stream segments of first, second, third, fourth and fifth order, respectively (Table 1). Wakode et al (2013) reported a higher stream order under humid mountain-plain settings than in a sub-humid plateau-plain environmental setting.

**Stream number (Nu)**: The total number of stream segments in the basin was 228 (Table 1) and the number of stream segments decreased as the stream order increased to higher orders. The higher number of lower order streams could be due to the uneven, hilly and undulating terrain. A higher count of stream segments in higher elevations of the basin denotes a young topography indicating that the basin is at a youthful developmental stage (Mahala 2020). There was an abrupt decrease in the number of streams as the stream order increases. This sudden drop in stream number indicates major morphological change within the watershed.

**Stream length (Lu):** The total stream length of the watershed is 130.72 km, of which 66.20, 34.40, 19.84, 6.35 and 3.9 km are of first, second, third, fourth and fifth stream orders, respectively (Table 1). The total length of stream decreases as the stream order increases to higher orders. Similarly, the overall stream length was highest for first order stream and declined with further increase in stream order, indicating that there is no lithological inconsistency in the watershed. Several studies have reported the occurrence of higher stream length in mountain–plain regions as compared to plateau–plain regions (Chitra et al 2011, Magesh et al 2013, Mahala 2020, Babu et al 2016)

**Mean stream length (Lsm):** The mean stream length of the first, second, third, fourth and fifth order streams of the watershed were 0.36, 0.96, 3.97, 3.18 and 3.92 km, respectively (Table 1). The increase in mean stream length from 1$^{st}$ order to the 5$^{th}$ order denotes that the lower order streams are shorter in length but greater in number whereas the higher order streams are longer but lesser in number as described by Strahler (1964). This could be due to the

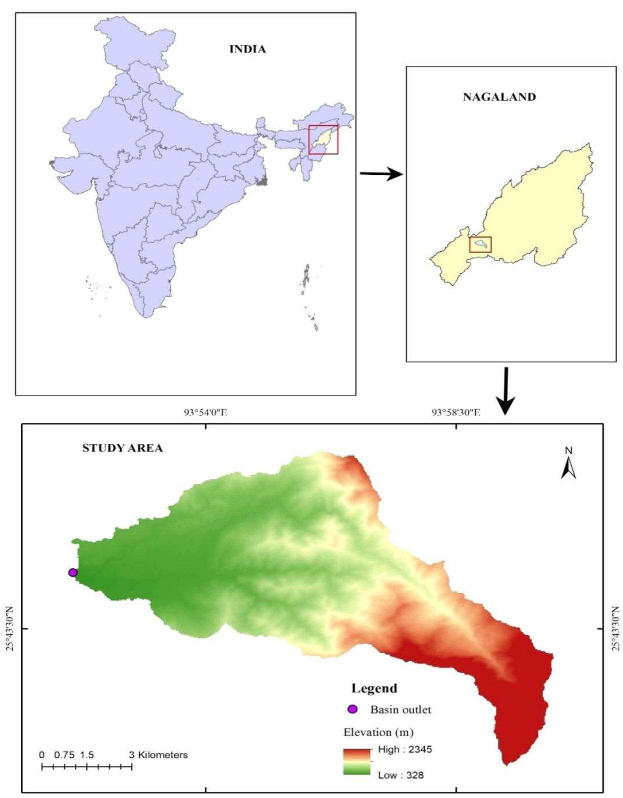


**Fig. 1.** Location and DEM representation of **s**tudy area

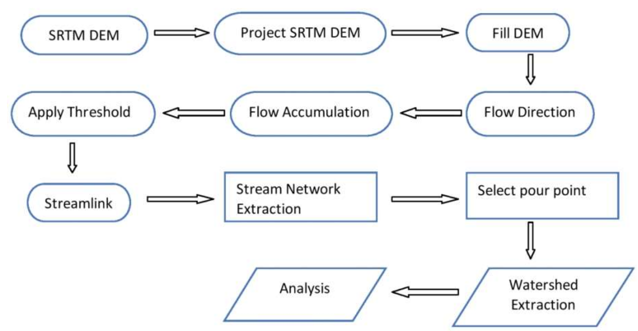


**Fig. 2.** Flow chart of methodology

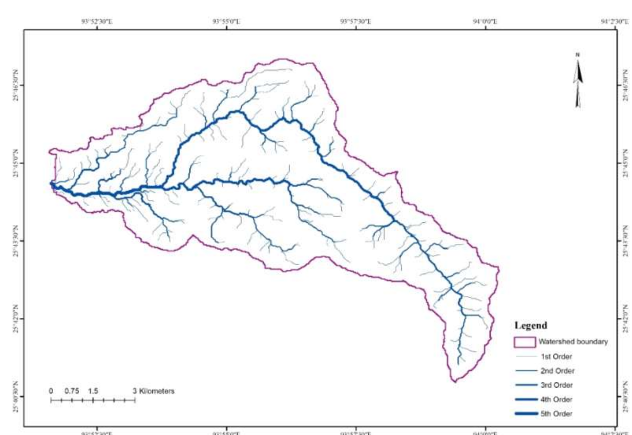


**Fig. 3.** Stream order map of Dzumah watershed

decrease in slope from the edges of the divide line to the confluence of the basin, which further suggests that the watershed is at a youthful stage (Gizachew and Berhan 2018). Short stream lengths suggest the presence of sharp and steep gradients whereas longer stream lengths are indicative of flat or gentle slopes (Withanage et al 2014).

**Length of overland flow (Lg):** It is categorized into three classes *i.e.,* low, moderate and high with value range of < 0.2, 0.2-0.3 and >0.3, respectively (Chandrashekar et al 2015). Low value of Lg denotes high relief, short flow paths, more runoff, less infiltration and vice versa. The length of overland flow calculated for the Dzumah watershed is 0.25 (Table 1) and thus, falls under the moderate class indicating that the watershed is prone to moderate risks of runoff and erosion.

**Stream length ratio (Rl):** The observed stream length ratio for the Dzumah watershed was 0.52 for first to second order

**Table 1**. Methods of calculation of morphometric parameters and observed values

| Morphometric parameters | Formula | Description | References | Observed values |
|---|---|---|---|---|
| A. Linear aspects | | | | |
| Stream order (u) | - | Hierarchical rank | Strahler (1964) | 5 |
| Stream length (Lu) | - | Length of the major stream | Horton (1945) | 1st = 66.20 km<br>2nd= 34.40 km<br>3rd= 19.84 km<br>4th= 6.35 km<br>5th= 3.92 km<br>Total =130.71 km |
| Stream number (Nu) | - | Total number of stream segments of order 'u' | Horton (1945) | 1st = 184<br>2nd= 36<br>3rd= 5<br>4th= 5<br>5th= 1<br>Total = 228 |
| Mean stream length (Lsm) | Lsm = Lu/Nu | Lu = Total stream length of order 'u'<br>Nu=Total number of stream segments of order 'u' | Strahler (1964) | 1st = 0.36 km<br>2nd= 0.96 km<br>3rd= 3.97 km<br>4th= 3.18 km<br>5th= 3.92 km |
| Stream length ratio (Rl) | Rl = Lu/Lu-1 | Lu = Total stream length of order 'u'<br>Lu-1 = Total stream length of its next lower order | Horton (1945) | 1:2=0.52<br>2:3=0.58<br>3:4=0.32<br>4:5=0.62 |
| Length of overland flow (Lg) | Lg = 1/(2xDd) | Dd = Stream density | Horton (1945) | 0.25 km |
| Bifurcation ratio (Rb) | Rb=Nu/Nu+1 | Nu = Total number of stream segments of order 'u'<br>Nu+1 = Number of stream segments of the next higher order | Schumm (1956) | 1:2=5.1<br>2:3=7.2<br>3:4=2.5<br>4:5=2.0 |
| Mean bifurcation ratio (Rbm) | - | Average of bifurcation ratios of all orders | Strahler (1957) | 4.2 |
| Basin length (Lb) | - | - | Schumm (1956) | 14.74 km |
| B. Aerial Aspects. | | | | |
| Watershed area (A) | - | - | Schumm (1956) | 65.55 $km^2$ |
| Watershed perimeter (P) | - | - | Schumm (1956) | 59.58 km |
| Form factor (Ff) | $Ff = A/Lb^2$ | A = Area of watershed<br>Lb = Basin length | Horton (1932) | 0.30 |
| Elongation ratio (Re) | $Re = (2/Lb)[(A/\pi)^{0.5}]$ | A = Area of watershed<br>Lb = Basin length | Schumm (1956) | 0.62 |
| Circulatory ratio (Rc) | $Rc = (4\pi A)/P^2$ | A = Area of watershed<br>P = Perimeter | Strahler (1964) | 0.23 |
| Drainage density (Dd) | Dd = Lu /A | Ratio of total stream length and area | Horton (1945) | 1.99 |
| C. Relief aspects | | | | |
| Basin relief (Bh) | Bh = H-h | Vertical distance between the lowest and highest points | Strahler (1952) | 2016 m |
| Relief ratio (Rr) | Rr = Bh/Lb | Ratio of basin relief and length | Schumm (1956) | 0.14 |
| Ruggedness number (Rn) | Rn = Bh x Dd | Bh = Basin relief<br>Dd = Drainage density | Strahler (1958) | 4.02 |

streams, 0.58 for second to third order, 0.32 for third to fourth order and 0.62 for fourth to fifth order (Table 1). The tendency of increasing Rl from lower order to higher order denotes their mature geomorphic stage of a basin (Vinutha and Janardhana 2014). Therefore, there is no classification for Rl (Sukristiyanti et al 2018). An increasing trend in the stream length ratio was observed up to the third order. However, a drop in the ratio trend was noticed between the third and fourth order stream and subsequently increases between the fourth and fifth order. The variation in Rl ratio could be attributed to the diverse topographic conditions and varying slopes (Qadir et al 2019). Such changes in Rl suggest an early stage of geomorphic development in the watershed, indicating that the watershed is subjected to changes and transformations in future (Mahala 2020).

**Bifurcation ratio (Rb):** Bifurcation ratio denotes the extent of integration among streams segments of different orders in the watershed (Gutema et al 2017). The observed Rb values between fifth to fourth order, fourth to third order, third to second order and second to first order streams are 2.0, 2.5, 7.2 and 5.1, respectively. The mean Rb of the watershed is 4.2 (Table 1). The bifurcation ratio among the lower order streams are much higher compared to those among the higher order streams. This could be due to a greater influence of geologic structures on the drainage pattern of lower order streams in the higher reaches of the watershed as compared to the higher order streams occupying flatter and plain locations of the watershed.

**Watershed area (A) and perimeter (P):** The Dzumah watershed falls under the Dhansiri river catchment and has an area of 65.55 km$^2$. The perimeter of the watershed was 59.58 km.

**Form factor (Rf):** Elongated basins tend to have lower values of Rf. Higher Rf values indicates a basin that is more circular in shape and having higher peak flows in shorter time periods whereas an elongated basin tends to have lower Rf values with relatively lower peak flows over a longer period of time (Bali et al 2011). The observed form factor for the Dzumah watershed is 0.30 indicating that the watershed is elongated (Table 1). This finding suggests that the discharge from the watershed will have flatter peak flows for longer period.

**Elongation ratio (Re):** The Re values are categorized into four classes *i.e.,* elongated, less elongated, oval and circular with value ranges of < 0.7, 0.7 to 0.8, 0.8 to 0.9 and > 0.9, respectively (Sukristiyanti et al 2018). The observed *R*e value of the Dzumah watershed is 0.62, which denotes the elongated and elliptical characteristics of the basin (Table 1). This finding further highlights the steep slopes and uneven terrain characteristics in the higher reaches of the study area.

**Circularity ratio (Rc**): Rc values of 0.4 and below indicates an elongated basin, Rc values ranging between 0.4-0.75 indicate intermediate shape of basin and values greater than 0.75 indicate circular basin (Miller 1953). Lower values of Rc indicate a higher vulnerability to soil erosion (Kadam et al 2019). The observed Rc value of the Dzumah watershed is 0.23 (Table 1), indicating that the watershed is elongated in shape. The drainage density pattern is coarse if Dd is less than 5 km/km$^2$, medium if Dd is between 5-10 km/km$^2$ and fine if Dd is more than 10 km/km$^2$ (Yousuf et al 2020). Several studies indicated that high values of drainage density occur in locations with impermeable surface materials, sparse vegetation and high relief, whereas, low values of drainage density are observed in places with relatively better vegetation cover, permeable soil and low relief (Asfaw and Workineh 2019, Babu et al 2016, Gizachew and Berhan 2018). The observed value of drainage density of Dzumah watershed is 1.99 km/km$^2$ (Table 1), indicating that it has a coarse drainage texture. Given the relationship of drainage density with other basin characteristics, it can be inferred that on account of low drainage density, the Dzumah watershed is expected to have good infiltration capacity/permeability and excellent vegetation cover.

**Basin relief (Bh):** Outlet of the Dzumah watershed is located at an elevation of 328 m above mean sea level whereas the highest elevation recorded in the watershed is at an elevation of 2345 m above mean sea level (Fig. 4). This results in a basin relief of 2017 m for the watershed.

**Relief ratio (Rr):** It is the ratio between the basin relief and basin length. In general, low Rr values imply low relief, whereas high Rr values suggest steep slopes and considerable relief. Considering the findings of other researchers, observed that the Rr values ranged from as low as 0.0028 (Mahala 2020) to as high as 0.19 (Adhikari 2020), with the latter indicating high relief and high slope. The observed relief ratio of the Dzumah watershed is 0.14 (Table

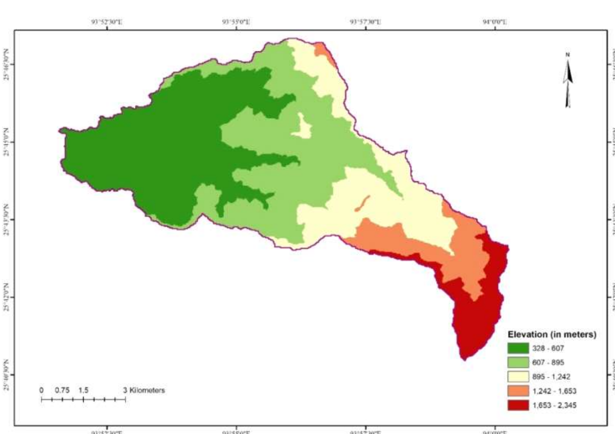


**Fig. 4.** Elevation map of Dzumah watershed

1). Based on relative assessment and comparison, it can be inferred that the study area has a high relief ratio indicating strong relief and steep slopes.

**Ruggedness number (Rn):** Rn is a combination of slope length and steepness suggestive of the degree of vulnerability of the land surface. Areas with low Rn values are less susceptible to erosion hazards (Pareta and Pareta 2011) and vice- versa. The ruggedness value of the Dzumah watershed is 4.02 (Table 1), which is high and indicates that the watershed has a rough and uneven topography vulnerable to soil erosion.

**Implications for soil and water conservation:** The present reconnaissance analysis of relief aspects indicates that the Dzumah watershed is characterized by rugged uneven terrain with steep slopes which would favour a considerable increase in flow velocity, thus increasing the risk of soil erosion. The results of aerial parameters such as form factor, elongation ratio and circularity ratio suggest that the watershed has an elongated configuration indicating flatter peak flows and less flooding hazards. The stream number and length of overland flow indicate that the watershed could have less infiltration and prone to moderate risk of soil erosion, whereas drainage density values suggest that the watershed has coarse drainage texture with permeable material, good infiltration, and adequate vegetation cover. The high permeability as inferred by low values of drainage density could be negated by high rainfall and steep uneven terrain characteristics of the watershed which not only decreases the absorption time but also increases the velocity of accumulated surface run off.

## CONCLUSION

The study corroborates the practical application of remote sensing and GIS techniques in morphometric characterization of watershed and determination of its hydrological behavior. Dzumah watershed is a fifth order drainage basin with a low drainage density value of 1.99 $km/km^2$ indicating that the watershed has good infiltration/permeability and vegetation cover. The observed values for form factor, circularity ratio and elongation ratio indicate that the watershed is elongated in shape. The observed values for relief ratio and ruggedness number indicate that the watershed has a rough, steep and uneven topography. The overall results from the study showed that the watershed is characterized by rugged uneven terrain with steep slopes which would favour a considerable increase in flow velocity, thus increasing the risk of soil erosion. It is therefore imperative to undertake adequate soil and water conservation measures to minimize sediment transport and increase ground water recharge in the watershed. Furthermore, the hydrological behaviour of the watershed exert profound influence on the siltation and water quality affairs in the downstream areas of the Dhansiri River, of which the Dzumah watershed forms an important tributary. The findings of this study can serve as a planning and decision-making guide for erosion risk mitigation and efforts for surface water conservation in the watershed.

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# GC-MS Studies on Bioactive Food Plant-*Linum usitatissimum* L. Grown Through Recovery Drip System

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***Abstract***: The aim of the current study is to monitor the phytochemical constituents in the *Linum usitatissimum* by GC MS analysis.The leaf, stem, root of hydroponically grown Flax *Linum usitatissimum* were extracted with methanol at room temperature for 8 h. Further subjected for evaluation using GC-MS.The phytochemical analysis revealed the presence of 20 compounds in leaf methanolic extract and the chromatogram showed peaks with individual compounds. The major constituents identified in the leaf methanolic of extract were Silane, Trimethyl-2-Propyne-, Cyano Methyl-Triiron Disulfide Octacarbonyl, Guanidino-L-proline, Cyclohexanecarboxylic acid, 2(3H)-Furanone, 5-methyl-, Ethane, 1-chloro-1-fluoro, 5,6-Dichlorohexene similarly in stem extract Carbonochloridic acid, Furfuryl glycidyl ether, 4-Amino-6-methyl-piperidin-2-one, Goitrin, Nerinine whereas in roots of Flax herbs seven compounds were shown and they are 2(3H)-Furanone, Ethane, 1-chloro-1-fluoro-, Silane, Trimethyl-2-Propyne, Guanidino-L-proline, 1,3,5-Triazine and many other compounds were identified as low level.The result of this study offers a platform of using *Linum usitatissimum*as herbal alternative for various diseases and it can be used as functional bioactive food.

***Keywords***: *Linum usitatissimum,* GC-MS, Hydroponic unit, Phytochemicalstudies, Bioactive food

Flax (*Linum usitassimum*) belonging to family Lineaceae, itis not a new crop and native to West Asia and the Mediterranean. By virtue of the presence of physiologically active food components that may provide health benefits beyond basic nutrition, flaxseed is often grouped into one of several categories namely; "functional food" "bioactive food" and an "endocrine active food." Ancient centres of flax-growing are mountainous areas of India and China early as in the 4th or 5th millennium B.C. flax was cultivated for its fiber in Mesopotamia, Assyria and Egypt.Wild narrow-leaved flax and semi-cultured procumbent flaxes are grown in Transcaucasia. The seed contains approximately 40% lipids, 30% dietary fiber and 20 % protein. The chemical composition varies considerably among varieties and also depends on the environmental conditions in which the plant is grown. Cotyledons of seeds contain 25% of the lipids, and 35% of proteins. The endosperm contains only 23% of the lipids and 16% of protein.Other species of Linum shows many compounds at high concentrations of omega-3 fatty acids and lignans which exhibits goitrin, nerinine content. Soilles culture through recovery drip system automatically promotes nutrients, fresh water in the form of irrigation with modern fertigation technology. (Savvas and Gruda 2018).

## MATERIAL AND METHODS

The study was laid out in hydroponic unit i.e., recovery drip system having a size 100 sq. ft with an anti-insect mesh, 15m wide, 15.0 m length and 4.70 m height. The pressurized irrigation system (on each shelf) was controlled with gate valves. The conductive and distribution pipes of the nutritive solution were made of black PVC tubing with 1cm diameter with one nebulizer at each 25 cm of distance, with a consumption of mineral nutrient enriched water at 3L $hr^{-1}$ in each device. Seedlings of each plantlet was placed in each slot running with the nutritive solution containing Ca (300 ppm), Mg (400 ppm), NPK (260 ppm), boric acid (300 ppm), Zn (400 ppm) and S (300 ppm) andwere applied from the 5th up to the 12th day after sowing while the plants were growing and at the time of harvest. The nutrientsolution was maintained with pH 6.5, E.C 1.10 ds $m^{-1}$ at 22°Cwith 70% humidity in a 500 L water tank circulated through PVC tubes. Later the growth was monitored with length of plant (LP), number of shoot lets (S) and number of days (d) (Fig. 1).

### Gas Chromatography–Mass Spectrometry (Gc/Ms) Analysis

Plant parts of *Linum usitatissimum* were taken to run under soxhlet for the extraction in presence of methanolic solvent. GC/MS analysis was performed using a Perkin Elmer GC Claurus 500 system and Gas Chromatograph interfaced to a Mass Spectrometer (GC/MS) equipped with an Elite-1 fused silica capillary column (30 m × 0.25 mm ID. ×1 μMdf, composed of 100% Dimethyl poly siloxane). For

**Table 1.** Phytocomponents in methanolic extract of hydroponically grown flax leaf

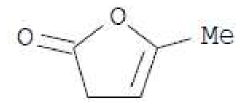
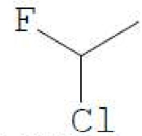
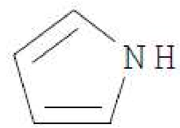
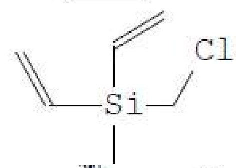
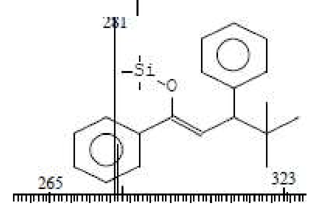
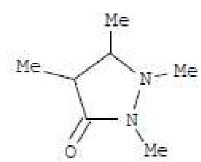
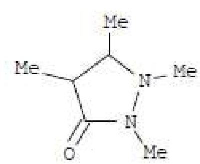
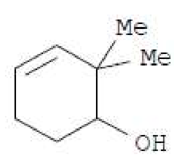
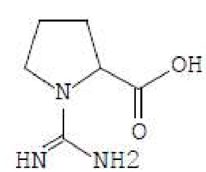
| RT | Name of the compound | Molecular formula | MW | Peak area | Chemical structure |
|---|---|---|---|---|---|
| 0.158 | 2(3H)-Furanone, 5-methyl- | C5H6O2 | 98 | 7.17 |  |
| 1.166 | Ethane, 1-chloro-1-fluoro- (CAS) 1-Chloro-1-fluoroethane 1-Chlorofluoroethane | C2H4ClF | 82 | 7.98 |  |
| 19.518 | Hexadecanoic acid (CAS) Palmitic acid | C16 H32 O2 | 256 | 22.84 | $HO_2C(CH_2)_{14}Me$ |
| 21.668 | 5,6-Dichlorohexene | C6 H10 CL2 | 152 | 3.99 |  |
| 29.100 | 1,2-Propadiene | C3H4 | 40 | 3.55 | $H_2C=C=CH_2$ |
| 30.335 | 2-methylene-7-oxabicyclo | C7 H10 O | 110 | 4.09 |  |
| 30.825 | Silane, trimethyl-2-propyne- | C6 H12 SI | 112 | 2.22 |  |
| 31.168 | Cyanomethyl-triiron disulfide octacarbonyl | C10 H3 FE3 N O8 S2 | 497 | 2.44 |  |
| 31.397 | 3-Pyrazolidinone, 1,2,4,5-tetramethyl- (CAS) 1,1 N-N Dimethyltetrahydrapyrazol-3-One | C7 H14 N2 O | 142 | 6.61 |  |
| 31.492 | 2',5'-diamine, N,N'-dicyclohexyl | C30 H36 N2 | 424 | 4.13 |  |
| 31.858 | 2,2-Dimethyl-3-cyclohexen-1-ol | C8 H14 O | 126 | 3.27 |  |
| 32.042 | Guanidino-L-proline | C6H11N3O2 | 157 | 3.76 |  |

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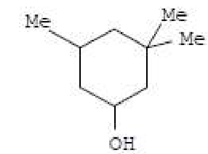
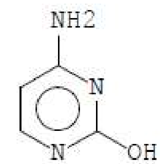
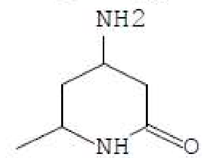
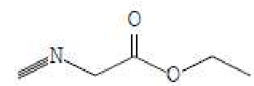
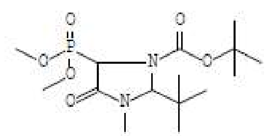
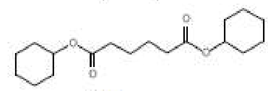
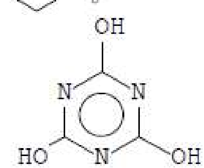
**Table 1.** Phytocomponents in methanolic extract of hydroponically grown flax leaf

| RT | Name of the compound | Molecular formula | MW | Peak area | Chemical structure |
|---|---|---|---|---|---|
| 32.217 | Cyclohexanol, 3,3,5-trimethyl- | $C_9H_{18}O$ | 142 | 3.37 |  |
| 32.383 | Thiophene, 3-methyl-2-pentadecyl | $C_{20}H_{36}S$ | 308 | 2.71 |  |
| 32.471 | 4-Amino-6-methyl-piperidin-2-one | $C_6H_{12}N_2O$ | 128 | 4.10 |  |
| 32.509 | 4-Amino-6-methyl-piperidin-2-one | $C_6H_{12}N_2O$ | 128 | 3.90 |  |
| 32.659 | Acetic acid,2-cyano-, ethyl ester | $C_5H_7NO_2$ | 113 | 4.77 |  |
| 33.641 | 2-t-Butyl-5-(dimethoxy-phosphoryl)-3-methyl-4-oxoimidazolidine-1-carboxylic acid, t-butyl ester | $C_{15}H_{29}N_2O_6P$ | 364 | 4.23 |  |
| 34.458 | Cyclohexanecarboxylic Acid, Cyclohexyl Ester (Cas) Cyclohexyl Cyclohexanecarboxylate | $C_{13}H_{22}O_2$ | 210 | 2.64 |  |
| 34.542 | 1,3,5-Triazine-2,4,6(1H,3H,5H)-trione | $C_3H_3N_3O_3$ | 129 | 2.23 |  |

GC/MS detection, an electron ionization system with ionization energy of 70 eV was used. Helium gas (99.999%) was used as the carrier gas at a constant flow rate of 1 ml/min. and an injection volume of 2 µl was employed (split ratio of 10:1). Injector temperature 250°C; Ion-source temperature 280°C. The oven temperature was programmed from 110°C (isothermal for 2 min.), with an increase of 10°C/min, to 200°C, then 5°C/min to 280°C, ending with a 9 min. isothermal at 280°C. Mass spectra were taken at 70 eV; a scan interval of 0.5 seconds and fragments from 45 to 450 Da. Total GC running time was 36 min. The relative percentages were calculated.

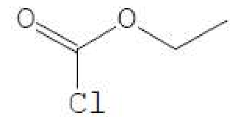
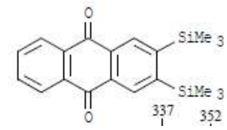
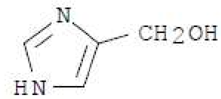
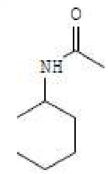
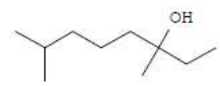
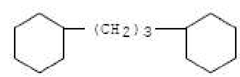
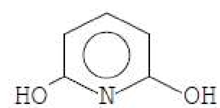
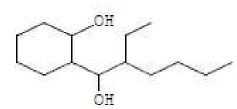
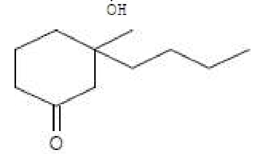
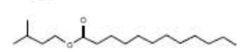
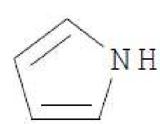
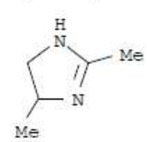
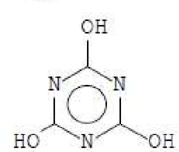
**Characterization of compounds:** Interpretation on mass-spectrum GC-MS was conducted using the database of National Institute Standard and Technology (NIST) having more than 62,000 patterns. The spectrum of the unknown components was compared with the spectrum of known components stored in the NIST library. The name, molecular weight and structure of the components of the test materials were ascertained.

## RESULTS AND DISCUSSION

Table 4 and Figure 1 showed the maximum length of shoot lets of Flax seeds grown in Hydroponics unit for 5 weeks of treatments. Table 5 showed the number of leaves of flax seeds grown in hydroponics for 5 weeks through one-way ANOVA statistical analysis was performed.

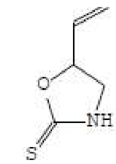
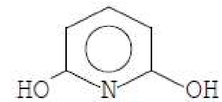
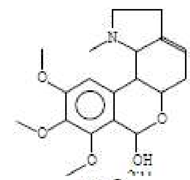
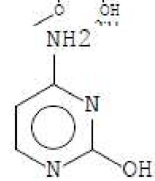
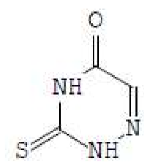
The studies on the active principles in the flax leaf methanolic extract by GC-MS analysis clearly showed the presence of twenty compounds with their retention time (RT). molecular formula, molecular weight (MW), and concentration (peak area (Table-1). The major components

**Table 2.** Phytocomponents in methanolic extract of hydroponically grown flax stem

| RT | Name of the compound | Molecular formula | MW | Peak area | Chemical structure |
|---|---|---|---|---|---|
| 1.166 | Carbonochloridic acid, ethyl ester (CAS) Cathyl chloride | C3 H5 CL O2 | 108 | 4.94 |  |
| 19.568 | Tridecanoic acid (CAS) Tridecylic acid | C13 H26 O2 | 214 | 8.26 |  |
| 30.826 | Furfuryl glycidyl ether | C8H10O3 | 154 | 4.12 |  |
| 31.348 | 4-Cyclohexene-1,2-diol | C6H10O2 | 114 | 4.77 |  |
| 31.867 | Tetrahydrolinalool | C10 H22 O | 158 | 3.78 |  |
| 32.725 | Cyclohexane, 1,1'-(1,3-propanediyl)bis- | C15H28 | 208 | 10.43 |  |
| 32.806 | Isoamyl laurate | C17H34O2 | 270 | 3.43 |  |
| 32.967 | 4-Amino-6-methyl-piperidin-2-one | C6H12N2O | 128 | 7.00 |  |
| 33.077 | Cyclohexanol, 2-(2-ethyl-1-hydroxy-1-hexyl)- | C14H28O2 | 228 | 4.11 |  |
| 33.167 | 1-Cyclohexanone, 3-butyl-3-methyl- | C11H20O | 168 | 4.62 |  |
| 33.242 | 3-methylbutyl decanoate | C15 H30 O2 | 242 | 3.80 |  |
| 33.418 | 1H-Pyrrole (CAS) Pyrrole Azole Pyrrol Imidole Monopyrrole Divinylenimine 1-Aza-2,4-cyclopentadiene | C4 H5 N | 67 | 4.40 |  |
| 33.800 | 1H-Imidazole, 4,5-dihydro-2,4-dimethyl- | C5 H10 N2 | 98 | 5.76 |  |
| 33.883 | 1,3,5-Triazine-2,4,6(1H,3H,5H)-trione | C3H3N3O3 | 129 | 3.89 |  |

***Cont...***

**Table 2.** Phytocomponents in methanolic extract of hydroponically grown flax stem

| RT | Name of the compound | Molecular formula | MW | Peak area | Chemical structure |
|---|---|---|---|---|---|
| 34.025 | Goitrin 2-Oxazolidinethione, 5-ethenyl-, (S)- | C5H7NOS | 129 | 6.16 |  |
| 34.208 | 3-oxocanone 1-oxacyclooctan-3-one | C7 H12 O2 | 128 | 4.95 | |
| 34.376 | 2,6-pyridinediol pyridine-2,6-diol | C5 H5 N O2 | 111 | 4.20 |  |
| 34.508 | Nerinine | C19H25NO5 | 347 | 4.17 |  |
| 34.650 | 2(1H)-Pyrimidinone, 4-amino- | C4H5N3O | 111 | 3.98 |  |
| 34.908 | 3-Thio-1,2,4-triazin-3,5(2H,4H)-dione | C3H3N3OS | 129 | 3.22 |  |

present in *Linum usitatissimum* L. leaf methanolic extract areSilane, Trimethyl-2-Propyne- (2.22%), Cyano Methyl-Triiron Disulfide Octacarbonyl (2.44%), Cyclohexanecarboxylic acid (2.64%),Guanidino-L-proline (3.76%), 5,6-Dichlorohexene (3.99%), 2(3H)-Furanone, 5-methyl-(7.17%), Ethane, 1-chloro-1-fluoro (7.98%) and Hexadecanoic acid (CAS) is a Palmitic acid ester which possess antioxidant,heomolytic, anti-androgenic property. The GC-MS analysis of *P. stratiotes* leaves revealed the presence of 7 major compounds L-Glutamine (0.38%), 2-hydroxy-1-(hydroxymethyl) ethyl ester (0.96%), Stigmasterol (2.57%), 9,12,15- Octadecatrienoic acid, methyl ester, (Z,Z,Z) (2.7%), n- Hexadecanoic acid (7.18%), Hexadecanoic acid, ethyl ester (13.29%), Hexadecanoic acid, Diisooctyl phthalate (53.84%), (Tulika Tyagi and Mala Agarwal 2017).Study of using coco peat as a medium in hydroponic system, while environmental and ecological concerns in the recent years suggested mitigating the use of peat because it may destroy endangered wetland ecosystems worldwide. Abul-Soud et al (2016). Asaduzzamana et al (2013).

The studies on the active principles in the flaxstem methanolic extract by GC-MS analysis clearly showed the presence of twenty compounds with their retention time (RT). Molecular formula, molecular weight (MW), and concentration peak area (Table 2). The major components present in *Linum usitatissimum* L. stem methanolic extract are3-Thio-1,2,4-triazin-3,5(2H,4H)-dione (3.22%). Isoamyl laurate (3.43%), Furfuryl glycidyl ether (4.12%), Nerinine (4.17%) Carbonochloridic acid (4.94%), Goitrin (6.16%) and 4-Amino-6-methyl-piperidin-2-one (7.00%) and Different phytochemicals have been found to possess a wide range of activities. The phytochemicals are known to have antimicrobial activity. Flavanoids show anti allergic, anti-inflammatory, anti-microbialand anti-cancer activity. Marinou et al (2013) reported that use of saw dust, coco soil & pumice can increase the growth abundantly for the cultivation. Glycoside, flavonoid, tannin and alkaloid have hypoglycemic activities.Number of multiple shoots was increased in *Mentha arvensis* grown to the length of 19-45cm with 15-37 numbers of shoots and Table top plant with 25-38 shoots after five weeks of nutritional treatment whenit was grown in cocopeat at different treatments (Nazneen Bobby et al 2021). Flax lignans are reported to have antioxidant property which presumably is the main reason of the anticancer activity. Secoisolariciresinol diglycoside existing bound form as a

**Table 3.** Phytocomponents in methanolic extract of hydroponically grown flax roots

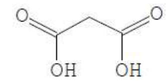
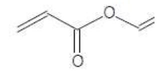
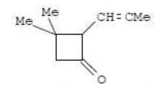
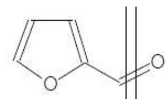
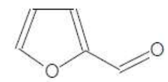
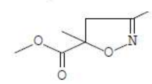
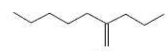
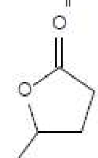
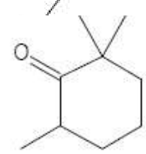
| RT | Name of the compound | Molecular formula | MW | Peak area | Chemical structure |
|---|---|---|---|---|---|
| 0.098 | Formamidinium acetate | C3 H8 N2 O2 | 104 | 6.86 |  |
| 0.300 | (2S,3S)-2,3-Epoxy-1-hexanol Oxiranemethanol | C6 H12 O2 | 116 | 3.29 |  |
| 1.140 | Beta.-ionone epoxide | C13 H20 O2 | 208 | 5.75 | |
| 29.052 | Propane, 2-methoxy-2-methyl- (CAS) | C5 H12 O | 88 | 3.42 | MeOBu-t |
| 31.108 | 1H-Cyclopropa[b]naphthalene-2,7-dion | C15 H22 O3 | 250 | 3.32 |  |
| 31.307 | Tetraethylsuccinic acid dinitrile Butanedinitrile | C12 H20 N2 | 192 | 3.03 | $NCCEt_2CEt_2CN$ |
| 31.518 | Furfural | C5H4O2 | 96 | 4.53 |  |
| 31.608 | Furfural | C5H4O2 | 96 | 5.53 |  |
| 31.850 | 1-(.alpha.-Carbethoxy)ethylazetidin-2- | C8 H13 N O3 | 171 | 3.08 |  |
| 31.950 | 4-brom-5-(phenylthio)tricyclo[4.1.0.0(2 | C13 H11 BR S | 278 | 3.10 | |
| 32.325 | Nonane, 4-methylene- 1-Heptene, 2 | C10H20 | 140 | 11.33 |  |
| 32.401 | 2(3H)-Furanone, dihydro-5-methyl- | C5H8O2 | 100 | 3.93 |  |
| 32.567 | Cyclohexanone, 2,2,6-trimethyl- | C9H16O | 140 | 5.21 |  |
| 32.759 | Dodecanoic acid, 2-hexen-1-yl ester | C18H34O2 | 282 | 4.89 |  |
| 33.001 | cis 3 hexenyl lactate | C9 H16 O3 | 172 | 6.98 | |
| 33.125 | 4-dimethylamino-2,3,4,6-tetra | C8 H15 N O2 | 157 | 3.58 | |
| 33.423 | n-Hexyl acrylate 2-Propenoic acid, hexyl | C9H16O2 | 156 | 6.91 | |
| 33.625 | (2H)Pyrrole_2_carbonitrile, 5_amino_3,4_ | C5H7N3 | 109 | 6.15 | |
| 33.983 | Hexanenitrile (CAS) Capronitrile Tricapronile | C6 H11 N | 97 | 5.04 | |
| 34.897 | 8-Pentadecanol | C15H32O | 228 | 4.09 | |

**Table 4.** Length of shoots and of flax seeds grown in hydroponics for 5 weeks

| Parameters | Week after sowing | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | Total |
| Length of shoots | | | | | | |
| Mean | 2.396 | 4.328 | 9.88 | 12.44 | 18.44 | 9.497 |
| Standard deviation. | 1.022 | 0.9689 | 3.6208 | 4.1037 | 4.9166 | 6.6568 |
| Number of leaves | | | | | | |
| Mean | 3.16 | 5.64 | 9.88 | 12.44 | 18.44 | 9.912 |
| Standard deviation | 2.6721 | 2.8994 | 3.6208 | 2.8994 | 4.9166 | 6.5044 |

**Fig. 1.** Multiple shoots of *Linum usitatissimum* L. grown in hydroponic unit

complex of five secoisolariciresinol diglycoside residues held together by four HMGA (3-hydroxy-3-methylglutaric acid) residues in the outer layers of the seed (Muir 2006).

The studies on the active principles in the flax root of methanolic extract by GC-MS analysis clearly showed the presence of twenty compounds with their retention time (RT). molecular formula, molecular weight (MW), and concentration (peak area%)(Table-. The major component present in *Linum usitatissimum* L. Root methanolic extract are Formamidinium acetate (6.86%), Beta. -ionone epoxide (5.75%), Furfural (4.53%), Nonane, 4-methylene-1-Heptene, 2 (11.33%), Cis 3 Hexenyl Lactate (6.98%), Hexanenitrile (CAS) Capronitrile Tricapronile (5.04%) and 8-Pentadecanol (4.09%). Conventionally grown *Linumusitatissimum* revealed the presence of seventeen compounds of which squalene (45.27 %) and 9, 12, 15-octadecatrienoic acid (z,z,z) (24.67) are the phytocomponents with high peak areas (Dharshini et al 2013). These alkaloids have been found to possess significant bioactivities such as antiviral, antiprotozoal, antitumor and cholinesterase inhibitory activities. (Zou G et al 2009). Flavonoids are antioxidants and free radical scavengers which prevent oxidative cell damage, have strong anticancer activity and protect the cell against all stages of carcinogenesis (Okwu2004). 1-Monolinoleoylglycerol trimethylsilyl ether has many biological activities such as Antiarthritic, Anticancer, Hepatoprotective, Antimicrobial, Antiasthma, Diuretic, antioxidant, anti-inflammatory and anti-diabetic (Senthil et al 2016). Several other compounds were also detected through GC/MS chromatogram having notable medicinal property. Among the identified phytochemicals, n-Hexadecanoic acid, Hexadecanoic acid, ethyl ester, Palmitic acid has the property of antioxidant, hypocholesterolemic, nematicide, pesticide, lubricant activities and hemolytic 5-alpha is a reductase inhibitor (Jegadeeswari et al 2012. Upgade and Anusha 2013). Almost the results output to the availability of nutrients is a vital factor influencing plant growth (Lazcano et al 2009).

## CONCLUSION

The major constituents identified in the leaf methanolic extract were Silane, Trimethyl-2-Propyne- etc., whereas the stem extract shows Carbonochloridic acid, Furfuryl glycidyl ether, Goitrin, Nerinine etc., whereas in roots of Flax herbs seven compounds were shown and they are Ethane and many other compounds at low level. These investigations can prove that *Linum usitatissimum* would be used as alternative medicine for treating various diseases.

## ACKNOWLEDGEMENT

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**NAAS Rating: 5.79**

# Evalution of Physico-Chemical Quality of Groundwater of Khemis Miliana Plain (North West Algeria)

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***Abstract*:** The demonstration of the main phenomena and the predominant chemical reactions in this evolution as well as the qualitative estimation of this water plus the comparison with the norms of the World Health Organization (W.H.O.), indicated that the positive (+) and negative (-) ions have a direct relationship with the geological and hydrogeological characteristics of the region. The maps of variation of hydro-chemical parameters were made for the spatial distribution of chemical components of groundwater, and also the Piper and Schoelleur diagrams were used to know the chemical facies of waters. The groundwater chemistry of the study area shows that the most dominant facies is chloride-calcic in the north and chloride-sodium in the south of the plain. Diffuse pollution, more difficult to identify, which have an agricultural origin affect almost the entire plain according to the concentrations observed in all periods, especially in 2018 with a value of 107 mg / l in the East of the plain, where there is no agricultural activity.

***Keywords:*** Quality, Physico-chemical, Groundwater, Plain of Khemis Miliana, Algeria

Water is an essential element for life and is important for countless human activities. Water may be scarce in some places, such as arid and semi-arid areas, or simply of poor quality in other places. It is certain that the increasing demand for water for human activities will increase the stress on this resource. In addition, natural factors, such as drought or geological constraints, have an effect on the supply and distribution of drinking water (Germain et al 2007). In its dynamics of development, Algeria did not address the issue relevant to hydrogeology and hydraulics all the intention which it deserves. This resulted in the disappearance of certain traditional orchards, the frequent tensions on water between cities and industries, a very significant decrease of the irrigated surface and the degradation of the quality of the underground water. It is therefore essential to quantify and analyse the quantity and quality of water reserves and to find ways of managing this resource to ensure its sustainability. In this context, the present study adds to earlier research works to provide a scientific overview of the current state of the Khemis Miliana region, from a qualitative and quantitative point of view (Abdelbak Boukli 2007, Calianno et al 2017, Kouadri et al 2021). The quality of the water in this region has deteriorated in recent years due to uncontrolled urban discharges, the intensive use of chemical fertilisers in agriculture, and disorderly exploitation. These elements change the chemistry of the water and make it unsuitable for desired uses (Bisht and Chauhan 2020). The study region has experienced, during the last years, a certain economic and particularly agricultural expansion, and this after the application of the National Agricultural Development Program (PNDA) in 2000 and the National Fund for the Regulation of Agricultural Development (FNRDA) in 2002, this has on the one hand increased the demand for water and on the other hand, exploded the water resources to different pollutions resulting from the agricultural activity.

## MATERIAL AND METHODS

**Geographical location of the study area:** The study area is the plain of Khemis-Miliana. It is located 120 km south-west of Algiers, 50 km west of Médéa and 920 km east of Chlef, on the RN4 (Fig. 1) and altitude tvaries from 230 to 380 m. It is limited to the North by the western continuity of the djebel Zaccar (1578 m of altitude), to the South by the foothills of the Ouarsenis which culminates more than 200 m near Bordj-Bounaama, to the East by djebel Gantas and to the West by the djebel Doui mountain. The surface area of the alluvial plain of Khemis Miliana is 360 $km^2$ and length is approximately 50 km for a width of 10 to 20 km.

The plain of Khemis Miliana is a vast area of depression with an East-West axis where Miocene, Pliocene and Quaternary sediments have accumulated (Fig. 2). The stratigraphy of the formations from bottom to top is as follows. The Primary consists of alternating layers of black shales and quartzites and clays. It is surmounted by the Triassic, which is generally made up of dolomites and dolomitic limestones, exposed in the Doui and Zaccar massifs). The Jurassic in the

Zaccar Massif is formed of compact, fractured and karstified limestones, overlain by sandstone shales and calcareous marls. The whole series reaches a thickness of about 700 m. At Jebel Doui, the Jurassic is mainly represented by dolomitic limestones with a thickness of about 80 m (Abbouda et al 2019). The Cretaceous is exposed on the lateral edges of the plain. It is represented by schist clays, about 800 m thick in the north and west of Zaccar and marls with interbedded limestone in the Dahra massif. The Miocene is up to 300 m thick. The lower Miocene is discordant on the ante-neogene basement and begins with a series of conglomerates about 220 m thick, then it ends with a marly series. The Miocene is marked by a new and progressive transgression. It begins with a series of blue marls visible mainly in the north-east of the plain, interspersed with clays and small sandy beds (Yelles et al 2009, Yahiaoui et al 2015). Fairly coarse red sandstones and interbedded conglomerates appear quite frequently in the Gantas and complete the Miocene cycle. The Mio-Pliocene consists of quartz pebbles, conglomerates, detrital sandstones and clays, and travertine deposited at the Zaccar sources.

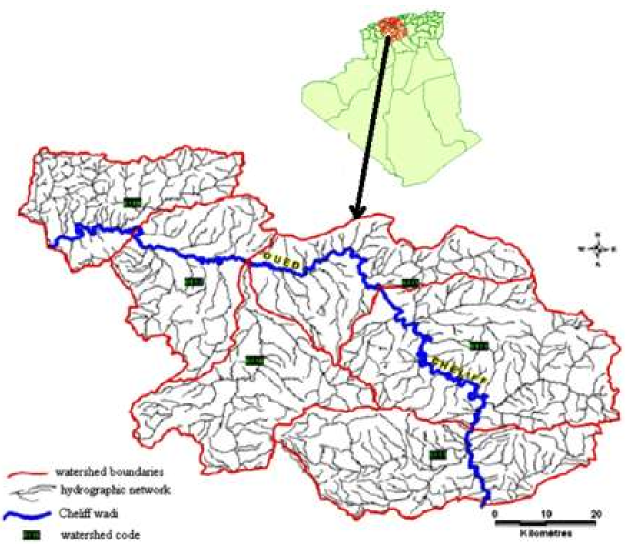


**Fig. 1.** Geographical location of the study area

**Hydrogeology**

**Main aquifers in the study area:** According to the study of the stratigraphic series and its lithological and structural characteristics, the following aquifer levels can be distinguished:

**Jurassic limestones:** Constitute an important reservoir which is characterised by the presence of fissures which favour the circulation and storage of water

**Miocene aquifers:** These are represented in the form of conglomerates of varying degrees of clay and sand.

**Pliocene aquifers:** Pliocene is in the form of Astian sandstones; with an average thickness of 100 m.

**Quaternary alluvial aquifers:** Quaternary alluvial formations constitute the most important and most exploited aquifer in the whole Khemis Miliana plain. The lithological descriptions of the boreholes show that more than 20% of the materials crossed are sands and gravels or sandstones and a range of borehole depths from 2 to 150 m.

**Inventory of water points:** Thirty six (36) water points were inventoried by the ANRH of El Khemis (Table 1) are

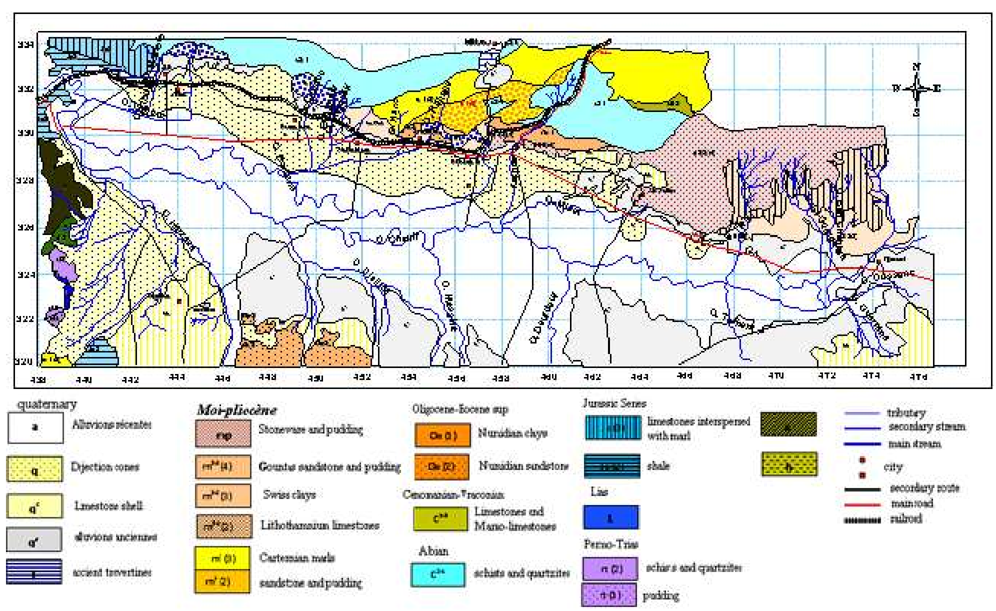


**Fig. 2.** Ggeological map of the Khemis Miliana plain (Geological map of Milian N°84)

**Table 1.** Inventory of water points (ANRH Khemis Miliana) based on the results of the well and borehole monitoring network

| Water points | Coordinates | | Z (m) | Depth |
|---|---|---|---|---|
| | X (m) | Y (m) | | |
| 84-5 | 461250 | 323550 | 287.41 | 15,69 |
| 84-8 | 462300 | 322800 | 293,40 | 20,66 |
| 84-12 | 462450 | 321750 | 308,38 | 21,21 |
| 84-14 | 462470 | 320850 | 315,80 | 25,10 |
| 84-39 | 461500 | 328000 | 292,83 | 23,11 |
| 84-57 | 456425 | 324400 | 275,73 | 13,92 |
| 84-63 | 452070 | 321950 | 280,60 | 15,00 |
| 84-72 | 454400 | 328400 | 279,30 | 12,59 |
| 84-73 | 453050 | 328950 | 277,30 | 8,50 |
| 84-80 | 448900 | 325250 | 260,12 | 17,00 |
| 84-91 | 447500 | 329600 | 256,64 | 5,50 |
| 84-92 | 447450 | 330600 | 284,31 | 21,10 |
| 84-93 | 449200 | 330800 | 286,90 | 32,41 |
| 84-107 | 447250 | 331000 | 264,81 | 17,00 |
| 84-110 | 441000 | 330100 | 246,76 | 12,00 |
| 84-114 | 446250 | 325250 | 264,53 | 15,00 |
| 84-125 | 442700 | 326000 | 258,29 | 20,00 |
| 84-127 | 441050 | 326350 | 274,14 | 16,00 |
| 84-129 | 440750 | 327900 | 251,75 | 8,65 |
| 84-136 | 459100 | 321900 | 295,92 | 17,90 |
| 84-139 | 459500 | 320900 | 303,64 | 15,00 |
| 84-140 | 458500 | 321300 | 296,90 | 11,20 |
| 84-143 | 458750 | 320300 | 301,10 | 14,00 |
| 84-154 | 456400 | 321850 | 290,05 | 16,20 |
| 84-155 | 456000 | 321050 | 293,02 | 13,50 |
| 84-166 | 442400 | 325250 | 269,18 | 12,72 |
| 84-169 | 442050 | 322650 | 313,15 | 12,01 |
| 84-182 | 444300 | 327550 | 252,28 | 16,00 |
| 84-185 | 457050 | 325500 | 274,84 | 8,21 |
| 84-196 | 447500 | 332600 | 278,02 | 13,01 |
| 84-310 | 456300 | 322100 | 289,75 | 19,10 |
| 84-311 | 455950 | 320250 | 310,84 | 18,00 |
| 84-313 | 443850 | 329500 | 250,85 | 23,00 |
| 84-314 | 454550 | 328350 | 279,22 | 280,00 |
| 85-6 | 471700 | 324700 | 346,26 | 18,00 |
| 85-14 | 469820 | 321500 | 316,43 | 19,50 |

distributed throughout the groundwater of Khemis Miliana for domestic and agricultural use, were subject to static level measurements, were used to establish piezometric maps (Fig. 3).

**Piezometry:** Piezometric maps, drawn up with data on piezometric levels, represent the spatial distribution of hydraulic loads and potentials at a given date. They also show the hydrodynamic boundary conditions. These maps will allow to determine the directions of groundwater flow, the recharge areas and the outlet of the water table. According to the piezometric maps of 2015 (Fig. 4a) and 2016 (Fig. 4b), flow directions converge towards Oued Cheliff where the water table feeds Oued Cheliff. However, the hydraulic gradient is quite strong in the eastern part and oscillates between 8.33. 10-3 and 7.14. 10-3 and in the south-western zone the hydraulic gradient becomes very strong and oscillates between 1.66. 10-2 - 1.25. 10-2, on the other hand in the central and north-western part the hydraulic gradient is 1.78. 10-3. The piezometric maps of 2017 (Fig. 4d) and 2018 (Fig. 4c) show that the flow directions converge towards the Oued Cheliff where the water table feeds the latter with a drainage axis oriented from East to West. However, at the level of the city of Djendel and Djellida, the piezometric curves become narrower which implies a strong hydraulic gradient varying between 8.33. $10^{-3}$ - 1. $10^{-2}$, and the city of Ain Sultan and the Doui Threshold, the piezometric curves become farther away which indicates a weak hydraulic gradient oscillating from 2.5. $10^{-3}$ - 1.22.$10^{-3}$. During the low water period of 2015, a depression zone was observed in the central and north-western part of the plain; this is due to the intensive exploitation of the water table, particularly at the level of the overexploited boreholes "84-185, 84-92", and in 2018 a convergence of the groundwater in the central eastern and central western part of the plain was observed at the level of the overexploited boreholes "84-182, 84-8".

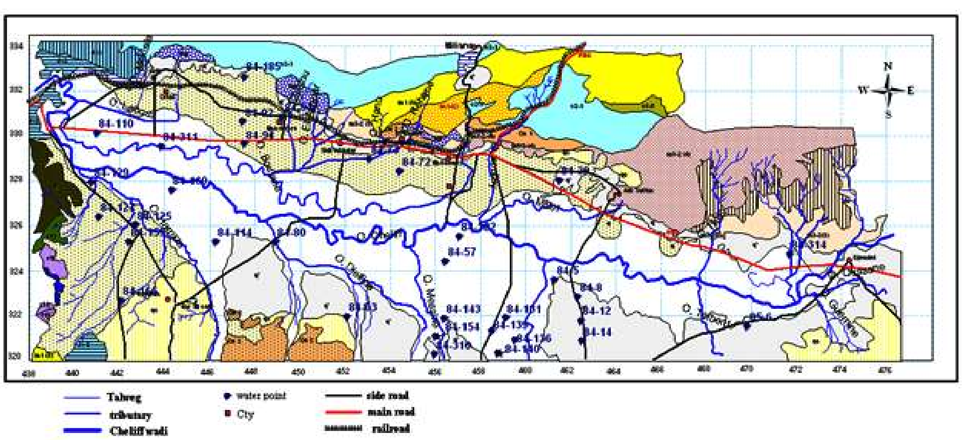


**Fig. 3.** Water point inventory map

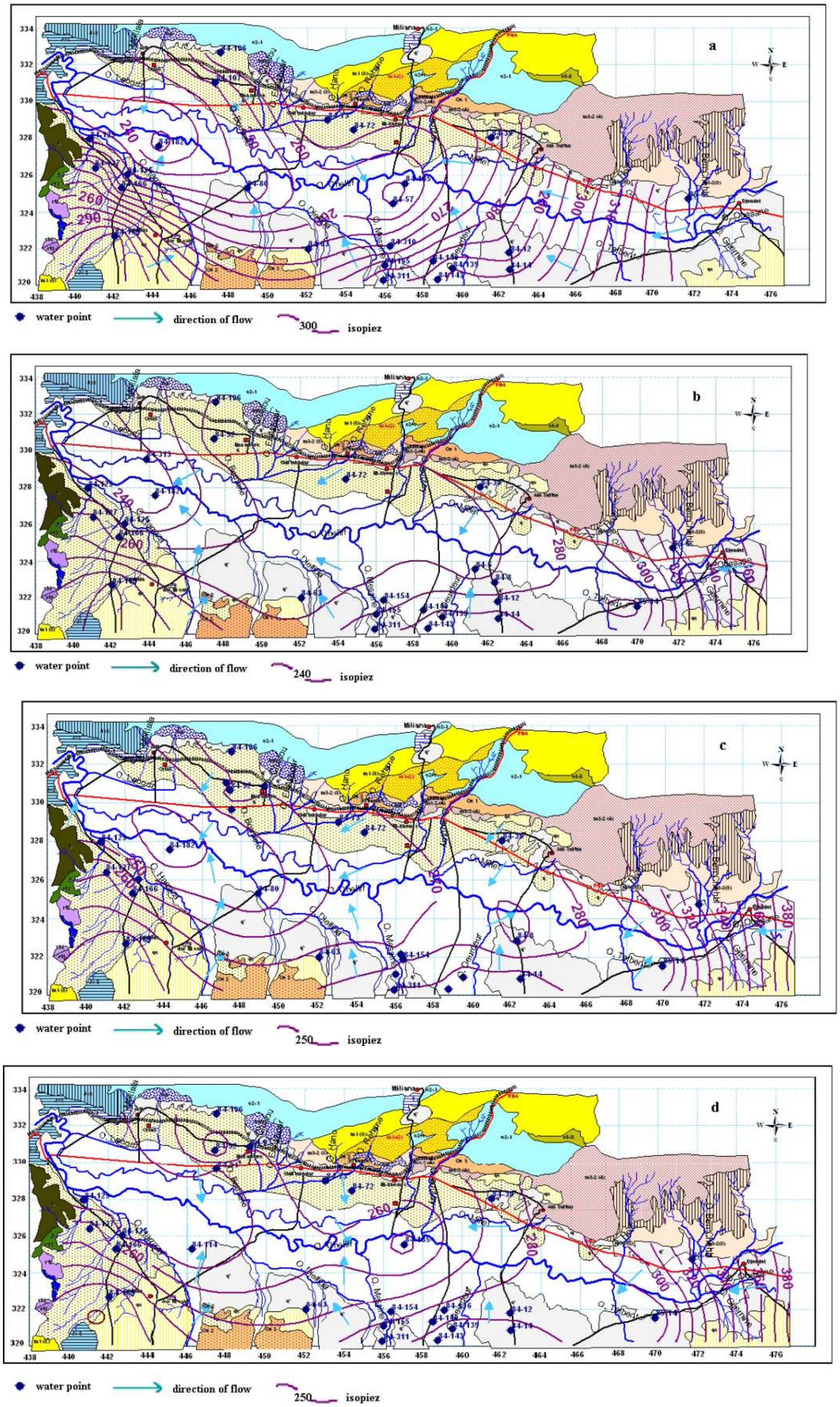


**Fig. 4.** Piezometric maps for 2015 (a), 2016 (b), 2017 (c), and 2018 (d)

**Physico-chemical parameters:** Water samples were taken in clean containers, rinsed several times with the water to be analysed, and closed tightly without leaving air bubbles in the bottle. They are kept in a at2-4◦C until the time of analysis. Analyses were performed as soon as possible, but no later than 72 hours after the sample is taken. If this time cannot be met, it was necessary to prepare the samples for storage. For cations, the sample is filtered on a 0.45 µm filter (it is possible to use the filtration system for bacteriological analyses), then acidified with Hcl or NH3 to obtain a pH<2. For anions. there was no major problem of conservation. Samples prepared in this way can be stored for six months. Temperature, pH, conductivity, alkalinity and dissolved oxygen are measured in situ. These parameters are very sensitive to environmental conditions and are likely to change significantly if they are not measured on site. The total hardness of water was estimated as sum of Ca++ and Mg++ cations expressed in °F.

$$TH = [Ca^{++}] + [Mg^{++}]..... .... ...... \qquad (1)$$

$Ca^{++}$, $Mg^{++}$ expressed in meq/l.

**Calculation of reaction quantity in meq/l:**

The meq/l was calculated as the ratio of the quantity of the element in reaction multiplied by the valency of the element divided by the molar mass of the same element

$$r = \frac{\mathrm{m} \times \mathrm{valence}}{\mathrm{M}} \qquad (2)$$

r: the quantity in reaction in meq/l , m: the quantity in reaction in mg/l, M: the molar mass in g/mol

Quantity in reaction in relation to the sum of ions of the same sign is calculated from the following formula**:**

$$r_c\,\% = \frac{r \times 100}{\Sigma re^{+}} \qquad (3)$$

$$r_a\,\% = \frac{r \times 100}{\Sigma re^{-}} \qquad (4)$$

rc%: reacting amount of cations, a%: reaction amount of anions: sum of cations and anions in meq/l

∑rc+: sum of cations in meq/l,∑ra-: sum of anions in meq/l

## RESULTS AND DISCUSSION

The average pH was7.7 in 2015, the maximum is 8.3 and the minimum 7. In 2016, 2017 and 2018 the pH varied from 7.1 to 8.3 which indicates that the groundwater in the region is slightly alkaline

**Conductivity:** The conductivity values (Table 3) indicate a very high mineralization as they are globally higher than 1000 µs /cm. Most of the conductivities exceed 2 to 3 mS/cm. this salinity is primarily of geological origin (primary salinity). However, it tends to increase as a result of poor exploitation of boreholes, and can even be aggravated by anthropogenic pollution, making the water unsuitable even for irrigation (Achour et al 2008).

To study the chemical facies of the groundwater of the Khemis Miliana plain, projected the chemism of the sampled water points onto the Piper diagram (Fig. 5) and the Schoeller diagram (Fig. 6). Diagram software of the LHA (Simler et al 2012).

**Stabler's method:** The classification of waters consists of

**Table 2.** Analysis of the low water campaign 2015

| Parameters | 084 129 | 084-166 | 084-115 | 084-8 | 084-155 | 084-14 | 084-39 | 084-63 | 084-80 | 084-91 | 084 -92 | 084-169 | 084-196 | 084-63 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $Ca^{2+}$ (mg/l) | 167 | 131 | 320 | 196 | 247 | 218 | 218 | 262 | 218 | 89 | 148 | 148 | 144 | 274 |
| $Mg^{2+}$ mg/l | 65 | 46 | 349 | 96 | 135 | 44 | 70 | 170 | 175 | 22 | 67 | 44 | 56 | 138 |
| $Na^{+}$ mg/l | 109 | 114 | 540 | 215 | 800 | 120 | 119 | 276 | 393 | 18 | 66 | 295 | 73 | 269 |
| $K^{+}$ mg/l | 17 | 2 | 4 | 4 | 6 | 4 | 2 | 4 | 7 | 15 | 2 | 0 | 0 | 19 |
| $Cl^{+}$ mg/l | 270 | 226 | 1 690 | 503 | 1 390 | 375 | 470 | 833 | 925 | 60 | 238 | 350 | 200 | 708 |
| $So_4^{2-}$ mg/l | 237 | 110 | 570 | 267 | 458 | 138 | 149 | 438 | 583 | 166 | 190 | 320 | 187 | 600 |
| Co3 mg/l | 281 | 281 | 378 | 235 | 265 | 209 | 195 | 307 | 271 | 183 | 278 | 268 | 352 | 363 |
| $No_3$ mg/l | 78,0 | 56,0 | 1,0 | 82,0 | 46,0 | 73,0 | 26,0 | 33,0 | 17,0 | 3,0 | 62,0 | 48,0 | 17,0 | 33,0 |
| r $Ca^{2+}$% | 2,33 | 2,24 | 1,32 | 1,92 | 1,04 | 2,83 | 2,67 | 1,84 | 1,38 | 3,09 | 2,62 | 1,52 | 2,64 | 1,96 |
| r $Mg^{2+}$% | 1,50 | 1,29 | 2,37 | 1,55 | 0,94 | 0,93 | 1,41 | 1,97 | 1,81 | 1,27 | 1,94 | 0,75 | 1,67 | 1,62 |
| r $Na^{+}$% | 1,32 | 1,69 | 1,94 | 1,83 | 2,93 | 1,35 | 1,27 | 1,69 | 2,16 | 0,55 | 1,02 | 2,63 | 1,16 | 1,67 |
| r $K^{+}$ % | 0,12 | 0,02 | 0,01 | 0,02 | 0,01 | 0,03 | 0,01 | 0,01 | 0,02 | 0,26 | 0,02 | 0,00 | 0,00 | 0,07 |
| r $Cl^{-}$ % | 0,88 | 0,95 | 1,81 | 1,30 | 1,82 | 1,33 | 1,58 | 1,46 | 1,45 | 0,41 | 0,87 | 1,00 | 0,75 | 1,17 |
| r $So4^{2-}$ % | 1,14 | 0,68 | 0,90 | 1,02 | 0,88 | 0,72 | 0,74 | 1,13 | 1,35 | 1,68 | 1,03 | 1,35 | 1,03 | 1,47 |
| r HCo3% | 1,57 | 2,02 | 0,69 | 1,05 | 0,59 | 1,27 | 1,12 | 0,92 | 0,73 | 2,15 | 1,75 | 1,32 | 2,25 | 1,03 |
| r No3% | 0,90 | 0,83 | 0,00 | 0,75 | 0,21 | 0,92 | 0,31 | 0,21 | 0,09 | 0,07 | 0,81 | 0,49 | 0,22 | 0,19 |

comparing the reaction qualities of cations and anions expressed as a percentage of the total concentration of the water using the characteristic Stabler formula (Table 4) and classifying the anions and cations separately in descending order to determine the chemical facies and the graphical representation of these elements on the diagram software (Simler 2009).

Piper, Schoeller Berkaloeff and Stabler indicated that the dominant ions are most often chlorides among the anions and sodium among the cations. The most dominant chemical facies was the calcium chloride facies extending to the north-east and west of the plain, with a percentage of 53.5. Secondly, the sodium chloride facies with a percentage of 21.4 that develops in the south of the plain; this is probably due to the presence of recent fine-textured alluvium, the Magnesium-Chloride facies has a percentage of 14.3 and the last one is presented by the sodium-bicarbonate. The Stabler classification, based on reaction quantities, has proved useful as a complementary method to the Piper diagram. According to Jasmin and Mallikarjuna (2014), for the calcium chloride and magnesium sulphate family as well as for the

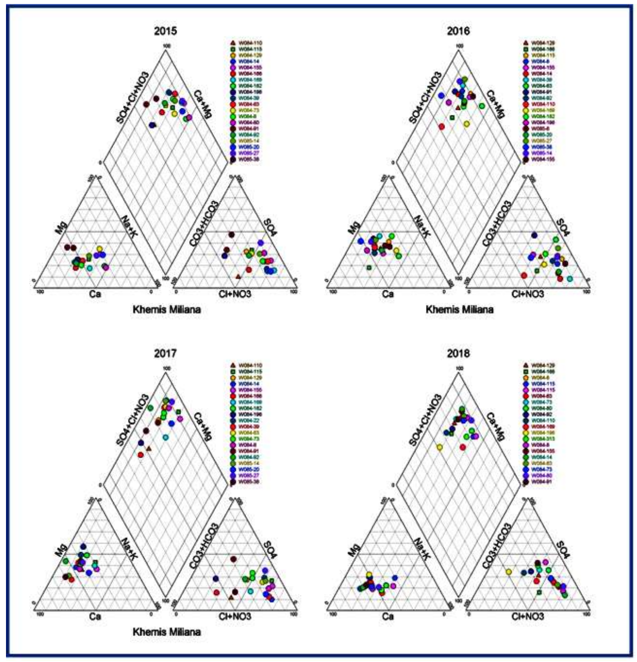


**Fig. 5.** Piper's diamond diagram of the groundwater of the Khemis Miliana plain

**Table 3.** Conductivity and pH values

| Période | 2015 | | 2016 | | 2017 | | 2018 | |
|---|---|---|---|---|---|---|---|---|
| Point | pH | CE μ/cm | pH | CE μ/cm | pH | CE μ/cm | pH | CE μ/cm |
| W084-110 | 7 | 1,034 | 7.8 | 1,600 | 8 | 4,000 | 7.9 | 1,800 |
| W084-115 | 7.8 | 3,500 | 7.6 | 3,470 | 8.2 | 1,200 | 7.5 | 4,750 |
| W084-129 | 7.8 | 1,702 | 7.8 | 5,210 | 8.1 | 2,490 | 7.3 | 4,080 |
| W084-14 | 7.6 | 3,160 | 7.6 | 3,000 | 8 | 1,800 | 7.2 | 1,928 |
| W084-155 | 7.5 | 5,260 | 7.7 | 3,500 | 8 | 4,460 | 7.8 | 3,880 |
| W084-166 | 7.7 | 1,512 | 7.7 | 333 | 7.9 | 3,000 | 7.4 | 3,620 |
| W084-169 | 7.4 | 3,130 | 7.9 | 3,800 | 7.4 | 5,000 | 7.3 | 2,580 |
| W084-182 | 7.4 | 4,000 | 7.6 | 3,780 | 7.7 | 2,200 | 7.5 | 2,890 |
| W084-196 | 7.6 | 1,292 | 8 | 4,080 | 7.4 | 2,000 | 7.7 | 2,400 |
| W084-39 | 7.7 | 2,540 | 7.7 | 3,400 | 8 | 2,400 | 7.1 | 1,313 |
| W084-63 | 7.6 | 3,600 | 7.8 | 1,224 | 8 | 3,900 | 7.7 | 3,650 |
| W084-73 | 7.8 | 3,030 | 7.5 | 3,430 | 8 | 2,350 | 7.7 | 4,200 |
| W084-8 | 7.5 | 2,670 | 7.6 | 5,310 | 7.8 | 2,300 | 7.8 | 2,350 |
| W084-80 | 7.7 | 4,300 | 7.6 | 3,000 | 7.4 | 2,800 | 7.2 | 2,720 |
| W084-91 | 7.6 | 7,35 | 7.5 | 2,850 | 7.3 | 4,700 | 7.3 | 3,420 |
| W084-92 | 7.6 | 1,565 | 7.3 | 3,440 | 7.5 | 3,500 | 7.3 | 1,369 |
| W085-14 | 7.9 | 4,000 | 7.9 | 2,970 | 8.1 | 2,980 | 7.3 | 3,450 |
| W085-20 | 7.6 | 2,700 | 8.3 | 1,500 | 7.4 | 1,300 | 7.3 | 900 |
| W085-27 | 7.5 | 5,840 | 8.1 | 6,100 | 7.5 | 3,800 | 7.3 | 4,060 |
| W085-38 | 7.7 | 1,200 | 8.1 | 2,000 | 7.5 | 3,500 | 7.2 | 3,170 |
| W085-6 | 7.5 | 2,510 | 7.8 | 1,653 | 7.5 | 1,500 | 8.3 | 2,720 |

sodium chloride and potassium family, the lithology of the aquifer is thinner, the circulation of water is difficult, the contact time between water and rock increases, hence the increase in salinity, and the influence of the clays becomes more marked. This interpretation reflects the phenomenon of concentration by dissolution.

**Maps**

**Calcium ca2+:** Figure 7 represents the evolution of Ca2+ in the plain of Khemis Miliana during the five and the values of Ca2+ vary between 49 and 466 mg/l, which exceed the WHO standards (200 mg/l). The highest Ca2+ were concentrated in the central part of the plain during the period of 2015, 2015, and 2017 which corresponds to the years of climatic and hydrological drought. The values that do not exceed the WHO standards correspond to the period of 2018, and from 2015 to 2018, the Ca2+ values started to increasing especially in the southern edges of the plain. The exceedance of the Ca2+ concentration in the period 2015 is mainly due to the dissolution of limestone in this part or to the residence time. The decrease of this element in 2018 is due to the dilution of these waters by the inflow of water due to the high precipitation of this year or by the infiltration of water from the releases of the dams.

**Magnesium Mg2+** : Figure 8 shows the evolution of Mg2+ over the five periods which varies between 18 and 320 mg/l. Mg2+ concentrations hardly exceed the WHO quality standards (150 mg/l) in 2016, however, for the periods 2015 a slight increase in concentration can be observed on the southern edges of a central part of the plain. This increase is perhaps due to the exchanges of the plain of Khemis Miliana with the wad's Massine, Djellida and Harrazza. The decrease of this concentration in the period of 2016 is probably due to the dilution by the heavy precipitations.

**Table 4.** Chemical facies classification according to Stabler

| Water points | Classification | Chemical facies |
|---|---|---|
| 84-129 | Ca2+ > Na+ > Mg2+ > K+ Cl- > SO42- >H CO3- > NO-3 | Chloride-Calcium |
| 84-166 | Ca2+ > Na+ > Mg2+ Cl- >HCO3- > SO42- > NO-3 | Chloride-Calcium |
| 84-115 | Mg2+ > Na+ > Ca2+ Cl- > SO42- > HCO3- | Chloride-Magnesium |
| 84-8 | Ca2+ > Na+> Mg2+ Cl-> SO42-> HCO3- > NO-3 | Chloride-Calcium |
| 84-155 | Na+ > Ca2+ > Mg2+ Cl-> SO42- > HCO3- > NO-3 | Chloride- Sodium |
| 84-14 | Ca2+> Na+ > Mg2+ > K+ Cl- > HCO3- > SO42- > NO-3 | Chloride-Calcium |
| 84-39 | Ca2+> Mg2+ > Na+ Cl- > HCO3- > SO42- > NO-3 | Chloride-Calcium |
| 84-63 | Mg2+ >Ca2+ > Na+ Cl- > SO42-> H CO3- > NO-3 | Chloride-Magnesium |
| 84-80 | Na+ > Mg2+ > Ca2+ Cl- > SO42- > HCO3- > NO-3 | Chloruré - Sodique |
| 84-91 | Ca2+ >Mg2+ > Na+ > K+ SO42- > HCO3- > Cl- > NO-3 | Sulphate-Calcium |
| 84-92 | Ca2+ > Mg2+ > Na+ Cl- > HCO3- > SO42- > NO3- | Chloride-Calcium |
| 84-169 | Na+ > Ca2+ > Mg2+ Cl- > SO42- > HCO3-> NO3- | Chloruré-Sodique |
| 84-196 | Ca2+ > Mg2+ > Na+ Cl-> HCO3- > SO42- > NO3- | Bicarbonate-Calcium |
| 84-63 | Ca2+ > Na+ > Mg2+ > K+ Cl- > SO42- > HCO3- > NO3- | Chloride-Calcium |
| 84-129 | Ca2+ > Mg2+ > Na+ > K+ Cl- > SO42- > HCO3- > NO-3 | Chloride-Calcium |
| 84-166 | Ca2+ > Na+ > Mg2+ Cl- > HCO3->SO42- > NO-3 | Chloride-Calcium |
| 84-115 | Mg2+ > Na+ > Ca2+ Cl- > SO42- > H CO3- | Chloride-Magnesium |
| 84-8 | Ca2+> Na+ > Mg2+ Cl-> SO42- > HCO3- > NO-3 | Chloruré- Calcique |
| 84-155 | Na+> Ca2+ > Mg2+ Cl-> SO42-> HCO3- > NO-3 | Chloruré-Sodique |
| 84-14 | Ca2+> Na+ > Mg2+ > K+ Cl- > HCO3- > SO42- > NO-3 | Chloride-Calcium |
| 84-39 | Ca2+ > Mg2+> Na+ Cl-> HCO3-> SO42- > NO-3 | Chloride-Calcium |
| 84-63 | Mg2+ > Ca2+ > Na+ Cl- > SO42- > H CO3- >NO-3 | Chloride-Magnesium |
| 84-80 | Na+ > Mg2+ > Ca2+ Cl-> SO42- > H CO3- > NO-3 | Chloruré-Sodique |
| 84-91 | Ca2+ >Mg2+> Na+ > K+ SO42- > H CO3->Cl- > NO-3 | Sulphate-Calcium |
| 84-92 | Ca2+ > Mg2+ >Na+ Cl- > HCO3- > SO42- > NO3- | Chloride-Calcium |
| 84-169 | Na+ > Ca2+ > Mg2+ Cl- > SO42- > HCO3- > NO3- | Chloruré-Sodique |
| 84-196 | Ca2+ > Mg2+ > Na+ HCO3- > Cl- > SO42- > NO3- | Bicarbonaté- Calcique |
| 84-63 | Ca2+ > Na+ > Mg2+ > K+ Cl- > SO42- > HCO3- > NO3- | Chloride-Calcium |

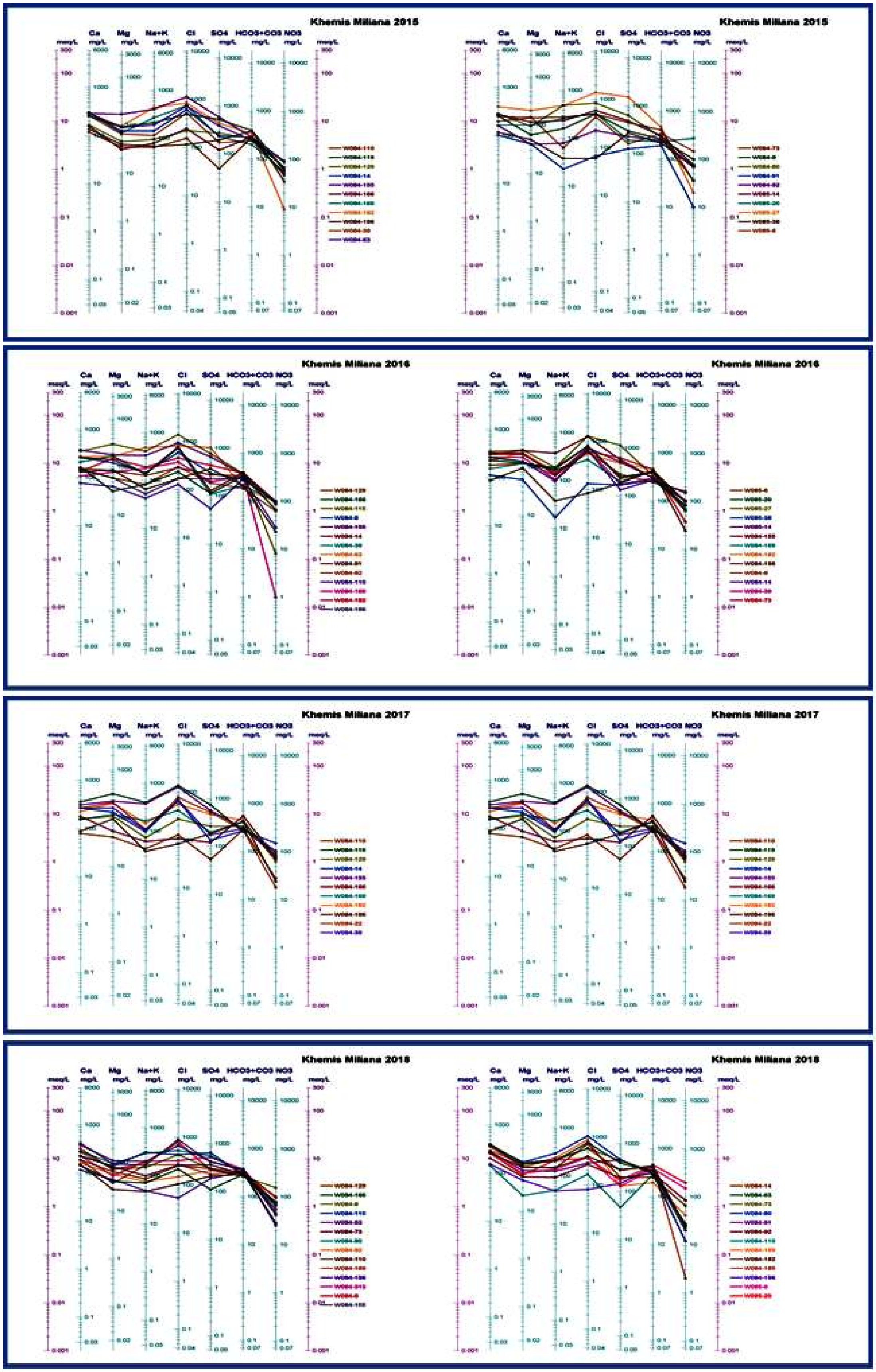


**Fig. 6.** Scholler logarithmic diagram for the groundwater of the Khemis Miliana plain

**Sodium Na+:** Figure 9 shows that the Na+ values vary between 12 and 800 mg/l, which exceed the WHO drinking water standards of 200 mg/l. This increase is due to the evolution of this chemical element. This may be due to the leaching of rock salt. This increase is very remarkable in the southern and central part of the plain, due to the presence of a diapir in the Triassic formations.

**Potassium K+:** These values are relatively low, with concentrations ranging from 0 to 48 mg/l, which exceeds the WHO potability standards of 12 mg/l (Fig. 10). This increase may be due to the exchange of the Khemis Miliana plain with the tributaries.

**Chlorides Cl-**: According to figure 11, the contents of Cl- ranged between 55 and 1690 mg/l, which exceeds the standards of WHO (250 mg/l), strong concentration of Cl- is observed during 2015, 2016 and 2017 in the southern part of the plain and can be the result of the presence of rock salts (Na Cl, $CaCl_2$) "Halite", or by the infiltration of water from the wadis, and from the period of 2018 observed a decrease in this concentration which is possibly due to dilution by water inputs Except in the central part where the inhabitants of this

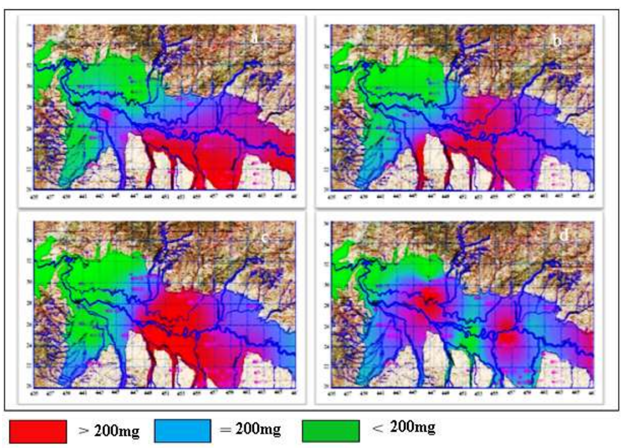


**Fig. 7.** Spatial variation of calcium levels in groundwater of the Hkemis Miliana plain (a: 2015, b: 2016, c: 2017, d: 2018)

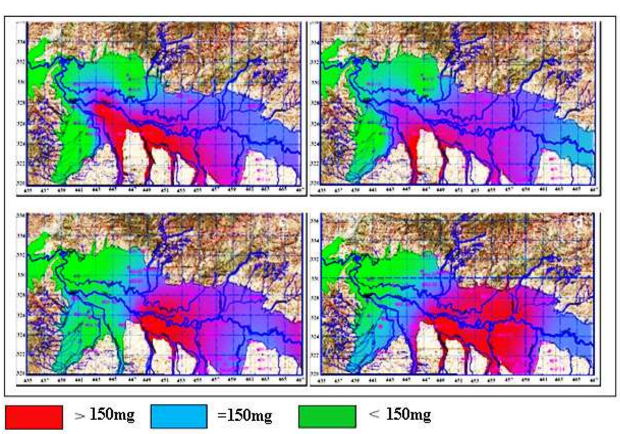


**Fig. 8.** Spatial variation of magnesium content in groundwater of the Hkemis Miliana plain (a: 2015, b: 2016, c: 2017, d: 2018)

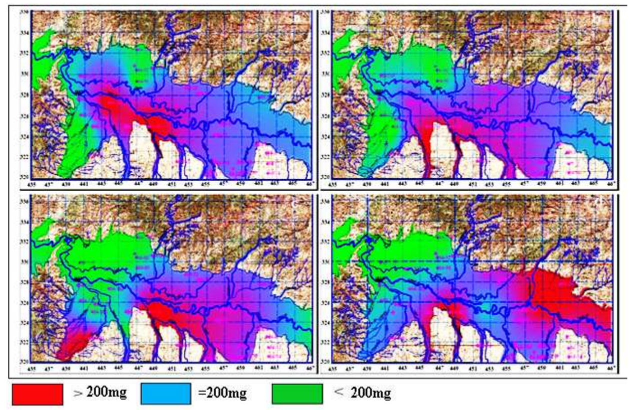


**Fig. 9.** Spatial variation of sodium levels in groundwater of the Hkemis Miliana plain (a: 2015, b: 2016, c: 2017, d: 2018)

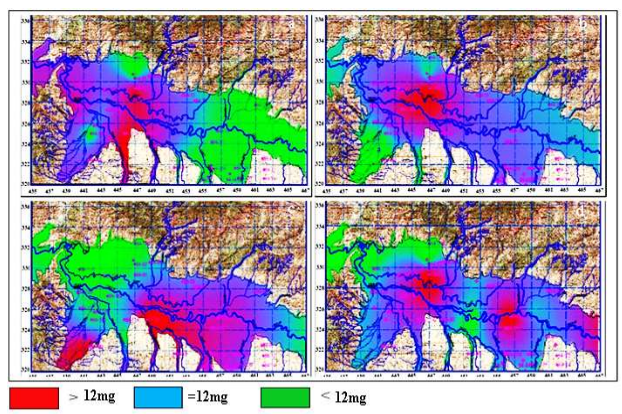


**Fig. 10.** Spatial variation of potassium levels in groundwater of the Hkemis Miliana plain (a: 2015, b: 2016, c: 2017, d: 2018)

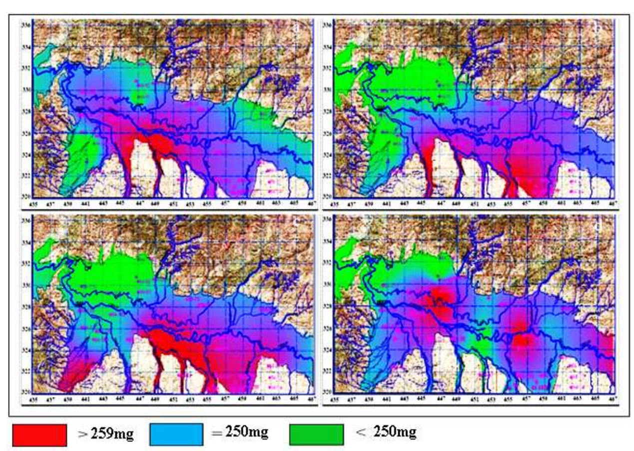


**Fig. 11.** Spatial variation of groundwater chloride levels in the Hkemis Miliana plain (a: 2015, b: 2016, c: 2017, d: 2018)

region are concentrated, which explains that the cause of this pollution is due to domestic discharges.

**Sulphates $SO_4^{2}$:** The concentrations of $SO_4^{2}$ vary between 47 and 2185 mg/l which are above the WHO standard (250 mg/l) with high concentrations recorded at the southern edges and the central part of the plain in the 2015 (Fig. 12). In 2016 and 2017 the concentration increases sharply in the whole central part of the plain, this increase is possibly due to gypsum outcrops, note that gypsum is a hydrated sulphate ($CaSO_4\ 2H_2O$), either it is of agricultural origin or it is due to domestic and industrial discharges.

**Bicarbonates $HCO_3$:** The bicarbonate level in the waters of the Khemis Miliana plain varied between 153 and 763 mg/l which exceeds the WHO standards (400 mg/l). There was increase in the concentration during 2015, 2016 and 2017, decreased during 2018 (Figure 13). This phenomenon is explained in the same way as $Ca^{2+}$.

**Anthropogenic pollution:** Urban, agricultural and industrial development often leads to rapid pollution of groundwater by chemical forms of nitrogen, especially nitrate, due to their high solubility and low affinity to ion exchange. The other forms of nitrogen appear only under reducing conditions. In order to identify the problem of the evolution of this pollution of the groundwater of the Khemis Miliana plain, based on the comparison of nitrate concentrations for different periods superimposed it on the land use map to find out if there is a pollution of agricultural origin. Figure 15 shows the evolution of nitrate concentrations during the years 1993, 2002, 2003, 2008, 2009 and 2010.

Figure 15 shows that nitrates exceed the standards required by the WHO. The concentration reached up to 250 mg/l in 2009, and there is also a trend of a progressive evolution of the concentration over time. The selected water points do not capture the same aquifer, which makes the comparison very delicate to this effect the ANRH of Bilida realized a new monitoring network composed of 14 well-equipped piezometers capturing all the water table, we are lucky to have a series of analysis of this new network (Table 5).

Nitrates occur naturally in groundwater. A natural level exists but does not exceed a concentration of 10 mg/1. The maximum concentration authorized for public use is 50 mg/1. It is the "artificial" pollution that increases the nitrate levels and exceeds the norm. The plain of Khemis Miliana is confronted with major pollution problem sand the threshold of 50 mg/l is often exceeded. The values are increasing, the groundwater is more and more loaded with nitrates but except for some delicate sectors, the 50 mg/l is still rarely reached. The two types of pollution were observed. Point source pollution, easy to locate, comes from industrial or

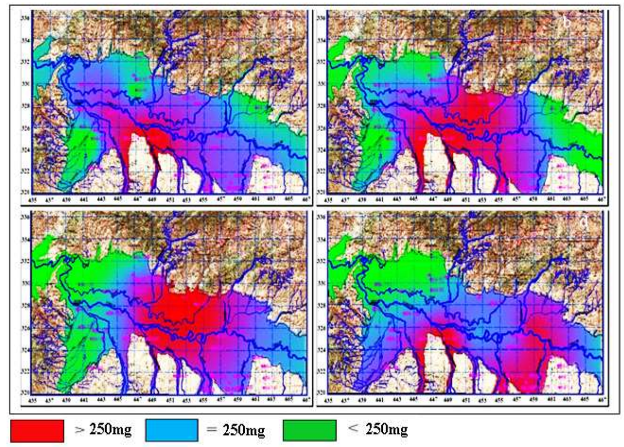


**Fig. 12.** Spatial variation of sulphate levels in the groundwater of the Hkemis Miliana plain (a: 2015, b: 2016, c: 2017, d: 2018)

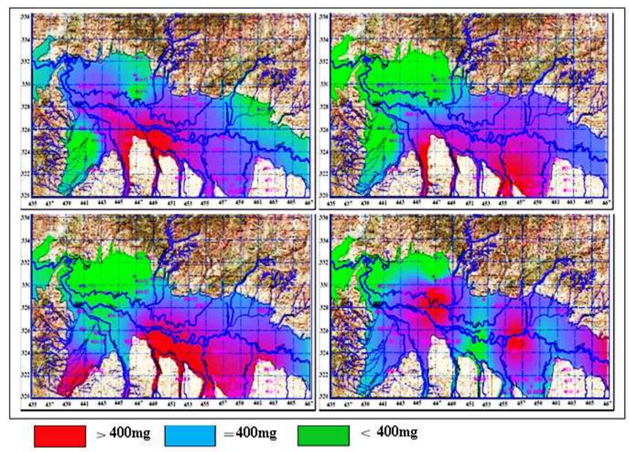


**Fig. 13.** Spatial variation of bicarbonate contents in the groundwater of the Hkemis Miliana plain (a: 2015, b: 2016, c: 2017, d: 2018)

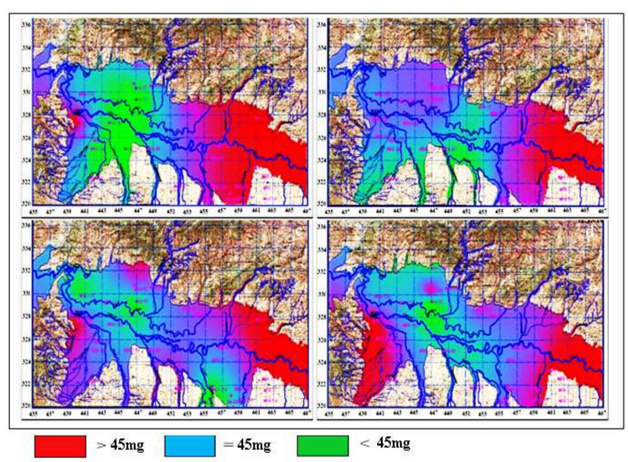


**Fig. 14.** Spatial variation of groundwater nitrate levels in the Hkemis Miliana plain (a: 2015, b: 2016, c: 2017, d: 2018)

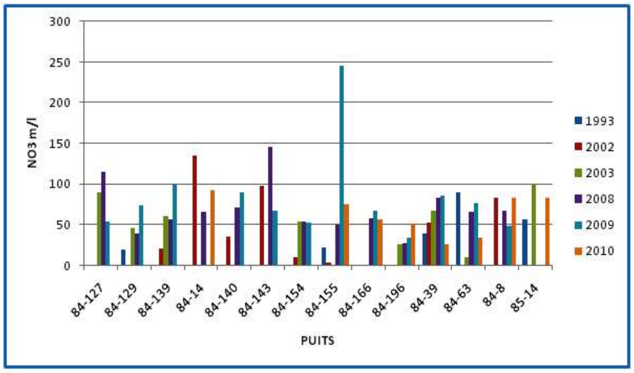


**Fig. 15.** Variation of nitrate for the periods (1993, 2002, 2003, 2008, 2009 and 2010)

domestic discharges, which are very noticeable in the western part of the plain, where the big cities are located (Khemis Miliana, Sidi Lakhdar, Arib and Ain Defla) as well as industrial activities such as the Aribes dairy, the Sidi Lakhdar sugar factory and the Ain Defla industrial zone. Diffuse pollution, more difficult to identify, has an agricultural origin, which affects almost the entire plain according to the concentrations observed in all periods, especially that of the year 2018 observed in the piezometer PZ1A with a value of 107 mg/l in the east of the plain, where there is no agricultural activity (Fig. 16). The carryover of soil constituents, in this case nitrates, depend on the one hand on climatic conditions, precipitation volume (drainage) and temperature

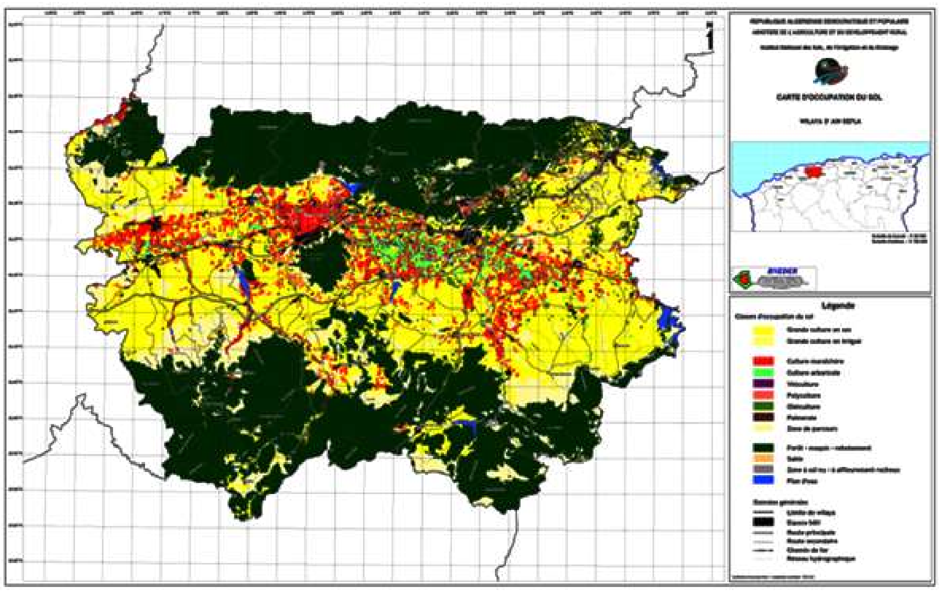

**Fig. 16.** Land use map of the study area (2011)

**Table 5.** Nitrate values at the Piezometers for the period 2014-2018

| Wells | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|
| PZ1A | 37.0 | 8.0 | 8.0 | 5.0 | 107.0 |
| PZ3A | 37.0 | 35.0 | 35.0 | 5.0 | 3.0 |
| PZ4A | 23.0 | 34.0 | 34.0 | 4.0 | 9.0 |
| PZ5A | 33.0 | 17.0 | 17.0 | 5.0 | 0.0 |
| PZ6A | 0.0 | 3.0 | 3.0 | 47.0 | 7.0 |
| PZ7A | 1.0 | 0.0 | 0.0 | 5.0 | 0.5 |
| PZ9A | 2.0 | 0.0 | 0.0 | 7.0 | 0.5 |
| PZ10A | 23.0 | 4.0 | 4.0 | 6.0 | 0.5 |
| PZ11A | 1.0 | 4.0 | 4.0 | 0.0 | 0.5 |
| PZ12A | 1.0 | 0.0 | 0.0 | 1.0 | 0.5 |
| PZ13A | 2.0 | 2.0 | 2.0 | 0.0 | 6.0 |
| PZ14A | 6.0 | 7.0 | 7.0 | 13.0 | 0.5 |
| PZ15A | - | 4.0 | 4.0 | 1.0 | 22.0 |

(evaporation) and on the other hand on plant cover and biological activity. Not all surfaces are equal when it comes to nitrate carryover. Bare soil will react differently from cultivated soil. On ploughed land, the danger is after the harvest, at the end of summer and beginning of autumn, when the rains start again on a warm and aerated soil, a factor that favours the bacterial mineralization of humus, and the leaching of soil constituents towards the water table is very important . The land use map of the study area (Fig. 16) shows that agricultural activities are very intense, particularly market gardening, dry farming, irrigated farming and tree farming, where the farmer uses a large quantity of fertilizer and irrigation is provided from groundwater. There was a National Agricultural Development Programme (PNDA) in 2000 and a National Agricultural Development Regulation Fund (FNRDA) programme in 2002 which aggravated the situation because the authorities allowed water drilling in the plain for those who have at least ten hectares of cultivated land without respecting the boundary conditions or the protection perimeter of the plain.

## CONCLUSION:

The lithostratigraphic and geological study determined the formations likely to be aquiferous which are presented by the multilayer aquifer with interstitial porosity formed by the Quaternary alluvium and the Mio-Pliocene sands and sandstones, and an aquifer composed by the Jurassic fissured limestone's. The hydrogeological study estimated that aquifer horizons represented by the Mio-Plio-Quaternary water table and that of the Jurassic limestones and this confirms the geological study. The evolution of the chemical facies since 2015 to 2018 with a dominance of the calcium chloride type in the North and sodium chloride type in the South of the plain. The maps of the variations of the various chemical elements have made it possible to determine the evolution of these parameters during four periods which present an excess of certain constituents, in particular Ca++, Na+ and Cl- at the central southern edges of the plain. In addition, the highest concentrations of nitrates affecting the whole plain are explained by the important use of fertilizers which have harmful effects on the health of living beings.

Nitrate levels in the plain of Khemis Miliana show that the area near the agglomerations of Djendel, Bir Ouled Khelifa and Djelida is much more exposed to pollution, with levels exceeding 50 mg/l. These high nitrate levels can be explained by the presence of various sources of pollution linked mainly to agriculture, livestock farming and urban practices (domestic and industrial waste). The majority of the chemical elements analysed exceed the standards set by the WHO. Indeed, the high levels of calcium, sodium and potassium make these waters very hard. For a more in-depth knowledge of the evolution of the quality of the groundwater of the Khemis Miliana plain, recommend that the general public be regularly made aware of the proper use of fertilisers in agricultural areas in order to reduce the contamination of the water table, particularly by nitrates, and that periodic checks be carried out on the quality of the groundwater. One or more monitoring points should be set up between the pollution zones and the water catchment area with the use of a geographic information system for qualitative and quantitative management of the water resource.

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# Morphometric Characterization of Giant River Catfish, *Sperata seenghala* from River Sutlej, Punjab (India)

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***Abstract***: The present study was conducted to characterize the stock of giant river catfish *Sperata seenghala* using morphometric and meristic approach and further different growth parameters and their relationships were calculated to assess the present fishery status and well-being of *S. seenghala* population from river Sutlej in Punjab (India). The total weight of fish ranged from 140-6730 g, while total length from 33-106 cm. In view of meristic characters observed the fin formula for *S. seenghala* can be expressed as D.1/7 0 P. 1/9, V. 0/8, A.0 /10. The Sutlej stock of *S. seenghala*, revealed a linear pattern of length weight relationship with strong correlation (r =0.94). The regression coefficient 'b' (2.56) indicated the negative allometric growth of the fish, tended to be thinner with increasing length. The length-length relationships between total length, standard length and fork length (LLR) indicated strong correlation (r = 0.90-0.99). The Fulton's condition factor (K = 0.544) and relative condition factor (Kn = 1.04) revealed optimum wellbeing of fish indicating suitability of habitat for the species. The data base generated in present study may serve in drafting of suitable management action plan for sustainable production of *S. seenghala* from river Sutlej.

***Keywords***: *Sperata seenghala*, Morphometry, Length-weight relationship, Condition factor, Sutlej

Riverine fisheries, the major inland fisheries resource, provide a range of benefits including a means of livelihood and a source of food for millions of people. The riverine resources of India are traditionally grouped into Himalayan and peninsular river systems. The Indus river system is among one of the Himalayan river system which include river Indus and its tributaries (Jhelam, Chenab, Ravi, Beas and Sutlej). Sutlej is the longest tributary of the Indus system which has its source in Trans Himalayas at an elevation of 4630 masl and it enters in India at Shipki pass (Himachal Pradesh) .The river enters the plains of Punjab near Rupnagar (Ropar), flows through industrial city of Ludhiana and finally reaches to Harike where it meets river Beas and finally flows towards Pakistan. The total length of river Sutlej in the state of Punjab is approximately 440 km with a total catchment area of approximately 20303 Sq. km. (Department of Science, Technology and Environment, Punjab 2019). The rapid urbanization and industrialization in the state of Punjab during the last few decades have adversely affected the biotic and abiotic components of ecosystem of river Sutlej including major fishes of the river.

Being one of the representatives of commercial fisheries from Sutlej, Giant river catfish, *Sperata seenghala* was selected for present study. This fish has a high demand in the domestic market due to presence of few intramuscular bones. Furthermore, the market for this catfish is entirely reliant on natural resources as its aquaculture technology has not yet been established. Morphometric characters are a set of characters that help to identify a particular species (Turan et al 2005). The number of discrete, serially repeated, countable structures that are fixed in fishes is known as meristic characteristics that originally corresponded to body variations in evolutionary development. Morphometric characters, the length-weight relationship, relative condition factor are significant parameters for evaluating possible differences among various populations and providing information about growth patterns and habitat conditions of fish species (Hossain and Sultana 2014). There are very few / negligible studies on morphometric characterization of *S. seenghala* form river Sutlej (Punjab). The present study was aimed to assess the population status of *S. seenghala* from river Sutlej to formulate effective management plan for its sustainable fishery.

## MATERIAL AND METHODS

Fish samples were collected from landing centers and fish markets representing fish catch from different stretches of river in Punjab covering upstream (near Ropar), midstream (Ludhiana) and downstream (Harike pattan) courses. The fish specimen were identified up to species level using taxonomic keys (Talwar and Jhingran 1991, Jayaram 1999) and further revalidated with information at www.fishbase.org. The individuals of *S. seenghala* were studied for 33 morphometric and 6 meristic characteristics. All the lengths were measured to the nearest 0.1 cm using a wooden measuring board and measuring scales and the weight was measured using a digital balance with an accuracy of 0.01 g. Numbers of fin rays were counted in both paired and unpaired fins and represented in the form of fin formula.

**Length-weight and Length-length relationship :** By assessing the length and weight of fish specimens obtained from the Sutlej River, the length-weight relationship was studied. Cubes equations can be used to compute the relationship between length and weight (Le Cren 1951).

$W = {}_{a}L^{b}$

Where, W = weight of the fish (g) , L = length of the fish (mm) ,a = Intercept, b = Regression coefficient

A linear function was used to the data to estimate the morphometric connection between these factors (Ricker, 1975).

$\text{Log } Y = \text{Log } a + b \text{ Log } X$

The length-length relationships (LLRs) between Total length (TL) and Fork length (FL), Standard length (SL), Head length (HL) were calculated using linear regression analysis. The equation was used to express these length relationships.

$Y = a + bX$

Where,Y= a dependent variable (various body lengths) ,X = an independent variable (total length)

a = constant (intercept) = regression coefficient (slope)

**Condition factor (K) and Relative Condition Factor (Kn) :** Condition factor (K) was calculated by using the formula given below (Fulton 1904)

$K = W * 100 / L^3$

Where, W = weight of the fish (g), L = length of fish (cm)

The ratio between the actual weight (observed weight) and the calculated weight based on the length-weight equation was defined as the relative condition factor (Kn) (Le Cren 1951).

$Kn = W/\hat{W}$

Where, W= Observed weight (g),Wˆ= Calculated weight ($\log W * \log L / \log L^2$)

## RESULTS AND DISCUSSION

In present study, a total of 70 specimens were observed for the morphometric characterization of *S. seenghala.* Thirty three morphometric and six meristic characters were recorded to observe the fish morphologically (Table 1). The total weight of fish ranged from 140-6730g while total length ranged from 33-106 cm. Average standard length and fork length was 52.72 cm and 55.55cm, respectively. In reference to meristic characters, four pairs of barbels viz. maxillary barbel, inner mandibular barbel, outer mandibular barbel, nasal barbel were present. Kaur (2020), Singh (2017) and Priyanka et al (2020) reported similar morphometric and meristic observations for *S. seenghala* from Sutlej and Harike wetland. All morphometric and meristic characters observed in the present study were in the same ranges as described by (Jayaram 1999).

All lengths measurements were taken in centimeters. Results are expressed as mean values ± standard error

**Relative morphometric characters in relation to total length:** The fork length (85.47%) and standard length (81.09%) were observed with maximum correlation with total length, whereas eye diameter has the least correlation (1.72%) (Table 2). Similar pattern were reported in three species of family Bagridae *viz. S. seenghala, S. aor* and *R. rita* from Harike wetland (Priyanka et al 2020). All the morphometric features change proportionally as total length increases. The morphometric characters with a higher correlation value with TL increase in accordance with TL while, the characters with lower values of relationship suggested that these characters grow slowly as TL increased.

**Biometric growth patterns of *S. seenghala:*** In present study, the Sutlej population of *S. seenghala* revealed a linear pattern of length weight relationship (Fig. 1) with a higher value of correlation coefficient (r =0.94). The value of regression coefficient 'b' was 2.56 for *S. seenghala,* indicating negative allometric growth pattern, where the fish increases in weight with slender body (Table 3). The value of 'b' in present study was within the expected range of 2.5-3.5 for optimum growth (Froese 2006). Priyanka et al (2018) reported similar growth pattern (b = 2.74) in *S. seenghala* from Harike wetland. The length- weight relationship of fishes by intercept (a) and regression (b) parameters are greatly influenced by sex, growth phase, season, gonadal maturity, health, nutrition, habitat, environmental circumstances; temperature and salinity variations in the length range of captured specimen and fishing gear (Froese 2006). However, these factors were not accounted in present study. The observed value of 'b' in present study might be

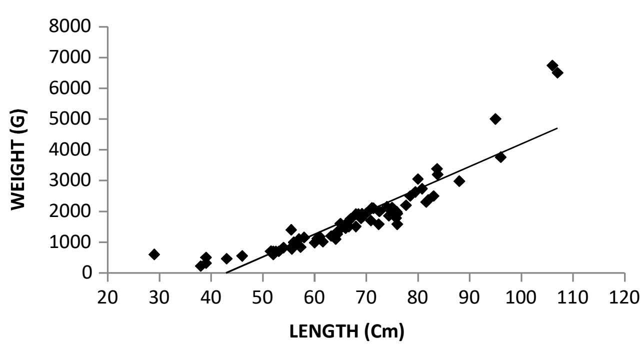


**Fig. 1.** Length-weight relationship of *S. seenghala* from river Sutlej

**Table 1.** Morphometric and meristic characters of *S. seenghala* (Nov 2020 - Oct 2021)

| Measurements | Maximum | Minimum | Mean ± SE |
|---|---|---|---|
| Total weight (g) | 6730 | 140 | 1679.9 ± 143.7 |
| Total length (TL) (cm) | 106 | 33 | 65.14±1.91 |
| Standard length (SL) | 92.5 | 23.5 | 52.72±1.65 |
| Fork length (FL) | 96.5 | 24.5 | 55.55±1.7 |
| Head length(HL) | 22.5 | 6.1 | 13.04±0.39 |
| Head depth (HD) | 6.2 | 1 | 3.19±0.14 |
| Snout length (Sn L) | 7.7 | 1.9 | 4.1±0.13 |
| Body depth (BD) | 13.5 | 2.8 | 6.89±0.22 |
| Pre-orbital length (POL) | 6.1 | 1.3 | 3.61±0.11 |
| Post-orbital length (PoOL) | 14.7 | 3.1 | 8.45±0.28 |
| Eye diameter (ED) | 2 | 0.4 | 1.12±0.03 |
| Maxillary barbel (MBL) | 33.4 | 13.7 | 21.36±0.45 |
| Inner mandibular barbel length (IMBL) | 11.6 | 2.3 | 5.03±0.15 |
| Outer mandibular barbel length (OMBL) | 12.4 | 4.2 | 7.16±0.16 |
| Length of pre-dorsal fin (PDL) | 38 | 9 | 21.95±0.67 |
| Length of nasal barbel | 4.3 | 0.5 | 2.09±0.08 |
| Length between dorsal & adipose fin (LtbAdDF) | 15.1 | 3.6 | 8.75±0.31 |
| Length of pre-pelvic fin (PPeL) | 48 | 12 | 27.72±0.85 |
| Length of pre-anal fin (PAL) | 65.1 | 16.3 | 38.99±1.14 |
| Height of dorsal fin (HtDF) | 15.7 | 4.2 | 9.84±0.3 |
| Length of dorsal fin base (LDFB) | 17.1 | 3 | 7±0.3 |
| Length of adipose fin (AdFL) | 12.5 | 3 | 6.93±0.22 |
| Length of pelvic fin (PeFL) | 5.5 | 0.8 | 2.1±0.08 |
| Length of pectoral fin (PFL) | 6.7 | 0.8 | 2.2±0.1 |
| Length of anal fin (AFL) | 8.6 | 0.9 | 4.94±0.18 |
| Length of caudal fin (CFL) | 23.6 | 5.4 | 12.84±0.37 |
| Length of caudal peduncle (CPL) | 12.4 | 2.3 | 6.48±0.22 |
| Caudal peduncle depth (CPD) | 9.6 | 2 | 5.57±0.18 |
| Length of pre-pectoral fin (PPL) | 22.9 | 5.2 | 12.32±0.37 |
| Inter-orbital length (IOL) | 6.8 | 1.2 | 3.6±0.13 |
| Length of upper jaw (UJL) | 7.5 | 1.7 | 3.91±0.13 |
| Length of lower jaw (LJL) | 7 | 1.2 | 3.46±0.12 |
| Distance b/w upper & lower jaw | 5.1 | 1 | 2.24±0.01 |
| Meristic Characters | | | |
| Number of barbels | 4 | 4 | 4 |
| Dorsal fin rays (spiny/ soft) | 1/9 | 7 | 7.19±0.04 |
| Pectoral fin rays (spiny/ soft) | 1/10 | 6 | 8.31±0.12 |
| Pelvic fin rays | 7 | 5 | 6.06±0.03 |
| Anal fin rays | 15 | 9 | 11.87±0.14 |
| Caudal fin rays | 27 | 17 | 23.12±0.22 |

Fin Formula: D.1 /7 I 0, P. 1/9, V. 0/8, A.0 /10
All lengths measurements were taken in centimeters. Results are expressed as mean values ± standard error

**Table 2.** Relative estimate of morphometric characters of *S. seenghala* as a function of total length

| Characters | Percent of total length |
|---|---|
| Standard length | 81.09 |
| Fork length | 85.47 |
| Head length | 20.03 |
| Head depth | 4.91 |
| Snout length | 6.27 |
| Body depth | 10.58 |
| Pre-orbital length | 5.57 |
| Post-orbital length | 12.97 |
| Eye diameter | 1.72 |
| Maxillary barbel | 32.39 |
| Inner mandibular barbel length | 7.69 |
| Outer mandibular barbel length | 10.86 |
| Length of pre-dorsal fin | 33.77 |
| Length of nasal barbel | 3.19 |
| Length between dorsal & adipose fin | 13.48 |
| Length of pre-pelvic fin | 42.56 |
| Length of pre-anal fin | 59.91 |
| Height of dorsal fin | 15.11 |
| Length of dorsal fin base | 10.79 |
| Length of adipose fin | 10.65 |
| Length of pelvic fin | 3.14 |
| Length of pectoral fin | 3.27 |
| Length of anal fin | 7.63 |
| Length of caudal fin | 19.63 |
| Length of caudal peduncle | 9.97 |
| Caudal peduncle depth | 8.57 |
| Length of pre-pectoral fin | 18.92 |
| Inter-orbital length | 5.56 |
| Length of upper jaw | 5.98 |
| Length of lower jaw | 5.30 |
| Distance b/w upper &lower jaw | 3.44 |

attributed to environmental variations, differences in numbers and length ranges of specimen studied.

In present study, all LLRs in *S. seenghala* were highly correlated with 'r' values ranging from 0.90 to 0.99 (Table 4). The present investigation indicated, the highest correlation between SL and FL (r=0.991) followed by TL-SL (r=0.959) and TL-FL (r=0.958) relationships. Similar observations were reported for *S. seenghala* from Harike wetland with higher correlations (r = 0.89-0.96) between TL, SL and FL (Priyanka et al 2020).

**Condition factor and relative condition factor:** In present study, Fulton's condition factor ranged from 0.22–0.93, with an average of 0.544 indicating the optimum well-being of *S. seenghala* in river Sutlej. Kaur (2020) also evaluated the value of 'K' in the range of 0.55-0.88 in *S. seenghala* from Sutlej, in corroboration with present study. However, Priyanka et al (2018) recorded the slightly lower 'K' value (0.49) from Harike wetland. Variations in the condition factor

**Table 4.** Length-Length Relationship (LLRs) of *S. seenghala* from Sutlej River

| Relationship | Y=a+bx | $r^2$ | r |
|---|---|---|---|
| TL vs FL | Log y = -0.058+0.993log X | 0.919 | 0.958 |
| TL vs SL | Log y = -0.114+1.011log X | 0.92 | 0.959 |
| SL vs FL | Log y = 0.066+0.974 log X | 0.982 | 0.991 |
| SL vs HL | Log y = -0.424+0.893 log X | 0.865 | 0.93 |
| HL vs TL | Log y = 0.811+0.897 log X | 0.827 | 0.909 |
| HL vs FL | Log y = 0.676+0.956 log X | 0.874 | 0.934 |

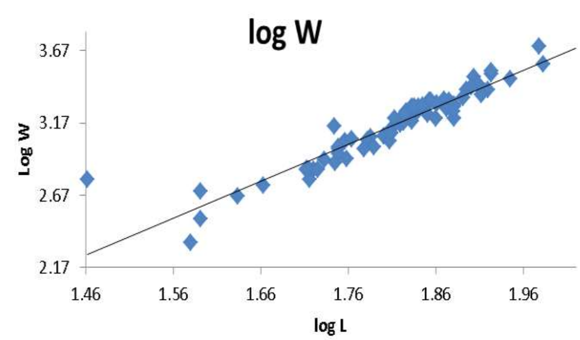


**Fig. 2.** Log length and log weight relationship of *S. seenghala* from river Sutlej

**Table 3.** Length-weight relationship (LWR) parameters of *S. seenghala*

| | Length (cm) | | Weight (g) | | Growth Parameters | | | |
|---|---|---|---|---|---|---|---|---|
| Species | Maximum | Minimum | Maximum | Minimum | a | b | r | $r^2$ |
| *S. seenghala* | 106 | 33 | 6730 | 140 | -1.49 | 2.56 | 0.94 | 0.88 |

Logarithmic equation of Length-Weight Relationship (LWR) as log W=log a +b log L

Log W= -1.49+2.56 log L

from different habitats might be attributed to food availability, ecology of a water body, different level of sexual maturity and physiological status of fish along with other unknown factors (Alam et al 2014). The relative condition factor (Kn=1.04) indicated suitability of habitat for the candidate species as overall fitness for fish species is assumed when Kn values are equal or close to 1. Jatoi et al (2013) recorded the relative condition factor value greater than 1 in *S. seenghala* from Indus river, Pakistan. Priyanka et al (2018) estimated relative condition factor in three species of Bagrids viz. *S. seenghala* (1.66), *S. aor* (1.65) and *Rita rita* (1.73) which may be attributed to different environmental conditions of wetland. Jisr et al (2018) reported a state of well-being for the nine species inhabiting in marine area of North Lebnon with Kn values of 0.99 to 1.01. The factors that could have caused the K and Kn to fluctuate were identified as general physiological parameters, seasonal variations, feeding intensity and environmental suitability.

## CONCLUSIONS

The population of *S. seenghala* from river Sutlej is in good condition as evidenced from morphometric characters and growth pattern. The species showed negative allometric growth pattern along with strong correlation between length and weight increment. Relative condition factor represented the suitability of habitat and conducive environmental conditions for the growth of *S. seenghala* in river Sutlej. The data base generated w.r.t. *S. seenghala* population may serve in drafting of strategic action plan for its sustainable production from river Sutlej.

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# Length Weight Relationship and Condition Factor of *Labeo rohita* (Ham.) Collected from Domesticated and Riverine Habitats

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***Abstract***: The length weight relationship and condition factor of *Labeo rohita* individuals collected from two different habitats and four sites i.e S-1 (River Sutlej at Ropar Headworks), S-2 (Harike Pattan at the meeting point of Sutlej and Beas) , S-3 (Instructional fish farm of College of Fisheries, GADVASU, Ludhiana), S-4 (Aquaculture ponds from nearby farms of district Ludhiana) was estimated. A total 134 individuals of *L. rohita* comprising males and females of varying sizes were collected and the length weigh parameters were recorded. The mean average length ranged from 32.9–51.54 cm with corresponding mean weight from 431-1926 g at all the selected sites. The length and weight parameters of Rohu collected from all the sites showed a linear relationship as is evident from the correlation coefficient values ranging from 0.90 to 0.94 from S1-S4. The species showed negative allometric growth at all the four sites as depicted by exponent (b) values ranging from 2.70-2.93. The condition factor values ranged from 1.11-1.54 at all the selected sites. The condition factor values of 1.11 at the domesticated sites suggested that the habitat was more conducive in terms of optimum physicochemical factors and more availability of natural as well as the artificial feed leading to optimum growth and well-being of the fish.

***Keywords***: Rohu, Allometric growth, Condition factor, b-values

The study of length-weight relationship (LWR) has a vast significance in fish biology studies as it helps to comprehend growth form, maturity, reproductive status and overall well-being of the fish (LeCren 1951). LWR can be a useful tool for biomass estimation as well as assessment of stock. LWR can simultaneously be used to assess intra species variation on the basis of body form of fish specimen collected from different habitats or varied geographical locations (Moutopoulos and Stergious 2002). The growth rate of fish species vary as per their genetic makeup, availability of food and the existing ecological conditions. Under such conditions, the cube law is used as one of the important measure to determine the growth of fish. For such estimates length and weight is used as an important indices since it elucidates that the fish weight increases thrice as compared to length. Condition factor (K) is a significant biological index which depicts how conducive water body is for fish growth. Condition factor (K) indicates the well-being of a fish with respect to its sexual maturity, availability and utilisation of food by fish. It is also useful in assessing even age and sex of some species (Anibeze 2000). Naeem et al (2010) has described the Length weight relationship and condition factor of *Catla catla* and *L. rohita* and stated that condition factor is greatly influenced by the availability of the food. Similarly, LWR and K of *L. rohita* were evaluated by Prasad et al (2012) from Govindgarh Lake. Rizvi et al (2012) described growth of *Labeo calbasu* in terms of length as a function of weight. Ujjania (2012) and Ujjania et al (2012) described condition factor and LWR of Indian major carps in their study from Rajasthan, lake. Present study examined the length-weight relationship and condition factor of Rohu collected from domesticated (private fish farms) and natural (River Sutlej) habitats of Punjab with an aim to see the effects of habitats, prevailing environment condition and availability of food on the well-being of the fishes.

## MATERIAL AND METHODS

**Study area:** The River Sutlej is one of the major sources of capture fisheries in Northern India. It originates southwest of the Tibetan lakes of Rakasthal and Mansarover, enters the plains of Punjab at Ropar, flowing via the industrial city of Ludhiana, and finally meets with river Beas at Harike-Pattan. Besides this,the fish farming in Punjab is mainly based on carp polyculture. For the present study, the fish was collected from following four sites.

**Site-1**: River Sutlej at Ropar Headworks at the entry point of Sutlej in Punjab (30°59'09.7"N 76°31'13.4"E).

**Site-2**: Harike Pattan at the meeting point of Sutlej and Beas (31°08'33.6"N 74°56'55.2"E).

**Site-3**: Sample collection from Domesticated habitat. Instructional fish farm at College of Fisheries, GADVASU, Ludhiana (30°54'19.2"N 75°48'04.9"E)

**Site-4:** Aquaculture ponds from nearby farms of district Ludhiana.

**Sample collection:** Samples were collected from the above-designated sites from November, 2020-September, 2021. *Labeo rohita* was selected for the study due to its commercial importance, consumer preference and greater contribution towards the faunal diversity of river Sutlej besides being the main candidate species of carp culture. A total of 134 *L. rohita* individuals comprising males and females of varying in sizes were collected and the length weight parameters were recorded.

**Length weight relationship:** The total length (TL) was estimated as a distance from tip of snout upto the end of caudal fin (corrected up to 0.5 cm) with the help of measuring scale, while fish weight was recorded with the help of a digital balance (corrected up to 1.0 g) after eliminating water and mucus from the fish body. For any biological organism the Length-Weight relationship is generally non-linear and expressed in the form of parabolic equation

$$W = a\,L^b$$

where weight (W) is proportional to a certain power (b) of the length (L) and 'a' is the intercept. Values of the exponent 'b' provide information on fish growth. When 'b'=3, increase in weight is isometric. When the value of 'b' is other than 3, weight increase is allometric (positive if 'b' >3, negative if 'b' <3) (Berhan et al 2019).Relationship between these two variables were adjusted by transforming them into linear regression (Ricker 1975)

**Condition factor:** The Condition factor (K) generally, used for determining the physiological state of a fish, including reproductive capacity. The heavier the fish for a length, the higher its condition factor (K). It is calculated by using the formula by (Fulton 1904):

$$K = \frac{W \times 100}{L^3}$$

where K is the condition factor, W is the body weight of fish in grams, and L is the total length in centimetres (Bagenal et al 1978).

## RESULTS AND DISCUSSION

The mean average length ranged from 32.9-51.54 cm with corresponding mean weight from 431-1926 g at the selected sites. During the present study, 'b' values ranged from 2.70-2.93 with corresponding 'r' values as 0.90-0.94 at the selected sites. *L. rohita* individuals showed negative allometric growth at all the selected sites.During the present study the values of b<3 clearly indicate that fishes are becoming slimmer with increase in length i.e the weight of fish is lower than cube of its length. Similar finding for *L. rohita* have been reported by several others researchers like Ujjania et al (2012) who stated that negative allometric growth patterns are characterised by fish becoming slimmer with increase in length. Many other workers have reported similar findings in cold water cyprinids where fish is becoming slimmer with increase in weight (Dar et al 2012). The values of correlation coefficient depicted a strong positive correlation between length and weight indicating an increase in length with corresponding increase in weight.

The values of condition factor (K) ranged from 1.11 to 1.54 with maximum and minimum values at S1and S4, respectively. K values greater than 1 reveal that the

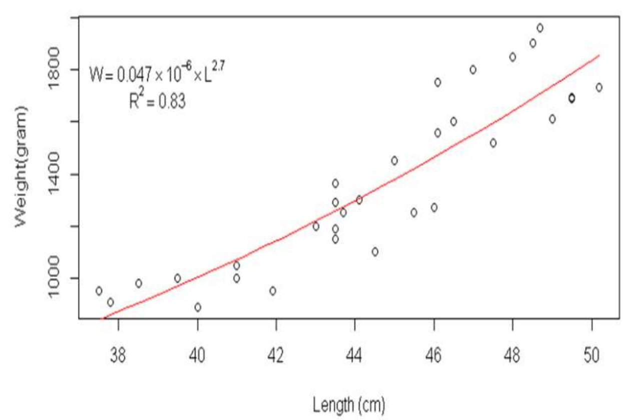


**Fig. 1.** Length-weight relationship of *L. rohita* from Site-1

**Table 1.** Length-weight relationship and condition factor (K) of *L. rohita* from four different habitats

| Parameters | Sampling sites | | | |
|---|---|---|---|---|
| | Natural population | | Domesticated population | |
| | Site- 1 | Site- 2 | Site-3 | Site-4 |
| Mean length (cm) | 44.5 | 51.54 | 32.9 | 33.8 |
| Mean weight (g) | 1361.75 | 1926.74 | 394.7 | 431.91 |
| Growth coefficient 'b' | 2.70 | 2.81 | 2.93 | 2.75 |
| Correlation coefficient 'r' | 0.91 | 0.94 | 0.92 | 0.90 |
| Coefficient of determination '$R^2$' | 0.83 | 0.85 | 0.84 | 0.81 |
| Condition factor 'K' | 1.54 | 1.40 | 1.11 | 1.11 |
| Growth type | Negative allometric growth | Negative allometric growth | Negative allometric growth | Negative allometric growth |

environment of the selected habitats were conducive for the growth and survival of the candidate fish species, however the domesticated fish species were getting more conducive environment as revealed by the condition factor value equaling near to 1.Present study indicated that the growth of *L. rohita* from domesticated as well as the natural habitats is satisfactory and same results have been recorded by Saxena et al (2013) for Rohu (1.03-1.46) from Raipur reservoir Gwalior. Kaur and Singh (2017) have reported condition factor in the range of 1.33 to 1.36 for *C. catla* from river Sutlej Punjab.

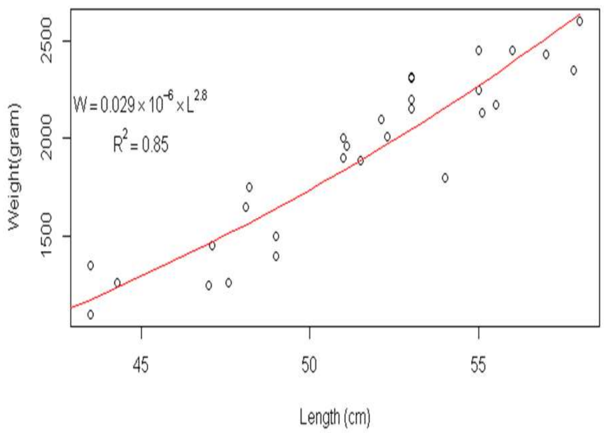


**Fig. 2.** Length-weight relationship of *L. rohita* from Site-2

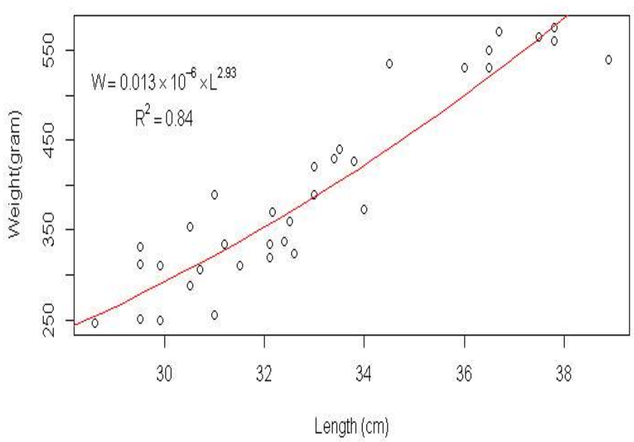


**Fig. 3.** Length-weight relationship of *L. rohita* from Site-3

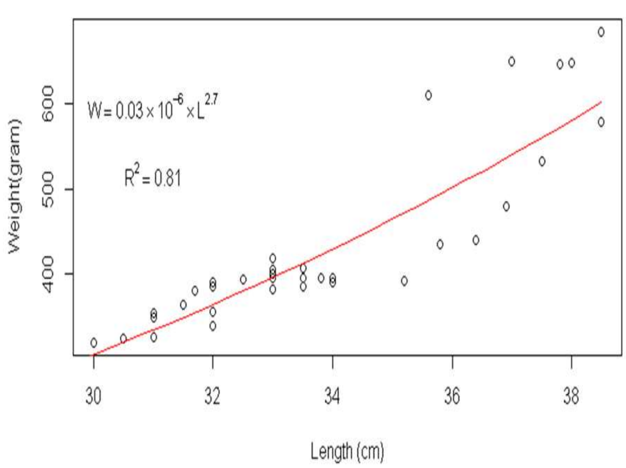


**Fig. 4.** Length-weight relationship of *L. rohita* from Site-4

## CONCLUSION

The length and weight parameters of Rohu collected from all the sites showed a linear relationship as is evident from the correlation coefficient values. The species showed negative allometric growth at all the four sites as depicted by exponent values. The condition factor values recorded in the present study clearly revealed that the environment at all the habitats was conducive for the well-being of the fish but comparatively it was more conducive at the domesticated habitats when compared to riverine environment. The domesticated habitats are well managed since fishes are cultured under semi-intensive conditions with all the inputs like balanced ration is being supplemented externally, thus making a more favorable environment for fish growth and reproduction. The present study is of paramount importance since it proves information on pattern of fish growth, its general well-being and can be of helpful for fishery managers in fish stock assessment and devising management plans for sustainable resource conservation.

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# Optimizing Stocking Density for Rearing Ornamental Koi Carp in Pond Cage Aquaculture System

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***Abstract***: The experimental study (90 days) was carried out to optimize the stocking density of ornamental koi carp in pond cage aquaculture system in integration with Indian major carps (IMCs). Koi carp fingerlings were stocked in 15 (5 treatments in triplicate) bamboo net cages (1.0 $m^3$) fixed in earthen pond (380 $m^2$) at stocking densities (fish $m^{-3}$) of 20, 40, 60, 80 and 100, whereas, IMCs (catla, rohu and mrigal) were stocked at standard stocking density of 4000 fingerlings $acre^{-1}$ (380 fish) in ratio of 3:4:3 in earthen pond. Koi carp were fed with commercial feed @ 5% of fish body weight (BW) twice daily and IMCs were fed with formulated pelleted feed @ 1% of BW once daily throughout the experiment. The physico-chemical parameters did not revealed any negative impact of stocking density on water quality. Significantly higher fish survival, growth as well as enhanced feed efficiency in terms of FCR was observed in low stocking density treatments (20 and 40 fish $m^{-3}$). Haematological parameters w.r.t. Hb and Ht increased with maximum value in treatment with 100 fish $m^{-3}$, whereas TLC decreased with minimum value in 60 fish $m^{-3}$, and TEC did not revealed any significantly change. Among biochemical parameters, significant variations were observed for blood serum glucose, total protein and total immunoglobulins, whereas, there were no significant variations in albumin, globulins and A/G ratio. Increase in serum concentration of cortisol, decrease in triiodothyronine and thyroid stimulatinmg hormone and no change in tetraiodothyronine were observed with increasing stocking density. Survival of all the three major carps remained above 90% with impressive growth and FCR. It can be concluded from the present study, that ornamental koi carp can be successfully integrated with carps in pond cage system up to 40 fish $m^{-3}$ for higher economic gain from the available water resource.

***Keywords***: Cage culture, Stocking density, Koi carp, Crowding stress, Physiology

In Punjab, carp farming remained most viable option in view of availability of raw material in the form of quality seed and environmental conditions. However, recently, in addition to carp culture, farmers are showing interest in adopting diverse culture systems and species for higher productivity and profitability. In this context, ornamental fish culture is one of the easily adoptable activity as a diversified component along with carp farming due to various reasons including small investment, ease of adoption as an ancillary activity and easy involvement of women. In comparison with food fish culture carried out in large sized earthen ponds, ornamental fish culture can be taken up in small concrete tanks, earthen ponds or even cages/hapas installed in earthen ponds. A management strategy based on the concept of integrating intensive and semi-intensive culture practices in cages and ponds simultaneously (cage-cum-pond-integrated system) has been suggested as an endeavour to increase per unit fish production (Mokoro et al 2014). Moreover, compared to nutrient utilization efficiency of about 30% in most intensive culture systems, the nutrient utilization efficiency could reach more than 50% in integrated pond-cum-cage culture system, resulting in release of much less nutrient to the surrounding environment (Asaduzzaman et al 2006). Further, the integrated pond-cum-cage system provide an option to small scale farmers to utilize limited resources in terms of land and water to generate additional income from high value ornamental fish cultured in cage integration with carps cultured in pond, so as to improve their livelihood. Stocking density is the most important factor determining the productivity of a culture system which affects survival, size and growth of fish (Swain et al 2018). Among various stresses which affects the fish while rearing under restricted environment like cages, is the inappropriate stocking density, as it represent a potential source of chronic stress, which may have adverse effects on physiological, behavioural and health status. It is a crucial factor in determining productivity and profitability of aquaculture systems (North et al 2006, Braun et al 2010). Among various freshwater ornamental fishes, 'Koi carp', *Cyprinus carpio* (family – Cyprinidae), ornamental mutation of common carp is a native from Asia, especially China and Japan. The term "Koi" refers to many strains of ornamental carp that have been genetically selected over many generations (Feldlite and Milstein 2000). In view of the importance of culturing ornamental fish especially koi carp in cages, there is need to standardize the stocking density for rearing koi carp fry to marketable size for getting maximum production without disturbing physiology of fish.

## MATERIAL AND METHODS

**Preparation and maintenance of experimental pond:** The experiment was carried out in bamboo net cages (1.0 $m^3$) installed in lime disinfected earthen pond (380 $m^2$). 15 cages were installed in the form of battery of 5 cages each in one row (3 rows x 5 cages=15 cages). Tube well water was used for filling, maintaining and exchanging the water in the pond. After one week of liming and initial filling of water, fertilizer slurry was added in the pond for natural food (plankton) production for fish. 1/4$^{th}$ of water from experimental tanks was exchanged with fresh water once every fortnight. Cages was cleaned thoroughly once in a week to get rid of algae. The water quality parameters of all the cages and earthen pond were analysed before stocking the fish.

**Acclimatization and stocking of experimental fishes:** Equal sized active and healthy ornamental Koi carp (length – 5.50cm; weight–3.01g) was acclimatized under well oxygenated conditions for 15 days under controlled conditions. During acclimatization, fish were fed @ 5% of their body weight twice a day with commercial feed. Acclimatized fish were stocked in 15 cages (5 treatments in triplicate) @ 20, 40, 60, 80 and 100 fish $m^{-3}$ designated as SD1, SD2, SD3, SD4 and SD5 respectively in June 2021 by following complete randomized design. Indian major carps (IMCs) i.e. catla (length – 4.13 cm &. weight – 0.96 g), rohu (length – 10.35 cm and. weight – 13.47 g) and mrigal (length – 12.06 cm and weight – 17.07 g) were stocked in ratio of @ fish $m^{-3}$ 3:4:3 in earthen pond, in which cages were installed.

**Fish feeding:** Experimental koi were fed with commercial feed @ 5% of fish body weight (BW) twice daily (10:00 and 16:00 h) and IMCs were fed with formulated pelleted feed (rice bran and mustard cake - 49% each, vitamin mixture – 1.5% and salt 0.5%) @ 1% of BW once daily (10:00) throughout the experiment (June-August 2021). Amount of feed for Koi carp was adjusted after each sampling according to increase in fish weight.

**Water quality parameters**: Water quality parameters in terms of temperature, pH, dissolved oxygen (DO), total alkalinity (TA), total hardness (TH), ammonical - nitrogen ($NH_3$-N), nitrite - nitrogen ($NO_2^-$-N) and nitrate - nitrogen ($NO_3^-$ -N) ($NH_3$) were analysed at fortnightly intervals following by the method of APHA (2012).

**Survival of fish:** Survival (%) of fish in each treatment was recorded by comparing the live fish recovered at the end of the experiment with that of total fish stocked according to following formula

$$\text{Fish survival (\%)} = \frac{\text{No. of fish recovered after completion of experiment}}{\text{No. of fish stocked at initiation of experiment}} \times 100$$

**Growth of fish**: Fish sampling was done at monthly intervals for koi carp and at the completion of experiment for IMCs to record fish growth in terms of total body length and body weight. Total body length gain (TBLG) and %TBLG, net weight gain (NWG) and %NWG, specific growth rate (SGR), feed conversion ratio (FCR) and condition factor (K) of fish for each treatment were calculated. (Halver 1976).

$$\text{SGR (\% weight gain day}^{-1}) = \frac{\text{In final BW (g)} - \text{In initial BW (g)}}{\text{Culture days}} \times 100$$

Where, In = natural logarithm

Feed conversion ratio (FCR) = Feed given (g)/weight gain (g)

Condition factor (K-value) = Body weight (g)/ body Length $(cm)^3 \times 100$

**Haematological parameters:** Haematological parameters were analysed at the completion of experiment for total erythrocytes count (TEC), total leukocytes count (TLC), haemoglobin (Hb), haematocrit (Ht) by following the methods of Sahli (1962) and micro-capillary (Mukherjee 1988).

**Biochemical parameters:** Biochemical parameters in terms of blood glucose (Trinder 1969), total proteins (Gornall et al 1949), globulin, albumin and total immunoglobulin were estimated and albumin/globulin ratio was calculated in blood serum after completion of the experiment with Erba Diagnostic Mannheim GmbH kits

**Hormonal profile**: Hormonal profile were analysed at monthly intervals for Cortisol, triiodothyronine ($T_3$), tetraiodothyronine ($T_4$) and thyroid-stimulating hormone (TSH) with the help of ELISA kit.

**Statistical analysis:** Statistical analysis of the data was performed with a Statistical Package for the Social Science (SPSS v.16.0) with Duncan's Multiple Range Test to determine significant differences among the treatments (Duncan 1955).

## RESULTS AND DISCUSSION

**Water quality**- The water quality parameters viz. temperature, pH, DO, TA,TH, $NO_2$-N and $NO_3$-N ranged between 28.33 - 35.30˚C, 7.38-8.23, 7.6-16.93 mg $l^{-1}$, 228.67 – 282.00 $CaCO_3$ mg $l^{-1}$, 226.00 – 282.00 $CaCO_3$ mg $l^{-1}$, 0.01 - 0.04 mg $l^{-1}$, 0.18 - 0.49 mg $l^{-1}$ in all treatments and earthen pond, whereas mean $NH_3$ remained nil. The differences were insignificant for all the parameters among all treatments except pH. Further, the values for all the water quality parameters were well within the desirable range required for normal growth and physiological activities of fish (Boyd and Tucker 1998), which revealed that stocking densities did not affected the water quality.

**Survival and growth of fish** - Survival (%) of fish ranged from 87.33 to 96.67 with significantly higher fish survival in SD1 (96.67) and SD2 (94.17) as compared to other treatments (SD3-SD5), which were insignificantly different from each other. At the end of experimental period, TBLG and TBLG (%) was significantly higher (2.47 and 45.44 cm) in SD2, but with no significant difference from SD1. The differences were insignificant for both the parameters among rest of the treatments. In accordance to length of fish, weight parameters (NWG and SGR) were also significantly higher in SD1 and SD2 as compared to other treatments. The remaining parameters i.e. % NWG and condition factor (K) did not differ significantly. Feed efficiency in terms of FCR was also significantly reduced in SD1 and SD2 as compared to all other treatments (Table 1). The best growth performance of fish in terms of weight gain and specific growth rate at lower stocking density of 20 and 40 fish m$^{-3}$, got affected with further increase in stocking density. The enhanced fish growth at lowest stocking densities may be explained as accessibility of comfortable space to fish for growth. Most of the previous studies also revealed that lower stocking densities had positive effect on fish in terms of weight gain, growth and survival of species like *Cyprinus carpio* Lin. (Ahmed et al 2002), goldfish (Stone et al 2003, Jahedi et al 2012), *Anabas testudineus* (Uddin et al 2016), *Oreochromis niloticus* (Gibtan et al 2008). In present study, fish growth decreased significantly with significantly increased feed conversion ratio with increase in stocking densities. Yang et al (2020), also reported decreased growth performance and increased FCR with the increase in stocking density.

**Haematological parameter:** At highest stocking densities, haematological parameters w.r.t. Hb and Ht of koi carp increased and maximum in SD5 (100 m$^{-3}$), whereas TLC decreased, with minimum in SD3, whereas TEC did not revealed any significantly change (Fig. 1). Most of the

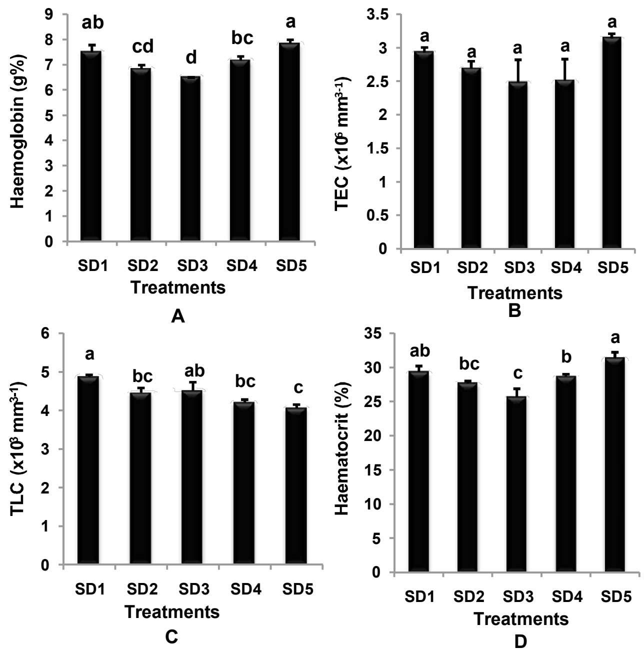


**Fig. 1.** Comparative A) Hb (g %) B); TEC (x10$^6$ mm$^{3-1}$); C) TLC (x10$^3$ mm$^{3-1}$) and D) Haematocrit (%) content in blood of Koi carp in different treatments after completion of the experiment

**Table 1.** Growth parameters of Koi carp in different treatments

| Parameters | Treatments | | | | |
|---|---|---|---|---|---|
| | SD1 | SD2 | SD3 | SD4 | SD5 |
| | | | Length parameters | | |
| ITBL (cm) | 5.38$^a$ | 5.44$^a$ | 5.48$^a$ | 5.51$^a$ | 5.70$^a$ |
| FTBL (cm) | 8.14$^a$ | 7.97$^a$ | 6.99$^b$ | 6.99$^b$ | 6.94$^b$ |
| TLG (cm) | 2.37$^a$ | 2.47$^a$ | 1.53$^b$ | 1.43$^b$ | 1.50$^b$ |
| TLG (%) | 42.90$^a$ | 45.44$^a$ | 28.68$^b$ | 26.90$^b$ | 29.10$^b$ |
| | | | Weight parameters | | |
| IBW (g) | 3.20$^a$ | 3.07$^a$ | 2.93$^a$ | 2.93$^a$ | 2.93$^a$ |
| FBW (g) | 11.60$^a$ | 11.27$^a$ | 8.47$^b$ | 7.40$^c$ | 6.53$^d$ |
| NWG (g) | 8.40$^a$ | 8.20$^a$ | 5.53$^b$ | 4.47$^c$ | 3.60$^d$ |
| NWG (%) | 264.43$^a$ | 253.43$^a$ | 188.57$^b$ | 152.47$^c$ | 122.73$^d$ |
| SGR (%) | 1.43$^a$ | 1.40$^a$ | 1.18$^b$ | 1.03$^c$ | 0.89$^d$ |
| Condition Factor (K) | 2.15$^a$ | 2.24$^a$ | 2.48$^a$ | 2.18$^a$ | 1.95$^a$ |
| FCR | 2.00$^b$ | 1.99$^b$ | 2.55$^a$ | 2.61$^a$ | 2.50$^a$ |

* SD = Stocking Density SD1 = 20 fish m$^{-3}$, SD2= 40 fish m$^{-3}$, SD3 = 60 fish m$^{-3}$, SD4= 80 fish m$^{-3}$, SD5 = 100 fish m$^{-3}$
Values with same superscript (a, b,…….d) in row do not differ significantly (p≤0.05)
ITBL – Initial total body length; FTBL – Final total body length; TLG – Total length gain; NWG – Net weight gain; SGR – Specific Growth Rate; FCR – Feed conversion ratio

previous studies also revealed variations in physiological responses (Bacchetta et al 2020, Khairnar et al 2020). Insignificant change in TEC and decreases in TLC at highest stocking densities coincides with the results of Yarahmadi et al (2015), in terms of decreased WBC at highest stocking densities. It may be due to sub chronic overcrowding stress and increased activity of pituitary internal axis caused by increased secretion of cortisol level (Tort 2011)

**Biochemical Parameters:** The blood serum glucose, total protein and total immunoglobulins of koi carp was significantly higher in SD5, SD3 and SD1 and SD2 respectively, whereas, the differences were insignificant for albumin, globulins and A/G ratio (Table 2). Increase in serum glucose level at highest stocking densities coincides with the findings of earlier researcher in different fish species like Asian seabass (Sadhu et al 2014); tilapia (Aly et al 2009); golden pompano (Yang et al 2020). The increase in serum glucose level is an indication of strategy to cope up with high stocking density stress. Decrease in total protein content at highest stocking densities, supported with the findings of Yang et al (2020), whereas the results of other parameters coincide with the investigation of Yarahmadi (2015), where

**Table 2.** Biochemical parameters in blood serum of Koi carp in different treatments after completion of the experiment

| Biochemical parameters (g $dl^{-1}$) | Treatments | | | | |
|---|---|---|---|---|---|
| | SD1 | SD2 | SD3 | SD4 | SD5 |
| Glucose | $97.43^{b}$ | $92.27^{b}$ | $90.97^{b}$ | $94.16^{b}$ | $108.60^{a}$ |
| Total Protein | $2.87^{ab}$ | $2.79^{b}$ | $2.90^{a}$ | $2.84^{ab}$ | $2.04^{c}$ |
| Albumins | $1.34^{a}$ | $1.38^{a}$ | $1.40^{a}$ | $1.30^{a}$ | $1.34^{a}$ |
| Globulins | $1.53^{a}$ | $1.45^{a}$ | $1.51^{a}$ | $1.57^{a}$ | $0.86^{a}$ |
| A/G Ratio | $0.88^{a}$ | $1.21^{a}$ | $1.04^{a}$ | $0.93^{a}$ | $1.62^{a}$ |
| Total Ig | $1.42^{a}$ | $1.42^{a}$ | $1.15^{ab}$ | $1.23^{ab}$ | $1.01^{b}$ |

Values with same superscript (a, b,…….d) in row do not differ significantly ($p \le 0.05$)
A/G ratio = Albumin/Globulins ratio; Ig - Immunoglobulins

**Table 3.** Variations in hormonal profile of blood serum of Koi carp in different treatments at monthly intervals

| Time of observation (days) | Treatments | | | | |
|---|---|---|---|---|---|
| | SD1 | SD2 | SD3 | SD4 | SD5 |
| T3 (ng $ml^{-1}$) | | | | | |
| 0 | $3.9^{a1}$ | $3.9^{a1}$ | $3.9^{a1}$ | $3.8^{a1}$ | $3.9^{a,1}$ |
| 30 | $3.7^{a2}$ | $3.5^{bc2}$ | $3.3^{d2}$ | $3.6^{ab2}$ | $3.4^{cd,2}$ |
| 60 | $3.6^{a2}$ | $3.5^{a2}$ | $3.3^{b2}$ | $3.5^{a2,3}$ | $3.2^{b,3}$ |
| 90 | $3.5^{a2}$ | $3.5^{ab2}$ | $3.2^{bc2}$ | $3.3^{ab3}$ | $3.2^{c,3}$ |
| T4 (ng $ml^{-1}$) | | | | | |
| 0 | $3.3^{a1}$ | $3.4^{a1}$ | $3.5^{a1}$ | $3.3^{a1}$ | $3.3^{a1}$ |
| 30 | $3.3^{a1}$ | $3.3^{a1}$ | $3.4^{a1}$ | $3.3^{a1}$ | $3.3^{a1}$ |
| 60 | $3.3^{a1}$ | $3.3^{a1}$ | $3.4^{a1}$ | $3.4^{a1}$ | $3.2^{a1}$ |
| 90 | $3.2^{a1}$ | $3.1^{a1}$ | $3.4^{a1}$ | $3.4^{a1}$ | $3.2^{a1}$ |
| TSH (ng $ml^{-1}$) | | | | | |
| 0 | $3.88^{a1}$ | $3.91^{a1}$ | $3.88^{a1}$ | $3.90^{a1}$ | $3.92^{a1}$ |
| 30 | $3.53^{b2}$ | $3.59^{ab2}$ | $3.79^{a1}$ | $3.53^{b2}$ | $2.26^{c2}$ |
| 60 | $2.61^{b3}$ | $2.14^{a3}$ | $2.13^{a2}$ | $2.83^{a3}$ | $2.40^{c2}$ |
| 90 | $0.58^{a4}$ | $0.35^{bc,4}$ | $0.50^{ab3}$ | $0.44^{ab4}$ | $0.17^{c3}$ |
| Cortisol (ng $ml^{-1}$) | | | | | |
| 0 | $3.43^{a2}$ | $3.51^{a12}$ | $3.36^{a3}$ | $3.49^{a2}$ | $3.37^{a3}$ |
| 30 | $3.43^{b2}$ | $3.45^{b2}$ | $3.61^{a2}$ | $3.69^{a12}$ | $3.76^{a2}$ |
| 60 | $3.44^{c12}$ | $3.51^{c12}$ | $3.76^{b1}$ | $3.78^{b1}$ | $3.93^{a1}$ |
| 90 | $3.52^{d1}$ | $3.62^{c1}$ | $3.83^{b1}$ | $3.84^{b1}$ | $3.99^{a1}$ |

Values with same superscript (a, b,…….d) in row and column (1, 2……4) do not differ significantly ($p \le 0.05$)

no significant changes on globulin and albumin with increasing stocking density. The biochemical parameters of the fishes are affected by several factors such as species, environmental, response of condition, dietary, age, maturation and nutrition. The variation in biochemical parameters is indicative of crowding stress along with poor nutritional status of fish at high stocking density (Wu et al 2018). Significantly high total immunoglobulins in SD1 & SD2 and minimum in highest stocking density (SD5) can be the result of crowding stress leading to decreased plasma lysozyme activity in fish (Yarahmadi et al 2015, Costa et al 2017). Lysozyme is a major index of the immune system that involves a lysis process of Gram-positive bacterial cell walls. These results coincides with the findings of Long et al (2019) in terms of significant decline in serum immunoglobulin M (IgM), lysozyme, alkaline phosphatase, and acid phosphatase activities at highest stocking density.

**Hormonal profile:** The present study in terms of decreased concentation of T3 and TSH and insignificant change in T4 (Table 3) with increasing stocking density supported with the results of Kpundeh et al (2013) and Li et al (2012) respectively. Reduced T3 & TSH levels in the present study with increase in stocking density must be associated with physiological stress. At monthy intervals, with increase in stocking density there is a significant increase in the level of cortisol (Table 3) corresponds well with the findings of earlier researcher in different fish species like Asian seabass (Sadhu et al 2014), Fancy carp (Yin et al 1995); Golden pompano (Yang et al 2020),and Jundia (Barcellos et al 2004).

**Survival and growth of Indian Major Carps (IMCs):** Survival of all the IMCs remained above 90% with maximum growth in terms of % NWG and SGR in catla (2787 and 6.3). Further, FCR of 0.072 also revealed that the available feed (IMC fed @ 1% BW + unfed feed of Koi carp, if any) was also efficiently utilized by the carps.

## CONCLUSIONS

The koi carp can be reared at stocking density of 40 $m^{-3}$ in cages in integration with carps in earthen pond with no negative impact on water quality, without compromising survival and growth of fish and without any major effect on other physiological parameters.

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# Sustainable Livelihood through Fish Cage Culture: Case of Chandil Reservoir in Jharkhand

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***Abstract***: Chandil is one of the largest reservoir with 18000 hectare (ha) area in Jharkhand and has 933 cages from which about 4 tonnes of fish is produced/cage/year. Impact assessment of cage culture on livelihoods of fisheries dependent people was done using sustainable livelihood framework having human, social, natural, physical, and financial capital as the asset pentagon. Interviews were done with 200 fisheries dependent people who scored their perceptions on a 5 point Likert scale for each livelihood capital before and after adoption of cage culture and percent changes were computed along with Wilcoxon sign-rank test to test if differences were statistically significant. There was positive impact on all livelihood capitals with human capital having maximum impact (34.66%) followed by social capital (30.99%), financial capital (28.90%), physical capital (25.95%) and natural capital (20.85%). However, area of agricultural land had decreased and had a statistically significant negative impact as people lost agricultural land due to reservoir construction. Statistically significant difference was found between before-after scores at 5% level of significance for all livelihood capitals. Cage culture has been able to provide flow of financial capital and had capacity to contribute to other forms of livelihood capitals like investment in assets, food, health, production equipment, education, and housing.

***Keywords***: Reservoir, Cage culture, Jharkhand, Livelihood, Impact assessment

Reservoirs of India have a combined surface area of 3.25 million hectares (ha) so they are an important inland water resource. Realising the huge untapped potential of reservoirs, India has undertaken culturing of fishes in cages in a big way. Cage culture is a technique where fish are reared from fry to fingerling, fingerling to table size, or table size to marketable size while captive in an enclosed space that maintains the free exchange of water with the surrounding water body. Fish yields of 50 kg/ha/year from small reservoirs, 20 kg/ha/year from medium-sized reservoirs and 8 kg/ha/year from large reservoirs have been realized while still leaving scope for enhancing fish yield through capture fisheries, including culture-based fisheries (Das et al 2009). National Fisheries Development Board (NFDB), which is under the administrative control of the Department of Fisheries, Ministry of Fisheries, Animal Husbandry & Dairying, Government of India was set up in 2006 and has supported several initiatives on cage culture in reservoirs, wetlands and beels in the states of Tamil Nadu, Telangana, Assam, Maharashtra, Rajasthan, Jharkhand and Chhattisgarh. A total of 3117 inland cages have been installed across the country, of which 2553 are in reservoirs, 560 in wetlands/beels and 2 in coal pits. It is expected that, these successful models will encourage several entrepreneurs to undertake cage culture in reservoirs across the country (NFDB, 2018). It has been recognized by many researchers that the cage fish farming in reservoir helps in generating employment (Ali et al 2008; Kumari et al 2019) and improving socio economic conditions for the rural people (Manasi et al 2009, Ali et al 2008). Cage culture is considered as an opportunity to increase fish production (Syandri et al 2015, Karnatak and Kumar 2014) from reservoirs as well as to create livelihood for the displaced people due to reservoir construction (Gurung et al 2009). One such reservoir in which cage culture is adopted is Chandil which is one of the largest reservoirs in Jharkhand state in India. Department of Fisheries (DoF), Government of Jharkhand has installed 933 cages with the help of fisher cooperative societies. It is reported that from each cage about 4 tonnes of fish is being produced. This helps rural unemployed, displaced people of Chandil to sustain their livelihood (Kumar 2018).

It is necessary to conduct livelihood impact assessment of people who are involved in cage culture in this reservoir. Impact assessment is a special form of evaluation that deals with the effect of intervention programme output on the target beneficiaries (Sanginga et al 1999). One of the frameworks of impact assessment is the Sustainable Livelihood Framework (SLF) of DFID (2008) which consists of five inter related dimensions. According to DFID (1999), the SLF seeks to take a more comprehensive and integrated approach to poverty than traditional interpretations, which largely consider poverty in relation to a narrow set of indicators (such as income and productivity). At the heart of the framework is the asset pentagon including human, social, natural, physical, and financial capital (Chambers and Conway 1992). In context of aquaculture, Sharma (2019) has used this framework. This study was undertaken with the objectives of assessing the impact of cage culture on the livelihood capitals of fisheries dependent people in Chandil reservoir, Jharkhand.

## MATERIAL AND METHODS

Locale of the study was Chandil reservoir which is spread over 18,000 ha area in the district of Saraikela-Kharsawan district in Jharkhand state, India. Total number of cages installed in the reservoir is 933 which is maximum among all reservoirs of the state. The size of cage is 6m (length) x 4m (width) x 4m (height) and the species cultured are Pangasius (Sutchi fish), tilapia and carps. There are 5 fisheries cooperative societies in Chandil reservoir. Care was taken to randomly select about 50% of members from each fisheries cooperative society. The total number of members in each of these societies and members selected for the study presented in Table 1. These cooperatives constitute of people who were displaced by the construction of reservoir.

To achieve the objectives of the study, information was collected from members of the fisheries cooperative society using an interview schedule which was prepared keeping DFID (1999) Sustainable Livelihood Framework (SLF) and included the livelihood capitals human, social, natural, physical and financial. For using the SLF framework, a list of indicators which were related to these 5 capitals were collected from review of literature, field study and 3 discussions with expert group. Expert group consisted of 2 social scientists, 1 aquaculture scientist, and 1 Department of Fisheries (DoF) official and 1 key informant each from the 5 cooperative societies. Relevancy of these indicators was tested by expert group with indicators using a 5 point Likert scale with score 4 assigned to very high relevance, 3 to high relevance, 2 to medium relevance, 1 to low relevance and 0 to no relevance. Indicators having average relevancy score of 2 and above were selected. Reliability of the scale was established by 'test-retest' method which was administered on all 9 experts within an interval of 15 days. Reliability coefficient was found to be 0.75. All indicators having an average relevancy score of 2 or above were included in the interview schedule. A total of 38 indicators were included with human capital having 11, social capital having 9, natural capital having 5, physical capital having 7 and financial capital having 6 indicators which are discussed in results section.To achieve the objectives of the study, randomly selected 200 members of the cooperative society were asked to score their perceptions of impact of cage culture on a 5 point Likert scale (0 to 4) for each indicator of 5 livelihood capitals before and after the adoption of cage culture using recall method. The scale had five scores Very high impact (Score: 4), High impact (Score: 3), Moderate impact (Score: 2), Low impact (Score: 1) and Very low impact (Score: 0).

Reliability of this scale was tested using Cronbach's Alpha (Cronbach 1978) calculated using equation 1 and was found to be 0.78. Thus the scale was considered reliable.

$$\propto = \frac{N\bar{c}}{\bar{v} + (N-1)\bar{c}} \qquad (1)$$

Here, N = the number of items, $\bar{c}$ = average covariance between item-pairs, $\bar{v}$ = average variance.

The obtained scores were normalized using equation 2.

$$\text{Dimension value} = \frac{\text{Actual value} - \text{Minimum value}}{\text{Maximum value} - \text{Minimum value}} \qquad (2)$$

The normalized scores were between 0-1 and a score of 0-0.25 was classified as low impact, 0.25-0.5 as moderate impact, 0.5-0.75 as high impact and 0.75-1.0 as very high impact. Change in 'before and after' scores were measured in percentage and this was considered as the percentage impact for that respective livelihood capital.

Wilcoxon signed rank test was performed to test the hypothesis whether there was any significant difference

**Table 1.** Sample information

| Name of fisheries cooperative society | Total number of members | Members selected for study | Members selected for study (%) |
|---|---|---|---|
| Chandil Bundh Visthapit Matsyjiwi Swawlambi Sahkari Samiti (CBVMSSS) | 275 | 137 | 49.82 |
| Lawa Gram Matsyajivi Sahyog Samiti (LGMSS) | 28 | 14 | 50.00 |
| Swarnarekha Bandh Visthapit Matsyajivi Sahkari Samiti Ltd. Chandil (SBVMSS) | 36 | 18 | 50.00 |
| Visthapit Matsyajiv Sahyog Samiti Ltd. Rasuniya (VMSS) | 50 | 25 | 50.00 |
| Visthapit Matsyajivi Swawlambi Sahkari Samiti Ltd. Bandveer (VMSSS) | 12 | 6 | 50.00 |
| Total | 401 | 200 | 49.87 |

between before and after scores. Wilcoxon singed rank test was calculated using equation 3.

$$Z = \frac{T^{+} - \mu_{T+}}{\sigma_{T+}} \qquad (3)$$

Where,

$$\mu_{T^{+}} = \frac{T^{+} - (N + N)}{4}$$

$$\sigma_{T^{+}} = \sqrt{\frac{N(N+1)(2N+1)}{24}}$$

$T^{+}$ = sum of ranks for smaller sample size (of singed-rank) ,N = sample size

Wilcoxon signed rank test for ties rank and large samples

$$\sigma^{2} T^{+} = \frac{N(N+1)(2N+1)}{24} - \frac{1}{2}\sum_{j=}^{g} t_j(t_j - 1)(t_j - 1)$$

Where, g = the number of groupings of different tied ranks, $t_{j=}$ the number of tied ranks in grouping j

The 'before after design' was used as it offered better evidence about intervention effectiveness than the other non-experimental designs. Information was collected about any other major programme being undertaken in the study area. No other major programmes and interventions were reported in the study area that could have obscured the effects of the intervention of cage culture thus reducing the threats to internal validity. Few schemes undertaken by State/Central Government posed minimal threat. So internal validity was established. This was done because more threats to internal validity, would give less confidence in the results that the different livelihood impacts are actually due to the intervention of cage culture. This helped in establishing the evidence of causality and attribution to impact of cage culture on different livelihood capitals. Attempts were made to explore people who could form a control group but this could not be done, so the traditional impact evaluation method of using randomised control was not used as it was not able to provide satisfactory answers. Due to this reason, counterfactual design where participants are compared to non-participants was not used. However, hypothetical counterfactual was constructed where enquiries were done by asking what would have happened if intervention of cage culture in this reservoir was not done and adopted by them and if this was a case of sole/joint/alternative (multiple) causal paths. This study represents a before and after comparison among the same population rather than a comparison of different groups at a given point in time. In addition to the before and after scores, enquires were made if the impacts were indeed due to the intervention of cage culture or some other reason/intervention. Judgements were made to include or rule out possible alternative explanations if any by using approach of 'ruling out alternatives' and 'process tracing'. SLF was used as an overarching framework complemented with approach of ruling out alternatives as suggested by Rogers (2014) and process tracing as given by Befani and Mayne (2014) resulting in stronger inferences. To strengthen causal attribution, approach of 'ruling out alternatives' was applied. This approach given by Rogers (2014) identifies possible alternative causal explanations and seeks information to see if these can be ruled out. In this, expert group was asked to identify other possible explanations for the observed impact of cage culture in this reservoir. Based on their judgements, the livelihood impacts were ascertained to be from cage culture. The records/ registers/ documentary proofs/ discussions with key informants were used as evidence-based process. Effort was made to undertake process tracing to rule out alternative explanatory variables. Process tracing holds potential as a rigorous ex-post approach to assess causal change, without having to rely on a control group. As per Punton and Welle (2015) this method of process tracing is relatively recent, and its application still requires further development and refinement but has been used beyond identifying statistical correlations. For process tracing, expert group was asked to identify other possible explanations, using evidence to rule out alternative explanatory variables and general elimination methodology was used. Thus attempts were made to design a rigorous method to establish causal inference, within the given time frame, resources and absence of detailed baseline data or counterfactual evidence.

## RESULTS AND DISCUSSION

**Background of fisheries in Chandil reservoir:** In the year 1978 Subarnarekha Multipurpose Project (SMP) was conceptualized in Bihar state. It was a multipurpose project that envisioned drinking water, irrigation and hydel power generation. The project consisted of two dams; one across river Subarnarekha at Chandil and the other across river Kharkai at Icha. Beside these two dams one barrage across Kharkai at Ganjia and the other across Subarnarekha at Galudih were also envisioned. Both these barrage consisted of canal system to take water for irrigation purpose. The estimated annual irrigation area was about 2, 36,846 hectare (ha). Members of this cooperative were from different villages of the submergence zone and they became part of a cage culture fishing initiative in collaboration with the Jharkhand Government. The DoF is responsible for fisheries management like leasing of reservoir, enhancing fish production and construction of temporary infrastructure like hatchery. Stocking in the reservoir is done by the DoF under different schemes/programmes of the NFDB. It was in 2011 when the cage culture activities started in the reservoirs of Jharkhand. As per the records of DoF, there are 933 cages in Chandil reservoir and *Pangasianodon hypophthalmus* is cultured in these cages. In the beginning, other than Pangassius; Anabas, Rohu, Tilapia and Grass Carp were also cultured on trial basis. But now Pangasius is cultured because it can be stocked at high density, grows faster and attains a size of 1 kg in 6-8 months of culture. So, it is considered as a candidate fish for cage culture.Members of the cooperative societies manage the fish rearing. NFDB provides 50% subsidy for cage fabrication and inputs and rest 50% is borne by the beneficiaries. In 2011, fish culture was done in 70 cages and the numbers have been increasing every year. In 2019, there were 933 cages (Table 2).

The number of cages has increased, average production per cage has not shown increasing trend. This was due to non-availability of seed. Sometimes cages were left unstock due to absence of seeds. It was reported that Pangas seeds were purchased from West Bengal and dependency for seed is from other states. Fish seed production has increased from 64.50 million fry (2003-04) to 103629.11 million fry (2018-19) in Jharkhand but is still dependent on seed from other states. As per the NFDB guidelines, 5000 cages can be installed in a reservoir of >10000 ha.

**Livelihood impact of cage culture:** There was impact in the range of 20 to 35% for all (Table 3). Interpreting the empirical evidence, it is clear that highest impact of cage culture was on human capital (34.66%) followed by social, financial, physical and natural capital. Wilcoxon signed rank test revealed a significant difference between the before and after scores at 5% level of significance for all livelihood capitals. Results highlights that there has been a positive impact for all livelihood capitals. Pant et al (2014) obserevd that aquaculture was able to benefit ethnic communities in Bangladesh. Gupta and Haque (2011) also found that due to cage based fish fingerlings, livelihoods of tribal households in north-east and north-west Bangladesh showed improvements. Gurung et al (2009) have suggested that cage fish culture was a good alternative livelihood option for communities displaced by reservoir impoundment in Kulekhani, Nepal. In Indian context, research has shown that fisheries have brought positive changes in the livelihood of people like studies by Dube (2014) in Dimbhe reservoir, Maharashtra, Kumari et al (2017) in Chandil reservoir, Jharkhand, Gautam et al (2017) in Rihand reserevoir, M.P., Kumari and Sharma (2015), Kumari et al (2017) in Raipur, Chhattisgarh and Babu et al (2021) in Andhra Pradesh. Sharma et al (2019) however reported that climate change impacted the livelihoods of fishers in Bhadra reservoir, Karnataka. In the present study impact of climate change was not studied which might be one of the vulnerability issue faced by the members and detailed study is needed for this.

Differences in the livelihood capitals are depicted through a radar chart in Figure 1.

A discussion on individual livelihood capitals is presented as follows.

**Physical capital:** This capital included nature of house, drinking water facility at home, electricity facility at home, medical facility, transportation facility, fish market facility and sanitary facility at home. It was reported by members that they had their own house and majority (61.5%) had pucca house. A total of 70% members had drinking water facility at home. Cycle as a means of transport was used by 70.5% members. Members reported that due to increase in income with cage culture, they were able to have better facilities of drinking water, electricity and sanitation facilities at home. Fish market facilities had also relatively improved.All the indicators of physical capital had positive impact. Out of the 7

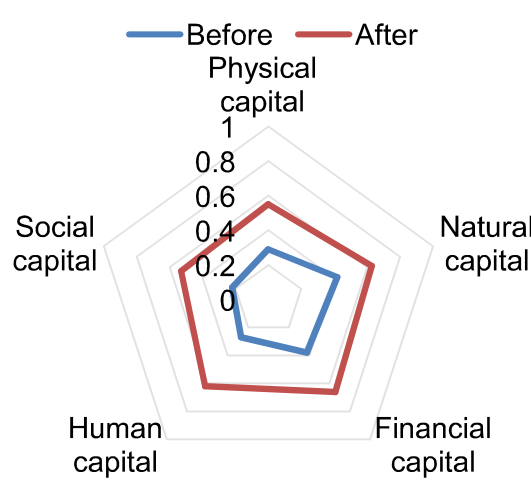


**Fig. 1.** Radar chart depicting impacts on livelihood capitals

**Table 2.** Year wise fish production in Chandil reservoir

| Year | 2011-12 | 2012-13 | 2013-14 | 2014-15 | 2015-16 | 2016-17 | 2017-18 | 2018-19 |
|---|---|---|---|---|---|---|---|---|
| Fish production (tonnes) | 110 | 150 | 180 | 220 | 350 | 400 | 180 | 250 |
| Number of cages | 70 | 196 | 487 | 487 | 593 | 821 | 897 | 933 |
| Average production per cage (tonnes) | 1.57 | 0.76 | 0.37 | 0.45 | 0.59 | 0.49 | 0.20 | 0.27 |

indicators, some facilities like electricity, transportation, nature of house were those which improved at household level and some which improved at the community level like fish market facility, sanitary facility, drinking water facility (Table 4). Wilcoxon sign rank test revealed that there was a statistically significant difference between before and after scores.

**Natural capital:** This capital included impact on agriculture land area, water area, fish production, availability of fish seeds and availability of various fish species and the scores (Table 5). Agricultural land had decreased after reservoir construction. This change was negative and statistically significant. It was reported that due to reservoir construction, people lost their agricultural land. Most of the cooperative society members (88%) had less than 1 ha agriculture land. Before the construction of reservoir, they were involved in agricultural activities. Panwar and Upreti (2015) also stated that agriculture is the main stay of surrounding villages of Tehri dam in Uttarakhand state which has been severely affected due to submergence of fertile agricultural land. Even though the agricultural land was reported to be reduced; the other indicators of natural capital, especially fisheries, had a positive impact and this change was statistically significant at 5% level of significance. McCartney (2018) also has reported that by creating reservoirs, potential for fish production can be increased in Malaysia. Ghosh et al (2016) also reported that fish biodiversity improved due to floating cages in Godavari Estuary, Andhra Pradesh and in a study by Uddin et al (2015) in Bangladesh natural capital was improved due to integrated farming.

**Financial capital:** This capital included annual respondent's income, annual family income, annual family expenditure, annual savings, general assets and fisheries assets. Average annual income of members from cage culture was reported to be ₹3, 50,000 which is more than the national average annual income of ₹1, 26,406. National Statistical Office, Ministry of Statistics & Programme Implementation Government of India (2020). Average annual income of cooperative society members was more than the average annual income of Jharkhand state which is ₹83,592. Planning cum Finance, Govt. of Jharkhand (2020). ($1=Indian Rupees/₹ 74.38). The changes in the financial capital of the members due to cage culture is presented in Table 6.

All the indicators related to financial capital, positive impact was reported which was statistically significant. It can thus be inferred that cage culture contribute to the flow of financial capital available to members. This has the

**Table 3.** Livelihood capital scores before and after adoption of cage culture

| Livelihood capital | Before | | After | | % change | \|Z\| values | Decision |
|---|---|---|---|---|---|---|---|
| | MS* | NMS** | MS* | NMS** | | | |
| Physical capital | 8.14/28 | 0.29 | 15.42/28 | 0.55 | 25.95 | 12.352 | Reject $H_0$ |
| Natural capital | 8.42/20 | 0.42 | 12.59/20 | 0.63 | 20.85 | 12.089 | Reject $H_0$ |
| Financial capital | 9.01/24 | 0.38 | 15.94/24 | 0.66 | 28.90 | 12.297 | Reject $H_0$ |
| Human capital | 11.82/44 | 0.27 | 27.08/44 | 0.62 | 34.66 | 12.281 | Reject $H_0$ |
| Social capital | 7.85/36 | 0.22 | 19.01/36 | 0.53 | 30.99 | 12.284 | Reject $H_0$ |
| Overall | 45.23/152 | - | 90.04/152 | - | 29.48 | | |

MS*: Mean score, NMS**: Normalized mean score

**Table 4.** Impact of cage culture on physical capital

| Livelihood capital | Before | | After | | % change | \|Z\| values | Decision |
|---|---|---|---|---|---|---|---|
| | MS* | NMS** | MS* | NMS** | | | |
| Nature of house | 0.84 | 0.21 | 2.02 | 0.50 | 29.13 | 13.155 | Reject $H_0$ |
| Drinking water facility at home | 0.90 | 0.23 | 2.20 | 0.55 | 32.38 | 12.780 | Reject $H_0$ |
| Electricity facility at home | 1.01 | 0.25 | 2.24 | 0.56 | 30.75 | 12.821 | Reject $H_0$ |
| Medical facility | 1.03 | 0.26 | 2.05 | 0.51 | 25.50 | 13.185 | Reject $H_0$ |
| Transportation facility | 1.01 | 0.25 | 2.09 | 0.52 | 26.75 | 13.184 | Reject $H_0$ |
| Fish market facility | 1.48 | 0.37 | 2.26 | 0.57 | 19.75 | 10.124 | Reject $H_0$ |
| Sanitary facility at home | 1.87 | 0.47 | 2.56 | 0.64 | 17.38 | 11.251 | Reject $H_0$ |
| Overall | 8.14 | | 15.42 | | 25.95 | | |

MS*: Mean score, NMS**: Normalized mean score

capacity to be converted to other forms of capital, for example, an investment in assets, food, health, production equipment, education, and housing. Principle explained by Mwebaza-Mdawula (1990) that you cannot change just one thing (YCCJOT) is applicable here that all elements are connected, directly or indirectly, so that a change in one element is eventually having some impact on every other element. Khatun et al (2013) in Bangladesh revealed that the socio-economic status of farmers of Charbata, Noakhali,Bangladesh improved with pond fish farming. Syandri et al (2015) in their study on social status of the fish farmers of floating net cages in lake Maninjau, Indonesia reported about the increase in fish production and income of the fish farmers from cage culture. Palita (2014) studied the fisher's livelihood and institutional arrangement in Hirakud reservoir, Odisha and stated high income of fishers compared to non-fishers.The cost of construction of 1 battery (4 cages) is ₹300000/- ($1=Indian Rupees/₹ 74.38). Assistance is provided by the state government and NFDB towards cage, inputs i.e., seeds for stocking in cages and feeds for fishes are also provided at subsidized rate. As there is subsidy provided by the state government and NFDB, the cooperative society members are dependent on government for cage culture in reservoirs. In such situation there can be a question that if the government and NFDB will not provide subsidy for cage construction and inputs, will cooperative society members be able to sustain this cage culture? However, the effect of subsidy on economic viability has been discussed in studies with reference to the small scale marine fisheries but not much in case of reservoir fisheries. This is a technology with potential benefits so there will be Government support for better adoption rates.

**Human capital:** Members reported that there was a positive impact for all the indicators related to human capital and this change was statistically significant (Table 7). It was observed that DoF and NFDB play an important role towards human capital development by providing skill and training to the members. Members had gained skill of fishing from these training programmes. They did not have cage culture skill before. Before adoption of cage culture very few (18.5%) were involved in fisheries activities and few had experience in fisheries. In addition, members now have skill in construction of cages, fish identification, fish handling, stocking, netting, fish breeding, feed dosage and marketing.

**Social capital:** The indicators which were included for social capital were leadership capabilities, desire to be a leader, participation in social meetings, participation in social works, social relationships with family, neighbours, and others cooperative society members, women's

**Table 5.** Impact of cage culture on natural capital

| Livelihood capital | Before | | After | | % change | \|Z\| values | Decision |
|---|---|---|---|---|---|---|---|
| | MS* | NMS** | MS* | NMS** | | | |
| Area of agri land | 2.52 | 0.63 | 0.46 | 0.11 | -51.63 | 12.377 | Reject $H_0$ |
| Area of water resource | 1.48 | 0.37 | 3.36 | 0.84 | 47.13 | 12.080 | Reject $H_0$ |
| Fish production | 1.52 | 0.38 | 3.30 | 0.83 | 44.50 | 11.912 | Reject $H_0$ |
| Availability of fish seeds | 1.38 | 0.35 | 2.18 | 0.55 | 19.88 | 12.225 | Reject $H_0$ |
| Availability of various fish sps. | 1.52 | 0.38 | 3.29 | 0.82 | 44.38 | 11.911 | Reject $H_0$ |
| Overall | 8.42 | | 12.59 | | 20.85 | | |

MS*: Mean score, NMS**: Normalized mean score

**Table 6.** Impact of cage culture on financial capital

| Livelihood capital | Before | | After | | % change | \|Z\| values | Decision |
|---|---|---|---|---|---|---|---|
| | MS* | NMS** | MS* | NMS** | | | |
| Annual respondent Income | 1.60 | 0.40 | 2.92 | 0.72 | 32.63 | 12.767 | Reject $H_0$ |
| Annual family income | 1.88 | 0.47 | 3.09 | 0.77 | 30.25 | 13.107 | Reject $H_0$ |
| Annual family expenditure | 1.92 | 0.48 | 2.97 | 0.74 | 26.38 | 12.463 | Reject $H_0$ |
| Annual saving | 0.54 | 0.14 | 1.91 | 0.48 | 34.25 | 10.769 | Reject $H_0$ |
| General assets | 1.67 | 0.42 | 2.72 | 0.68 | 26.38 | 12.108 | Reject $H_0$ |
| Fisheries assets | 1.40 | 0.35 | 2.34 | 0.59 | 23.50 | 11.712 | Reject $H_0$ |
| Overall | 9.01 | | 15.94 | | 28.90 | | |

MS*: Mean score, NMS**: Normalized mean score

participation in fisheries work, contact with Government Organisations (GO)/NGO and participation of women in decision making ( Table 8).All indicators of social capital, there was a positive impact due to cage culture and this difference was statistically significant. Members had better relationship with other fishers, cooperative members, participation in meetings was relatively high and they had more contacts with the officials of DoF. Relations and connectedness were further stimulated by the capacity building programmes with frequent gatherings and training. It was reported that this increase in social capital resulted in an increase in trust among the cooperative society members. This was similar to what DFID (2007) has stated that the connectedness and relations help in the facilitation of cooperation, reduction of transaction costs and providing the basis for safety nets. Communication tools which were commonly used were simple mobile phones. About 30% had television and 10% subscribed to newspaper. Participation in social and regional activities and few political gatherings was common. However, usage of the communication device

**Table 7.** Impact of cage culture on human capital

| Livelihood capital | Before | | After | | % change | \|Z\| values | Decision |
|---|---|---|---|---|---|---|---|
| | MS* | NMS** | MS* | NMS** | | | |
| Fisheries skills | 1.10 | 0.28 | 2.73 | 0.68 | 40.75 | 12.552 | Reject $H_0$ |
| Production skills | 1.11 | 0.28 | 2.20 | 0.55 | 27.13 | 13.368 | Reject $H_0$ |
| Marketing skill | 1.05 | 0.26 | 2.26 | 0.57 | 30.38 | 13.032 | Reject $H_0$ |
| Technical skill | 0.72 | 0.18 | 1.82 | 0.46 | 27.63 | 13.466 | Reject $H_0$ |
| Children going school for primary education | 1.30 | 0.33 | 2.64 | 0.66 | 33.50 | 12.509 | Reject $H_0$ |
| Children going to school for higher education | 1.27 | 0.32 | 2.48 | 0.62 | 30.38 | 12.823 | Reject $H_0$ |
| Knowledge about cage culture | 0.07 | 0.02 | 2.40 | 0.60 | 57.75 | 12.880 | Reject $H_0$ |
| Awareness about government schemes | 1.30 | 0.33 | 2.88 | 0.72 | 39.63 | 12.455 | Reject $H_0$ |
| Participation in training programmes | 1.24 | 0.31 | 2.45 | 0.61 | 30.38 | 12.884 | Reject $H_0$ |
| Attitude towards DoF | 1.34 | 0.34 | 2.66 | 0.66 | 32.88 | 12.831 | Reject $H_0$ |
| Attitude towards fish culture/ cage culture | 1.32 | 0.33 | 2.56 | 0.64 | 30.88 | 13.133 | Reject $H_0$ |
| Overall | 11.82 | | 27.08 | | 34.66 | | |

MS*: Mean score, NMS**: Normalized mean score

**Table 8.** Impact of cage culture on social capital

| Livelihood capital | Before | | After | | % change | \|Z\| values | Decision |
|---|---|---|---|---|---|---|---|
| | MS* | NMS** | MS* | NMS** | | | |
| Leadership capabilities | 1.11 | 0.28 | 2.11 | 0.53 | 25.00 | 13.658 | Reject $H_0$ |
| Desire to have leader position | 0.58 | 0.15 | 1.45 | 0.36 | 21.63 | 12.854 | Reject $H_0$ |
| Participation in social activities | 1.20 | 0.30 | 2.46 | 0.62 | 31.38 | 12.763 | Reject $H_0$ |
| Participation in social meetings | 1.40 | 0.35 | 2.45 | 0.61 | 26.13 | 12.228 | Reject $H_0$ |
| Participation of women in fisheries activities | 0.37 | 0.09 | 1.97 | 0.49 | 40.13 | 12.425 | Reject $H_0$ |
| Participation of women in social activities | 0.42 | 0.10 | 1.48 | 0.37 | 26.63 | 13.059 | Reject $H_0$ |
| Participation of women in decision making | 0.76 | 0.19 | 1.81 | 0.45 | 26.13 | 13.282 | Reject $H_0$ |
| Contact with GOs & NGOs | 1.17 | 0.29 | 3.04 | 0.76 | 46.88 | 12.522 | Reject $H_0$ |
| Membership in organizations | 0.84 | 0.21 | 2.24 | 0.56 | 35.00 | 12.658 | Reject $H_0$ |
| Overall | 7.85 | | 19.01 | | 30.99 | | |

MS*: Mean score, NMS**: Normalized mean score

was not included in the impact study as it was difficult to attribute that this change was only due to cage culture.Results of hypothetical counterfactual where enquiries were done by asking what would have happened in the absence of adoption of cage culture in this reservoir revealed that in the absence of alternatives, migration to other places by the displaced would have happened. The results of the study have clearly shown that there is a demonstrated link between the interventions inputs of cage culture and the livelihood impact that are observed. Rogers (2014) has explained three conceptualizations of cause and effect as sole/joint/alternative (or multiple) causal attributions. In the present study 'sole causal attribution' was observed by field study as well as reported by the members and it could be established that the intervention of cage culture was able to produce the impacts independently (or relatively independently) of contextual factors or other interventions. Usually, programmes or policies are rarely sufficient to produce the intended impacts alone which was not the case as no other major development programme was reported and observed. Hypothetical counterfactual enquiries also revealed that in the absence of alternatives, migration to other places by the displaced would have happened. The approach of 'ruling out alternatives' and 'process tracing' was able to provide strong inference that the impacts were indeed due to the intervention of cage culture. So in this reservoir, the new stocks of potential resource were introduction of fisheries through cage culture which generated benefits for the human elements in the system. The benefits were distributed among the cooperative society members thus resulting in distributional impacts.

## CONCLUSIONS

The adoption of fish culture in cages can be a good alternative livelihood option especially for displaced people. Cage culture can increase fish production and ensure sustainable livelihoods for people. The study has shown that cage culture in reservoirs had a statistically significant positive impact on all the livelihood capitals with highest impact being on human capital followed by social capital and physical capital. Cage culture in Chandil reservoir has been successful with synergetic efforts by GOs, NGOs and community participation.

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# Impact of Selected Environmental Parameters on Marine Fish Landings of Coastal West Bengal

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***Abstract***: With the advent of satellite oceanography, environmental and oceanographic variables like Chlorophyll a, rainfall can be estimated on a scale not possible before. The objective of this study, is to investigate the relationship between the total annual marine catch of West Bengal of the last 20 years and these three important variables, coastal rainfall, Chlorophyll a and sea surface temperature. The relevant independent variables are rainfall for the months of May to August, Chl a for the months of November to December, and sea surface temperature for the months July to December. The study has found significant statistical correlations between the annual marine landings of West Bengal and the above mentioned parameters. Both Chlorophyll a and rainfall have been found to have significant statistical correlations with annual catch.

***Keywords***: Chl a, MODIS, SEAWIFS, SST, Monsoon rainfall, West Bengal Marine Fisheries, Climate change, Cobb Douglas model

Ocean color remote sensing started with the CZCS (Coastal Zone Colour Scanner) instrument in the 1980s. More advanced instruments like SEAWIFS (Sea Viewing Wide Field of View Sensor) from 1997, and the MODIS (Moderate Resolution Imaging Spectroradiometer) sensor from 2002, have made estimating ocean color (Chlorophyll a), over a wide area. Similarly sea surface temperature (SST) has been estimated from Sensors like AVHRR (Advanced Very High Resolution Radiometer). Agencies like NOAA (National Oceanographic and Atmospheric Agency), and NASA (National Aeronautics and Space Administration) maintain a large database of atmospheric and oceanic parameters like SST (Sea surface temperature), Chl a (Chlorophyll a) and rainfall online. The primary production in a given area(which is closely related with planktonic biomass), is governed by the flow of nutrients like N, P, K, Si as well as other factors like sea surface temperature. In shallow coastal estuarine areas the major source of nutrients is river discharge and runoff. The positive effect of rainfall on coastal marine fish landings is well established (Ayub 2010, Hoguane and Cuamba 2012). The second variable is Chl a, is a pigment present in marine algae like diatoms, cyanobacteria which make up the bulk of the phytoplankton. Therefore by quantifying this variable with satellite sensors can estimate the concentration of phytoplankton over a given area. Therefore a positive relationship with this variable and marine nekton in a given area is expected (Friedland et al 2012, Nammalwar et al 2013, Hu et al 2015, Dutta et al 2016). The third variable is sea surface temperature (SST), which can give an estimate of upwelling in an ocean area,a low SST contributes to ocean productivity. Studies have also been conducted on linkages between catch of specific pelagic species like mackarel, tuna and these parameters with positive results (Zainuddin and Saitoh 2004, Pitchaikani and Lipton 2012, Nurdin et al 2013). Therefore, it can be said that in tropical coastal zones, the most important variables governing marine productivity are discharge and runoff (quantified with coastal rainfall), Chl a and SST .In this study SST was found to be inversely correlated with catch, but since the correlation was not statistically significant, the empirical Cobb Douglas model was empirically estimated using only rainfall and chl a as independent variables.

The state of West Bengal is situated between latitudes, $21^{0}$- 0'- 5" N and $24^{0}$-0'- 5" N and longitudes $86^{0}$ E and $89^{0}$ E. It is the northern-most Indian state bordering the Bay of Bengal and has to its south the state of Orissa, while Bangladesh is to its north and north-east. West Bengal has a short coastline - only about 158 km, spread along the edge of its two maritime districts, south 24 parganas and east Mednipur. The marine resource base includes around 780 sq km of inshore area (about 20 m depth ,1815 sq km(about 20 m and 80 m depth ) and a continental shelf of 17,049 $km^2$ (upto 200 m depth). The short coastline, around 158 km is however very productive, as the river discharge from the Ganges river system acts as a rich source of nutrients, the coastal waters in the Bengal delta region has high primary productivity, as can be seen clearly from NASA MODIS satellite imagery. The continental shelf is also much wider than the average in the eastern Indian coast in this sector, more than 50 km long. The wide continental shelf, due to the high sedimentation of the region, as well as seasonal monsoon rainfall runoff and river discharges from the Gangetic river system as well as smaller rivers like the Subornorekha contribute to the productivity of this area. The fishing season is highly seasonal starting in late June and ending in April. May and half of June has been enforced as a fishing ban .The peak season is from September to January. Historicaly, the major species caught in these fishing area is Hilsa, Bombay duck, species from the Catfish family and croaker family. Central Marine Fisheries Research Institute (CMFRI) found the major species during monsoon to be hilsa, prawn, B duck and post monsoon (October - January) species from the croaker family, Arius sea catfish family, hilsa and prawn (Mini and Kuriakose 2013). From a commercial point of view, hilsa and prawns are most important, because of high prices, but from an ecological point of view, the benthic and benthopelagic species like the croaker and catfish family dominate. This is probably because of the high turbidity of the coastal waters. The total retail value of annual marine catch of West Bengal is more than 8000 crores (Selim et al 2017). Therefore the investigation of whether the annual catch can be predicted from relevant environmental variables quantified from SRS (Satellite Remote Sensing) is of substantial economic importance and is the focus of this study.

## MATERIAL AND METHODS

**Study area:** The coastal ocean off the Digha coast, West Bengal was chosen, because Digha along with nearby Shankarpur are the major marine fish landings zones of West Bengal. For coastal rainfall coastal area corresponding to Digha coast was chosen. The area corresponding to this data (Chla) is represented by (Fig. 1).

**Data sources**: Data was obtained from various sources, secondary data as well as remotely sensed data from online data severs of NOAA and NASA. The variables are:

Chl a data (MODIS and SEAWIFS) was obtained from NASA Ocean color website. SEAWIFS and MODIS data was correlated and a very strong correlation was observed and regression equation was used to estimate of the MODIS equivalent of SEAWIFS data for the years 1998-2001 (since MODIS is not available prior to 2002). For the years 2002-2018, MODIS data was used (4 Km resolution, OCI algorithm). This algorithm measures Chl a with the reflectance in the blue green region of the spectrum. The three bands used are in the 440 -660 nm region. The unit for the Chl a data is mg/m$^{-3}$. The estimates are derived using empirically derived relationships between the in situ measurements and reflectance's in the blue green spectrum.

VGPM (Vertically Generalised Productivity Model) net primary productivity data (strongly correlated with MODIS Chl a data), was downloaded from the University of Oregon Website to estimate the Chl a for a few months for which MODIS data was not available due to cloud cover.

**Rainfall:** Rainfall data for the Bengal Coastal region was obtained from NOAA PSL website. Data was sourced from NOAA PSL, CMAP precipitation data provided by (NOAA/OAR/ESRL PSL, Boulder, from their website). The variable chosen was CPC merged analysis (enhanced) average daily rainfall for the months of May, June, July, August (CMAP). The advantage of this method to get rainfall over for a wide area, just by giving latitude and longitude. The system subsets the wide area data in a color coded format, rainfall data is provided in mm/day. The values are calculated using a combination of satellite measurements and in situ measurements calculated on a global 2.5 by 2.5 degree grid. This coastal rainfall data was used to estimate the river discharge and coastal runoff. The latitudes and longitudes taken into consideration were (21, 22.5 and 87, 88).

**Dependant variable**: The dependant variable is total annual marine catch (1998-2018) of West Bengal.

**Fish landings data:** The annual landings data was obtained from Handbook of state fisheries published by the state fisheries department, for the years 2002-2018. Data for the years 1998-2001 has been sourced from the handbook of fisheries statistics (ministry of fisheries and agriculture). The estimate was arrived by sampling done at multiple landing centers like Digha, Shankarpur, Bakhali, Fraserganj, Namkahana, Kakdwip, Bakhkhali etc, (Handbook of Fisheries Statistics, 2014). The catch has been largely stable for the last 20 years, following a period of rapid growth due to intensive mechanization of the catch in the 90s, hence total volume of catch has been taken for 1998-2018, where

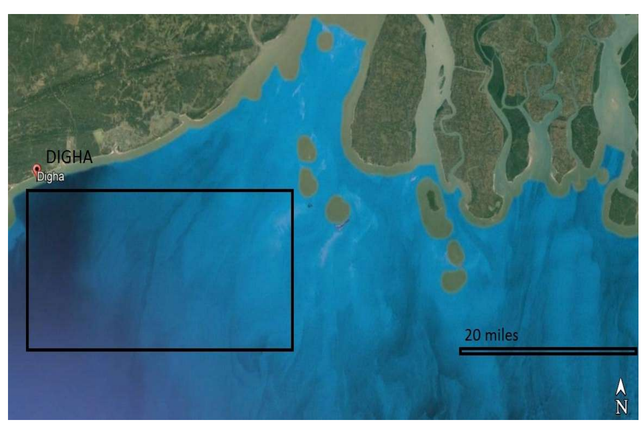


**Fig. 1.** Digha coastal area

the catch can be said to be dependent on environmental factors only. Most of the statistical computations were performed with SPSS software.

**Digha coastal area**: Digha along with Shankarpur are two of the major zones for marine fish in coastal west Bengal. Digha is close to the Hooghly estuary on the right as well the river Subarnorekha on the left. The Black boxed area represents the area chosen for calculation of average Chla concentration, this area represents the area in which most of the mechanized fishing takes place.

## RESULTS AND DISCUSSION

**Multivariate relationship using Cobb Douglas Model:** The dependent variable is annual catch (1998-2018) and the independent variables are Chl a, and rainfall. The widely used Cobb Douglas model ( Najimuddin and Sathiadas 2007, GG et al 2016) was used to model the relationship between catch and the independent variables rainfall, SST and Chl a. The Model can be defined as the form Y (output )= $kA^{a1}B^{a2}$ (k is a constant, A, B inputs, a1, a2 are the parameters ).

In Linear multivariate form, can be represented as Log Y=Logk+a1logA+a2LogB. Using Method of least squares (OLS method). The Model equation was estimated to be Y (catch) =98.6Rain$^{0.187}$Chla$^{0.09}$, where Y (catch) is in 1000 tonnes. Rainfall is in mm/day, Ch la = mg/m$^{-3}$.

**Model summary:** R=0.667 R$^{sq}$=0.44, Adj R$^{sq}$=0.378 ,S. E =0.042,(p<0.01). N=20. Both rainfall and Chl a are positively related to total catch. From the multivariate relationship, it follows that a 100 % increase in Chl a and rainfall will result in a 9% and 19% increase in the catch respectively.

**Relationship between rainfall and annual catch**

Model of rainfall (R) with total catch.

**Model equation:** Y=107.5R$^{0.23}$, Y (catch) in 1000 tonnes. Rainfall=mm/day.

**Model summary**: R= 0.48, R$^{sq}$=0.23, S.E =0.04 , N=20. There is a significant positive bivariate relationship (p< 0.04 ) between 4 months average rainfall and total annual catch. From the regression equation, 100 percent increase in rainfall will lead to increase of catch by 23 %.

**Relationship of Chla with annual catch**:

**Model equation:** Y=144.3Chla$^{0.11}$. Y (catch) in 1000 tonnes.Chla: mg/m$^{-3}$.

**Model summary:** R=0.53,R$^{sq}$=0.28 ,S.E=0.044,N=20.

There is a statistically significant positive relationship (p< 0.02), between Chl a and total catch. The null hypothesis that there is no significant statistical correlation between total catch and Chl a, can be rejected (95% level). An 100 % increase in the quantity of Chl a will result in the 11 % increase in total catch. It can concluded that among the independent variables Chl a has the greatest variation, followed by rainfall.

The positive correlations between catch and Chl a, and catch and rainfall were e significant at 0.05 level. From the multivariate relationship (Fig. 1), there is a statistically significant correlation between annual marine fish landings as dependent variable, and monsoon rainfall and post monsoon Chl a as independent variables. The positive relationship between runoff / river discharge and primary productivity/marine fish landings in coastal ecosystems is well established. These contribute essential nutrients like nitrates, phosphates, and silicates into the coastal ocean. In coastal tropical regions because of high sea temperatures,

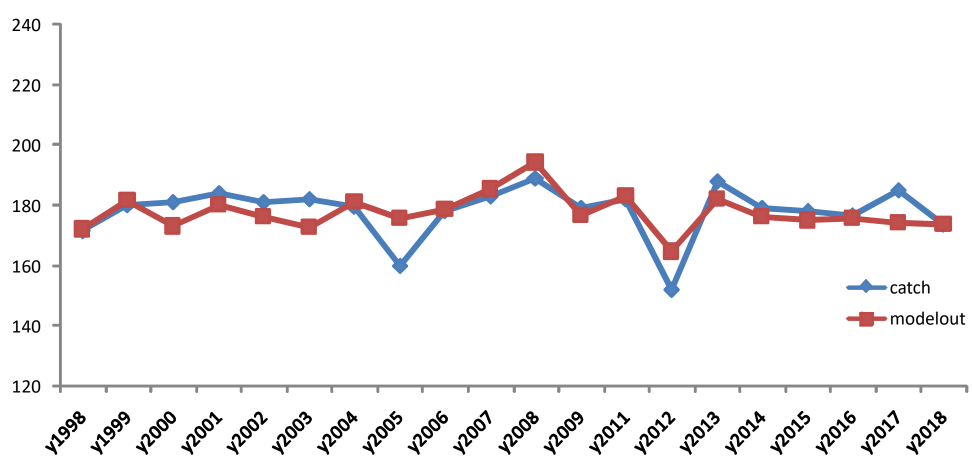


**Fig. 2.** Multivariate relationship of total catch (1998-2018 ) with rainfall and Chl a. Annual catch, Model output is in 1000 tonnes

ocean productivity is relatively less and more dependent on coastal runoff and discharge. Monsoon rainfall (4 months average), over a wide area( 21 N,22.5N,87 E,88 E), has been used to estimate the variation in discharge and runoff. Monsoon rainfall generally contributes significantly to the runoff and discharge in the Ganges system, (Jian et al 2009). There is discharge into the coastal waters of Bengal not only from the Ganges system but also from the Subornorekha system, near Digha. The inflow of nutrients from the Ganges Brahmaputra System leads to an increase of primary productivity from the month of August-September (Das et al 2015). The post monsoon season contributes to majority of the fish landings (Mini and Kuriakose 2013). The monsoon rainfall also contributes to migration of fishes like Hilsa and Bombay duck. According to a study in the Rhone River delta, apart from dissolved nutrients, there is a linkage between benthic productivity and particulate organic matter (POM) in the freshwater discharge. The POM content in the river water in the deltaic regions contributes to a food source for benthic invertebrates like prawn and polychaete worms (Darnaude et

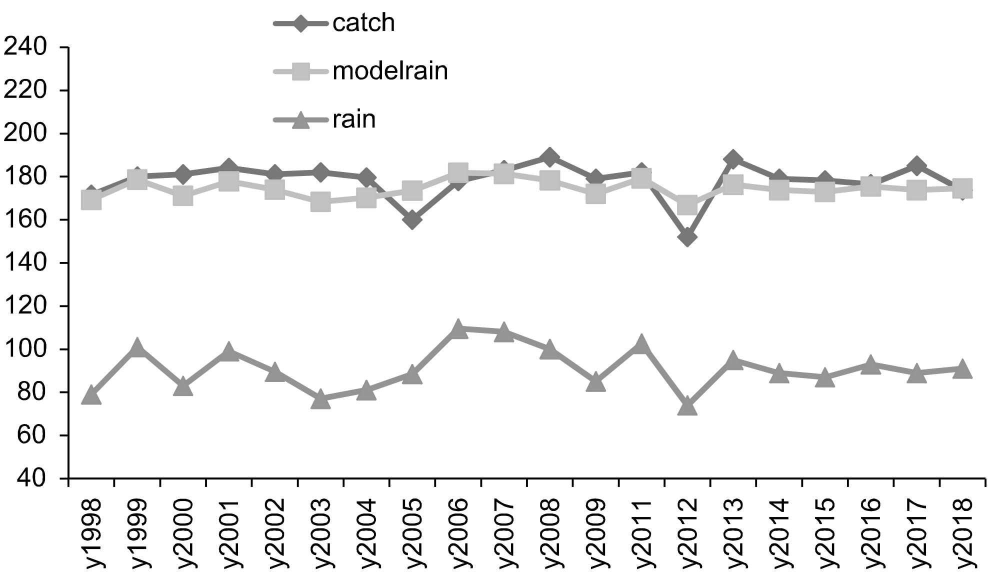


**Fig. 3.** Model output (with rainfall as independent variable), Catch (1998-2018 ) and rainfall. Catch and model output is in 1000 tonnes. Rainfall is in 0.1 mm/day

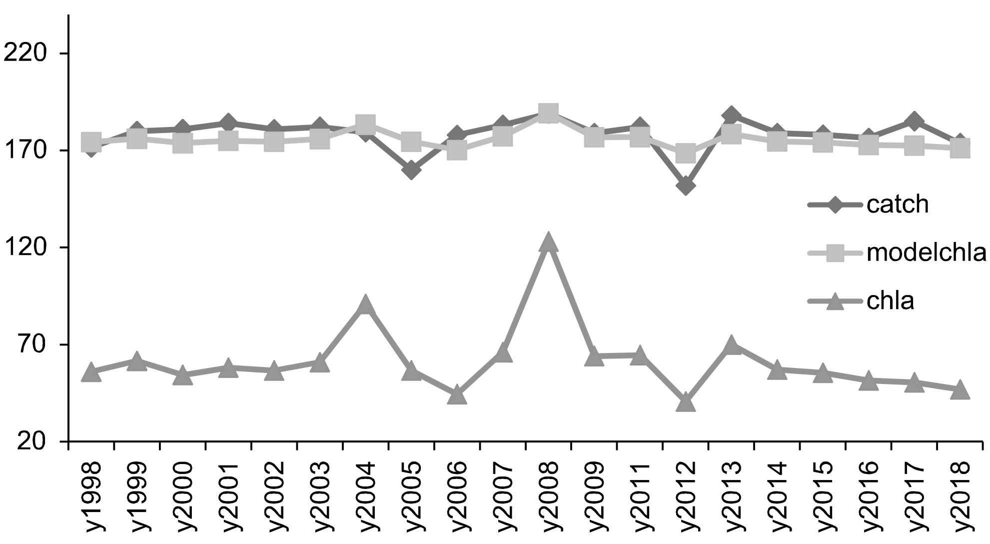


**Fig. 4.** Annual catch (1998-2018), model output (with Chl a as independent variable ), and Chl a (2 months average , Nov-Dec ). Catch and Model outputin 1,000 tonnes. Chla in 0.1 mg/m$^{-3}$

**Table 1.** Experimental details of various parameters

| Variable | Units | Latitude and Longitude | Years | Months |
|---|---|---|---|---|
| Chl a, 4 km | $mg/m^{-3}$ | (21.11 N,21.28 N ,87.11 E,87.46 E) | 1998-2018 | November-December |
| Rainfall (CMAP) | mm/day | (21 N,22.5 N and 87 E, 88 E) | 1998-2018 | May-August |
| Annual catch | Tonnes | | 1998-2018 | Annual |

**Table 2.** Cobb Douglas model parameters

| Parameter | Value | P-value |
|---|---|---|
| Rainfall | 0.187 | 0.044 |
| Chl a | 0.09 | 0.02 |

**Table 3.** Mean and standard deviation of rainfall, Chl a and total catch

| Variable | Units | Mean | Standard deviation |
|---|---|---|---|
| Total catch | 1000 tonnes | 178 | 8.74 |
| Rainfall | mm/day | 9.1 | 0.99 |
| Chl a | $mg\ m^{-3}$ | 6.12 | 1.78 |

**Table 4.** Correlation Matrix

| | Rainfall | Chla | Catch |
|---|---|---|---|
| Rainfall | 1 | 0.168 | 0.47 |
| Chl a | 0.013 | 1 | 0.478 |
| Catch | 0.47 | 0.478 | 1 |

al 2004). Since there are significant number of benthic species in the Bengal delta and coastal region, it is quite possible that this pathway contributes to the production of benthic species in the region.

The second significant variable is Chl a. High values of Chl a in surface waters is used as a proxy for plankton biomass, and primary productivity, which in turn enhance secondary productivity and landings of marine nekton. Average value of Chl a (MODIS 4km, OCI algorithm) was taken of November and December. These months were chosen because of a high percentage of noise free data during these months. November and December are also are ideal for plankton growth, because of low turbidity, adequate nutrients, and low SST. A higher value of SST leads to stratification, resulting in decreased productivity, also increased temperatures lead to fall in dissolved oxygen. The Chl a concentration in the coastal waters of this region starts increasing from August on an average (Jutla and Akanda 2011). The highest values are in the months of October, November and December in a typical year. The significant positive relationship with Chl a also validates the concept Of PFZ(Potential fishing zone), of INCOIS, in which remotely sensed Chl a and SST is used to prepare maps of productive ocean areas (Nammlawar et al 2013). Previous research has indicated that inverse relationship between Chla and SST (Chaturvedi and Pandya 2016, Kumar and Swapna 2016). Hence, climate change, leading to SST rise is likely to affect Chl a and hence catch. In conclusion there is a positive significant correlation of both rainfall and Chl a with annual catch, which is borne out by the multivariate relationship (Table 4).

## CONCLUSIONS:

There is a positive significant correlation at both the multivariate as well as bivariate level between Annual catch as dependent variable and rainfall and Chl a as independent variables. As a consequence of climate change, there might be changes in rainfall and SST, which will affect the total catch .Since Chl a is negatively correlated with SST, SST rise due to climate change will have an negative impact on the catch .It is evident that despite limitations in accuracy of remotely sensed values atmospheric and oceanographic variables, they can be used for quantifying annual marine fish landings in West Bengal, which are of considerable economic importance to the state of West Bengal.

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# Recurrence of Dinoflagellates, *Noctiluca scintillans* Bloom and Impact on Marine Faunal Communities of Mandapam Coastal Waters in Gulf of Mannar, Southeast Coast of India

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***Abstract***: Massive blooms of *Noctiluca scintillans* reoccurred at several regions of Mandapam coastal waters between $22^{nd}$ September and $30^{th}$ September, 2020. Bloom lasted for nearly one month, causing mortality of fishes and other marine organisms by facilitating hypoxia condition in the water column. Fifteen locations in four areas, namely Hare Island, Vedhalai seashore, Seniappadarga, Pudhumadam and Manoli Island have been surveyed thoroughly to understand the bloom's intensity and its impact on marine biota. Mass mortality of marine organisms was reported during this survey including fishes, octopus, sea cucumbers, sea anemones, crabs and sea shells due to the bloom incidence. A total of 371 numbers of marine organisms were dead during the bloom. The cell density of *N. scinitillans* bloom was $14.7 \times 10^5$ cells $l^{-1}$ in core dense area, $8.6 \times 10^5$cells $l^{-1}$ in semi-dense area, $0.47 \times 10^5$cells $l^{-1}$ in less dense areas, and 1440 cells $\times$ $l^{-1}$cells in clear water. Physicochemical parameters measured in the bloom region were sea surface temperature 32.3°C, Salinity 35.78ppt, dissolved oxygen 4.61 mg/l and pH 7.11 ± 1.02, Phosphate 2.831µM, Nitrate 2.407 µM and ammonia 31.324µM. The high level of phosphate triggers the growth of algal bloom which results in sudden drop of dissolved oxygen and triggers the death of fishes and marine invertebrates in the bloom regions. There is no adverse impact found on scleractinian corals. Post bloom investigations are underway to report the further adverse effect on the ecosystem's marine resources or resilience to recover from the sudden natural damage.

***Keywords:*** Algal bloom, *Noctiluca scintillans*, Cell density, Nutrient, Sea surface temperature

Several colossal green colour patches were observed on $22^{nd}$ September 2020 at different places of Mandapam coastal waters. The same dinoflagellate species bloom was documented last year on $11^{th}$ September. Microscopic observations of collected samples confirmed *N. scintillans* bloom. The same bloom incident was recorded in the last year from Mandapam coastal waters during September months which last for 14-17 days and causes mass mortality of fishes near to Krusadai Island. *N. scintillans* is a common bloom-forming dinoflagellate in the World Ocean, considered as toxic to the marine organisms, especially for caged fishes (Smyda 1997, Vijayalakshmi et al 2018). Generally, these microscopic heterotrophic unarmoured dinoflagellates are colourless, but they appear as green in colour due to the presence of endosymbiotic free-swimming cells of *Pedinomonas noctilucae* (Gomes et al 2014). The persisting occurrence of *N. scintillans* blooms were well documented in India, including the Arabian Sea (Sulochona et al 2014), Gulf of Mannar (Gopakumar et al 2009, Anatharaman et al 2010, Shanmugaraj et al 2019), Andaman and Nicobar Islands (Dharani et al 2010), Southwest coast of India (Vijayalakshmi et al 2018), and Rushikulya river of Bay of Bengal (Mohanty et al 2007). The present report of *Noctiluca* blooms was more intense near the shore of the mainland than the offshore Islands, which may be a warning sign for the future cage culture practices. This study aimed to highlight the density of the bloom, the role of physic-chemical parameters on the bloom formation, and the impact of bloom on coral reefs.

## MATERIAL AND METHODS

Bloom water samples in triplicate were collected from five selected areas of the Mandapam region, namely Hare Island, Vedhalai seashore, Seniappadarga, and Pudhumadam. Locations were marked using a GARMIN e-TREX handheld GPS device (Table 1 & Fig.1). The collected samples were preserved in 8% formalin solution for further analysis. Physico-chemical parameters of the bloom water samples were analyzed using Manta 2+ multi-probe water quality parameters snode (pH, temperature, $DO_2$, salinity, nitrate, phosphate, and ammonia). *N. scintillans* cells were counted on Sedgwick-rafter counting chamber under 4x and 10x magnification in Lynx binocular microscope. Bloom density was calculated in *Noctiluca* cells per litre. Based on the cell density, the intensity of the bloom was categorized into four groups called core-dense area (CD), semi-dense area (SD), less-dense area (LD), and clear water (CW). Photographic evidence of the impact of bloom on coastal fauna and coral reefs health status was recorded using NIKON W300 underwater camera.

## RESULTS AND DISCUSSION

The coastal water of the Mandapam region appeared in green patches during the bloom period. Water samples analysis revealed the bloom forming dinoflagellates *Noctiluca scintillans* (Fig. 2). The cell density of *N. scintillans* varied at different study sites. The average size ranged from 270 - 1120µm. Cell density of the CD area was 14.7 x $10^5$, 8.6

**Table 1.** Coordinates details of study area

| Location | GPS coordinates |
|---|---|
| Hare Island | N09°12.638' E79°04.796' |
| | N09°12.393' E79°05.378' |
| | N09°12.632' E79°05.654' |
| Vedhalai | N09°15.562' E79°06.195' |
| | N09°15.154' E79°06.011' |
| | N09°14.669' E79°05.908' |
| Seniappa Darga | N09°15.446' E79°02.572' |
| | N09°15.436' E79°02.444' |
| | N09°15.409' E79°02.217' |
| Pudhumadam | N09°15.415' E79°00.614' |
| | N09°15.542' E79°00.915' |
| | N09°15.405' E79°01.120' |
| Manoli Island | N09°11.412' E79°06.732' |
| | N09°11.806' E79°08.193' |
| | N09°11.608' E79°06.959' |

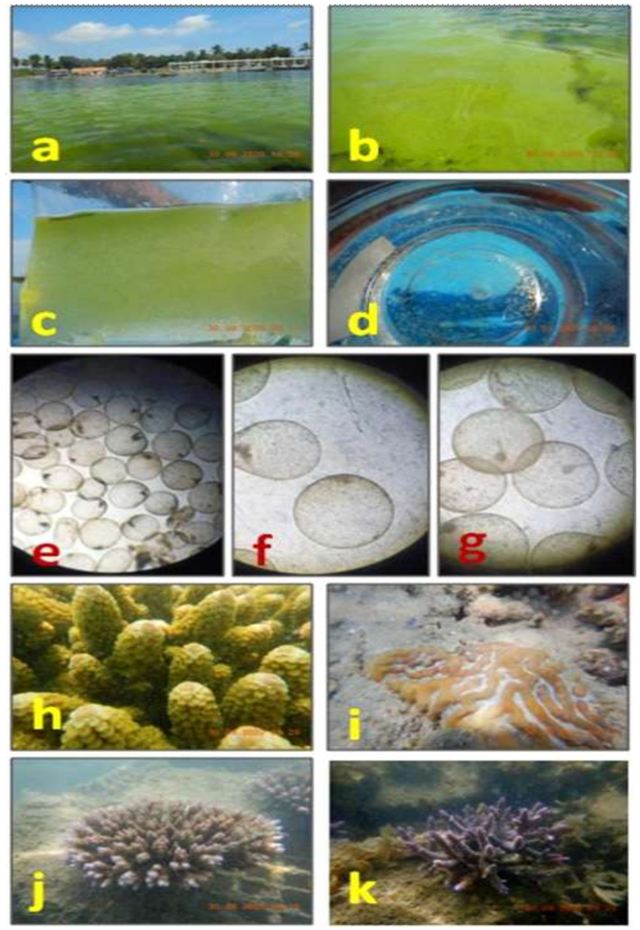


**Fig. 2a-d:** Field observation of *Noctiluca* bloom; e: Microscopic observation of *Noctiluca* cells (4X magnification); f-g: Microscopic observation of *Noctiluca* cells (4X magnification); h-i: Healthy coral colonies in the natural site during bloom; j-k:Healthy coral colonies in restoration site during bloom

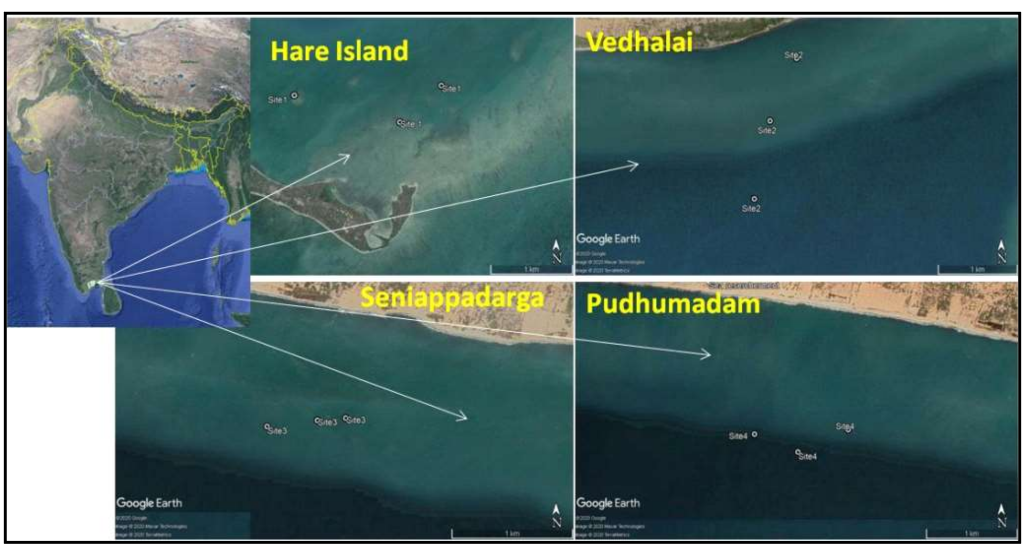


**Fig. 1.** Map showing the study area

x $10^5$ in SD, 47 x $10^3$ in LD and 2840 cells $l^{-1}$ in clear waters. Among all the study sites, Vedhalai seashore showed the maximum bloom density with 19 x $10^5$ cells $l^{-1}$(Fig. 3). Massive mortality of fish death documented from Pudumadam, Seniappa Darga and southern side of the Manoli Island. Semi-dense bloom was observed near Hare Island, which doesn't have any adverse effect on the coral reefs (Fig. 2). The bloom was more intense on 24th, 25th, 26th in Vedhalai seashore, and 28th, 29th was in Pudhumadam. The bloom intensity was declined after 29th September, and on 30th September Based on field observation, bloom was concentrated up to 1.7m depth, and no bloom formation was found beyond 2m. Coral reef Monitoring in natural and restored sites revealed the unaffected, normal and healthy state of corals found in reef sites.

A total of 310 dead specimens were counted from the mainland coast of which fishes are 84.19%, crustaceans are 7.74%, Echinodermata 2.90%, Mollusca 2.26%, Sea anemones 1.61% and sea snakes are 1.29% (Fig. 4). Among the fishes, 22 different families were dead due to this bloom effect. Based on the field observation and statistical analysis, mortality was major for Puffer fish (Tetraodontidae) 17.24%, snake eel (Ophichthidae) 9.96%, Parrot fish (scaridae) 9.96% followed by Silver sillago (Sillaginidae) and Moray eel (Muraeinidae) 7%, (Fig. 5). In southern side of the Manoli Island, 61 marine organisms were dead in the bloom area which includes 74% of fishes, 21% of Octopus, 2% of Jellyfish and 3% of Sea cucumber. Among the fishes, mortality of scaridae (Parrot fish) family fishes was 24%, Lathrinidae (Emperor fish) was 13% followed by Lutjanidae (Snappers), Siganidae (Rabbitfish), Tetraodontidae (Porcupine fish), Muraenidae (moray eel) and Balistidae (Triggerfish) (Fig. 6, 7 & 8). Bloom in several places of Manoli Island was found to be decomposed by the bacteria and settled down to the bottom which causes a serious change in the oxygen level of the water and it causes the death of marine organism specially those lives inside the rocks or underneath of the rocks such as eel, groupers, octopus etc.

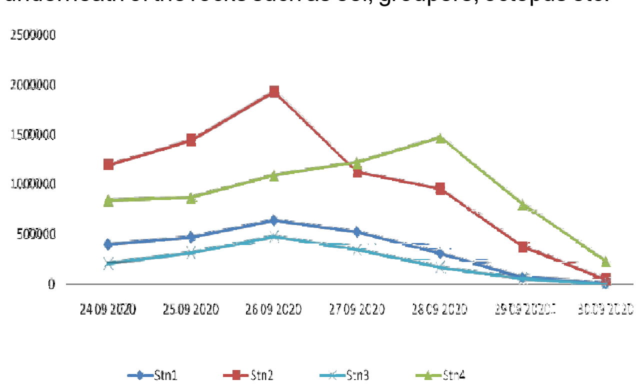


**Fig. 3.** Day-wisecell density of *Noctiluca scintillans* in GoM

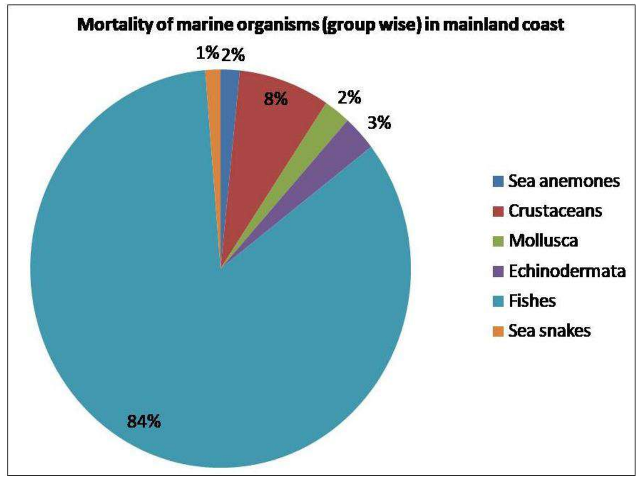


**Fig. 4.** Mortality of marine organism in mainland coast

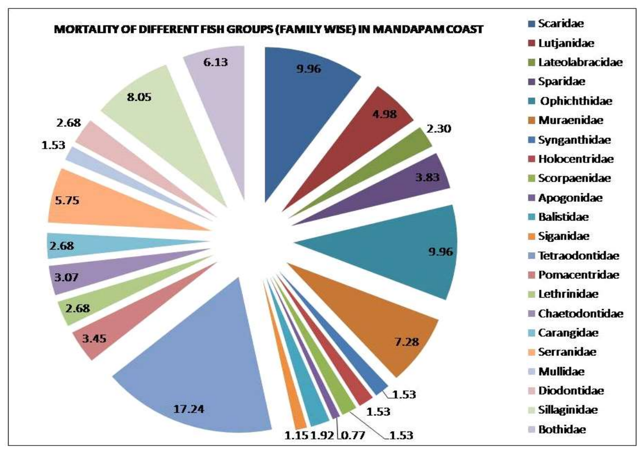


**Fig. 5.** Mortality of different fish families recorded in Mandapam Coast

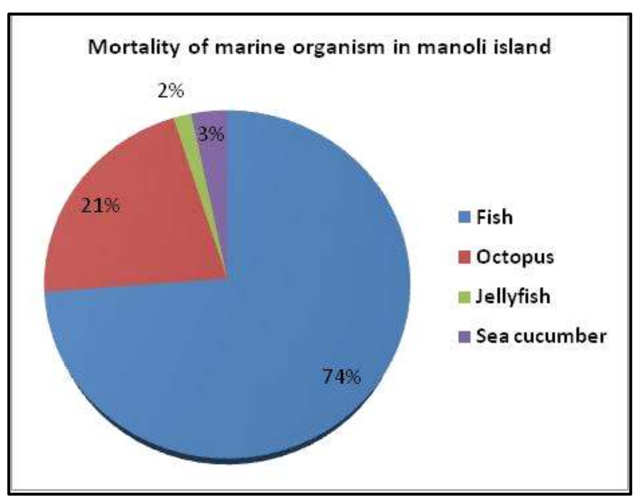


**Fig. 6.** Mortality of marine organism in Manoli Island

Nutrient analysis of the water samples collected from bloom affected area reported that phosphate level ($PO_4^{3-}$) was high 2.831 μM, while nitrate ($NO_3^-$) and ammonium ($NH_4^+$) contents were under the optimum limit. During the warning phases, the environmental parameters are SST 33.2°C, pH was 7.2, and $DO_2$was 4.61mg/l (Table 2). The presence of a high amount of nutrients in the water lowers the concentration of oxygen and causes asphyxiation. The low level of oxygen in water caused by *Noctiluca scintillans* bloom is the major cause of fish death and other marine organism in Mandapam waters. The sudden increase of phosphate content triggers the *Noctiluca* bloom, which might be occurred in present study (Montani et al 1998). Heavy wind and strong current patterns appear to disperse the *Noctiluca* bloom from the Mandapam region to the southern part of Sri Lanka. Gopakumar (2009) observed the transition period between summer and monsoon in GoM is exposed to high wind variable and strong monsoon driven currents and within 7 days, a sharp decline of *Noctiluca* cell density was observed (12-14 x $10^5$ cells $l^{-1}$ to 2-9 x $10^3$ cells $l^{-1}$).

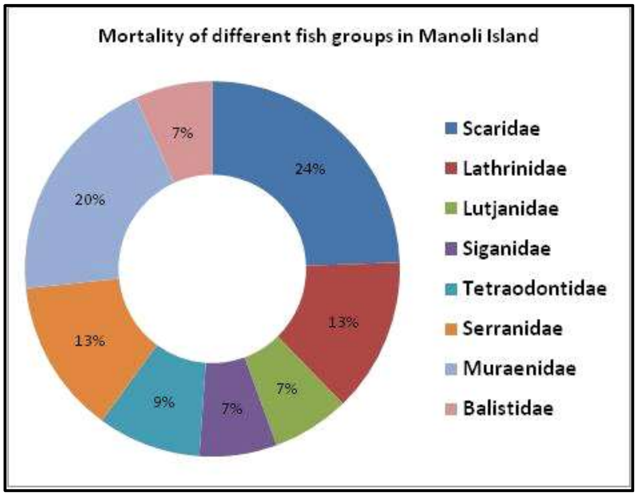


**Fig. 7.** Mortality of different fish groups in Manoli Island

Physicochemical parameters during the intense bloom formation were not drastically changed. Consistent monitoring of water quality parameters revealed no sharp changes in the $DO_2$, as documented by Eashwar et al (2001). Average $DO_2$ content was between 4.61mg/l to 4.88 mg/l (Table 1). The earlier report strongly supports our present observation of high SST in Mandapam regions could have triggered *Noctiluca* to form intense bloom in the Vedhalai seashore and Pudhumadam area (Gopakumar 2009). Based on visual observation, constant current between Manoli and Hare Island channel might reduce the massive accumulation of *Noctiluca* cells. Therefore, bloom appeared in Hare Islands as less dense (LD) and clean water (CW). Although several reports concluded that nutrient enrichment causes algal


**Fig. 8a-e.** Mortality of marine organism found in southern side of the Manoli Island, f-l: mortality of fishes and crabs photographed in Pudumadam area of Mandapam village

**Table 2.** Water quality parameters of study sites during Noctiluca bloom (Mean± SD)

| Study area | pH | SST | Salinity | $DO_2$ |
|---|---|---|---|---|
| 1 | 7.00±0.30 | 30.02±0.06 | 35.24±0.22 | 5.21±0.08 |
| 2 | 7.13±0.09 | 31.81±1.02 | 35.17±0.36 | 5.10±0.10 |
| 3 | 7.45±0.02 | 31.77±0.07 | 35.82±0.19 | 6.07±0.13 |
| 4 | 7.30±0.03 | 30.16±0.45 | 35.55±0.10 | 5.43±0.75 |
| 5 | 6.11±0.09 | 30.41±0.09 | 36.00±0.32 | 4.11±0.30 |
| 6 | 6.27±0.11 | 31.28±1.00 | 35.89±0.45 | 4.72±0.05 |
| 7 | 8.00±0.07 | 31.70±0.06 | 36.09±0.19 | 5.09±0.21 |
| 8 | 8.10±0.01 | 32.61±0.54 | 35.22±0.07 | 5.89±0.15 |
| 9 | 8.25±0.04 | 32.44±0.06 | 35.17±0.21 | 6.10±0.22 |
| 10 | 7.75±1.07 | 31.47±0.49 | 34.89±0.14 | 5.29±0.50 |
| 11 | 8.90±0.07 | 31.81±0.19 | 34.77±0.11 | 4.76±0.12 |
| 12 | 8.02±0.03 | 31.99±0.26 | 34.61±0.09 | 4.00±0.28 |
| 13 | 7.38±0.15 | 32.19±0.12 | 35.51±0.35 | 3.42±0.42 |
| 14 | 8.02±0.09 | 32.00±0.24 | 35.24±0.12 | 3.00±1.54 |
| 15 | 8.12±0.17 | 32.19±1.06 | 35.06±0.27 | 2.53±0.90 |

bloom and, as a consequence, it adversely effects on coral reefs, there is also some other cases where corals respond positively to the higher nutrient concentration in water in terms of growth, survival, and resistance to bleaching (Bongiorni et al 2003, McClanahan et al 2003, Dunn et al 2012, Aouititen et al 2021). In the present study, no mortality of corals was observed during the survey, and no information on marine mammal's death was reported from local fishermen communities. In summary, the repetitive occurrence of *Noctiluca* bloom in the Gulf of Mannar might not have any fatal effect. Still, it could increase the multiple stressors which collectively and synergistically lead to habitat change and alteration in trophic structures. Continuous monitoring of physicochemical parameters and nutrient analysis could identify algal blooms' trend and further effect on the GoM marine ecosystem.

## CONCLUSION

*Noctiluca* bloom observed in Mandapam Coastal Water is unique because it appeared twice within a gap of one year at the same time which earlier never reported from this region. The repeated bloom occurrence causes severe impact on marine faunal communities especially on fishes and marine invertebrates of Gulf of Mannar which leads into an economic loss to the coastal communities of Gulf of Mannar. The present study doesn't find any impact on scleractinian corals which provides a sign of reef resilience and a hope of healthy reef recovery after this fatal bloom incident.

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# Evaluation of Cooking and Physico-Chemical Properties of Rice

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***Abstract***: A study was undertaken to compare cooking properties, physico-chemical parameters and sensory quality attributes of white rice, brown rice, quick cooking white rice and quick cooking brown rice. Freshly harvested paddy of *Prativa* variety was milled in rubber roll sheller and polished in laboratory polisher to get brown rice and white rice. Quick cooking white rice and brown rice were prepared by pressure cooking followed by refrigerated storage at 4°C for 24 h and drying at 90°C. The decrease in cooking time of quick cooking brown rice (9.66 min) and quick cooking white rice as compared to brown rice (25.66 min) and white rice respectively was due to gelatinization of starch during cooking and development of cracks and porous structure during drying. Higher water uptake ratio and volumetric expansion ratio with lower solid loss were observed in quick cooking white rice and quick cooking brown rice as compared to corresponding white rice and brown rice sample. The minimum peak viscosity of quick cooking brown rice was less (726cP) which was followed by quick cooking white rice respectively. The bio-chemical parameters of quick cooking brown rice were found to be more than quick cooking white rice.

***Keywords***: Brown rice, Quick cooking rice, Pasting properties, Amylose content, Gamma-aminobutyric acid

Demand for brown rice (BR) is increasing because for nutritional excellence and health benefits. BR contains numerous nutritional and bioactive components including dietary fiber, functional lipids, amino acids, vitamins, phyto-sterols, phenolic compounds, gamma-aminobutyric acid (GABA) and mineralsbecause the presence of intact bran and embryo. In rice, polyphenols are mainly associated with the pericarp, which is removed during processing to obtain polished grain (Zhou et al 2003).Gamma-aminobutyric acid (GABA), which is a non-protein free amino acid having high biological activity including pharmacological functions and neuro-transmitter in the brain and spinal cord of mammals (Tiansawang et al 2016). Bahadur (2003) reported that it is better to eat unpolished (brown) rice, because the outer bran layer of the rice grain, which is removed during the milling process, is rich in fiber, iron, vitamins and minerals. Though brown rice contains more nutritional components, white rice (WR) is primarily consumed by the people (Lamberts et al 2007). Brown rice is not favourite to consumers due to its poor cooking and eating qualities with dark colour and unpalatable texture, which are attributed to the presence of tough fibrous bran layer (Das et al 2008). There is significant increase in the consumption of ready-to-eat rice and the market for such product is growing fast. The accelerated pace of modern life has promoted new ways to consume rice in the form of instant or quick cooking rice, which is fully or partially cooked and dehydrated. Instant rice is pre-cooked rice which is rehydrated or cooked before being served and quality of rice after rehydration is very important for consumer acceptability. Rice kernels are soaked before cooking to reduce cooking time, then cooked for starch gelatinisation and dried to a low stable moisture content to produce instant rice. Soaking, cooking and drying process affected the physical and cooking qualities of quick cooking rice (Sirisoontaralak et al 2015). Quick cooking white and brown rice are novel convenient rice product which can be prepared with improved cooking, eating and nutritional quality to cater the need of modern food market. Though many works have been carried out on quality evaluation of white rice and brown rice, study on comparison of quick cooking white rice and brown rice is scanty. So, the present study was undertaken to compare the cooking and physico-chemical qualities of white rice, brown rice, quick cooking white rice and quick cooking brown rice.

## MATERIAL AND METHODS

Freshly harvested paddy of *Prativa* variety was collected from the Central Farm of Odisha University of Agriculture and Technology, Bhubaneswar. Paddy was first cleaned and graded in a cleaner-cum-grader to remove all foreign matters and immature grains. Paddy samples were dehusked using rubber roll sheller (MG make) followed by aspiration to obtain brown rice. The brown rice (BR) was polished to 6% degree of polish in a laboratory rice polisher (Satake make) and aspirated for 30 to 60 seconds to obtain white rice (WR). The obtained brown rice and white rice were cooked in a domestic pressure cooker at 1 bar gauge pressure until 90 % gelatinization was obtained. The cooked white and brown rice were washed and kept at 4°C for 24 h inside a household refrigerator. The samples were then taken out, tempered for 1 h and subsequently dried in hot air dryer at 90°C to get quick cooking white (QCWR) and brown rice (QCBR). The rice samples obtained were analysed for cooking and physic-chemical quality parameters for comparison.

**Cooking properties:** In a 20ml of distilled water, 2g of sample is taken, kept for boiling recording the time when 9-10 kernels of the rice samples were fully gelatinized then cooking time of the sample is determined(Singh et al 2005). Water uptake ratio of the rice is calculated by the ratio of increase in weight to the initial weight of the sample (Singh et al 2005). The gruel was taken in petridish and oven dried at 105°C until constant weight to determine the solid loss (Singh et al 2005). The volume expansion ratio was calculated by taking the ratio of volume of cooked rice sample to that of initial volume of uncooked rice measured by water displacement method (Patil and Khan 2012)

**Physical Properties**

**Pasting properties:** The pasting properties of the rice samples were measured using a rapid viscoanalyer (MCR 72, Anton Paar, Austria) (Klein et al (2013). Rice samples were ground in a willey mill to 100 micron size and 3 g of rice powder in 25ml distilled water was taken in the aluminium canister. The samples were held at 50° C for 1 min, heated from 50 to 95°C in 3.5 min, held at 95°C for 2.5 min followed by cooling to 50°C in 4 min, and finally held at 50°C for 2 min. the pasting properties namely peak viscosity, peak temperature and Final viscosity were recorded.

**Scanning electronic microscopy (SEM):** Starch granule morphology and size distribution were determined using a scanning electron microscope (s-3400-II, Hitachi, USA) at 2.125 keV. The samples were placed on an SEM stub by double-backed cellophane tape. The stub and sample were coated with gold-palladium, then examined and photographed (Ghasemi et al 2009).

**Determination of bio-chemical parameters:** About 0.5 g of rice sample was soaked for 30 minutes and cooked for 15 minutes in 3 ml of water. Amino acids were extracted from the cooked rice paste by 2.5 ml of ethanol: deionized water (7:3).Standard GABA solution and sample solutions were applied to the 10 cm x 10 cm high-performance standard silica gel plate in HPTLC. The scanned areas of the all rice samples were matched with the scanned area of the standard GABA solution and GABA content was calculated based on concentration of the standard solution (Babu et al 2011).Amylose content of rice was determined by the method reported by Williams et al. (1958). The phenolic content of the samples were quantified by the Folin-Ciocalteu methodology (Iqbal et al 2005; Singleton et al 1999) by measuring absorbance in a spectrophotometer at 765 nm and comparing with standard Gallic acid. About 0.3 g of sample was taken and 5 ml of diacid was added and kept it in the digestion chamber. Digestion tubes were heated at 150°C until the production of red $NO_2$ fumes ceased. The completion of digestion was confirmed when the liquid became colourless. After cooling of digestion tubes, the content was filtered through Whatman no 1 filter paper and the volume was made 50 ml by adding distilled water. Aliquotes of this solution were used for the determination of Calcium, Iron, Zinc and Magnesium content by using ICP-OES (Inductively Coupled Plasma Optical Emission Spectrometer).

## RESULTS AND DISCUSSION

**Cooking properties:** Brown rice (9.66min)acquired the longest time to cook due to the presence of an unbroken strong bran layer. The gelatinization of starch during cooking and the creation of cracks and porous structure after drying resulted in a reduction in cooking time for QCBR and QCWR when compared to BR and WR, respectively. Because of the bran layer, the cooking time of QCBR was much longer than that of QCWR. Due to the presence of an impermeable bran layer, the water uptake ratio of BR (2.17) was found to be higher than that of WR (3.38). In QCBR and QCWR, there was a significant increase in WUR. In comparison to WR (2.66), leaching of soluble compounds from the bran layer resulted in increased solid loss from BR (6.26). Solid loss from QCBR and QCWR was found to be lower than the raw sample, which could be attributed to starch gelatinization during cooking, which seals cracks. The leaching of a significant amount of amylose and other soluble chemical components before during the cooking process of quick cooking rice preparation may account for the significant drop in solid loss values of QCBR as compared to BR.

The volume expansion ratio of different rice samples varied significantly from each other ($p < 0.05$). The lowest volume expansion was observed in BR (2.17±0.06) as the intact bran layer restricted expansion of kernel. Volume expansion ratio of QCWR (4.45±0.05)and QCBR were found to be significantly higher than WR and BRrespectively is presented in Table 1.

**Physical Properties of Rice Samples**

**Pasting properties:** Pasting viscosity of starch relates to the cooking and eating quality of rice. The amylographs of flours from WR, BR, QCWR and QCBR are shown in Figure 1. The peak viscosity (PV) of white rice (2119cP) was highest followed by QCWR (1091), BR (1044) and QCBR (726) (Table 2). Break down (BD) viscosity was absent in QCWR and QCBR due to the presence of degraded starch. However, Break down viscosity of BR (187.5 cP) was less than white rice (828.1 cP). Peak viscosity and final viscosity values of BR were less than WR due to the presence of bran which is rich in fat content.Peak viscosity decreased in all quick cooking rice samples due to the presence of gelatinized starch. Setback viscosity of quick cooking white rice was found to be more than WR. Similar results of higher peak viscosity and lower setback viscosity in white rice than brown rice was also reported by Wu et al (2018).

The viscosity-time curves of white rice and brown rice flour were of similar pattern, whereas quick cooking rice from WR and BR showed similar behavior. The viscosity decreased slightly after attaining a peak value during heating phase in WR and BR, whereas the depression was not observed in quick cooking rice from WR and BR. Cold paste viscosity were found to be more in QCWR (89.9 cP) and QCBR (50.4 cP) as compared to corresponding WR (23.6 cP) and BR (25.4 cP) indicating higher soluble compounds at low temperature. Lower pasting time and temperature were observed in quick cooking white rice as compared to other rice samples.The results are in agreement with Sirisoontaralak et al (2015), Cheevitsopon and Noomhorm (2015) and Hu et al (2017). Viscosity profile of QCWR and QCBR attained peak at hot paste viscosity and breakdowns were not visible in the QCWR and QCBR pasting profiles (Sirisoontaralak et al 2015, Hu et al 2017).

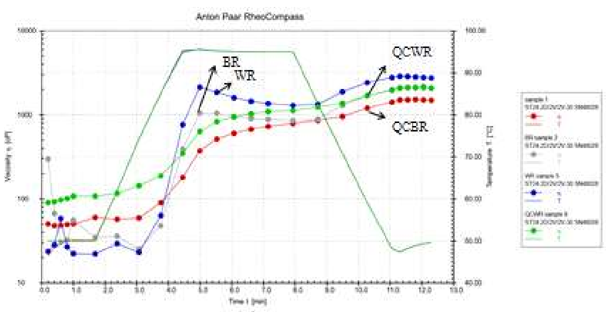


**Fig. 1.** Amylograph of different rice samples (A- Whiterice, B-Brown rice, C-Quick cooking white and D- Quick cooking brown rice)

**Surface morphology:** Morphological features of the rice samples were vary from each other at micro level (Fig. 3). The surface of white rice was rough due to the presence of irregular coarse bran layer that was removed during polishing, whereas it was smooth for brown rice due to the presence of intact bran layer. The surface of the QCWR and QCBR were be porous with higher number of voids and developed cracks which accounted for its high water uptake ratio and less cooking time. In QCBR and QCWR, the net structure between starch and protein were destroyed, reconstructed and internal texture of rice was changed greatly with fusion of starch granules into a coherent mass. During cooking of WR and BR, there was swelling, gelatinization and agglomeration of starch granules due to effect of heat treatment on moist starch granules. The starch morphology of quick cooking brown rice and white rice exhibited differences from those of brown rice and white rice due to gelatinization and retrogradation of starch during processing.

**Bio-chemical Parameters**

**Gamma-amino butyric acid content:** There was significant difference ingamma-aminobutyric acid (GABA) content among the entire rice sample. GABA content of WR, BR, QCWR and QCBR were 6.82, 11.91, 4.66 and 5.21mg/100 g d.m. (Table 3). GABA content in BR and QCBR were higher than WR and QCWR, respectively because of the presence of bran layer. Decrease in GABA content in QCWR and QCBR might be due to leaching loss during cooking process and subsequent drying. Loss of GABA content was

**Table 1.** Cooking properties different rice samples

| Sample | Cooking time (min) | Water uptake ratio | Solid loss (%) | Volume expansion ratio |
|---|---|---|---|---|
| WR | 12.33±1.74 | 3.38±0.24 | 2.66±0.11 | 4.09±0.24 |
| BR | 25.66±1.14 | 2.17±0.06 | 6.26±0.61 | 2.17±0.06 |
| QCWR | 2.66±1.77 | 3.76±0.06 | 2.27±0.25 | 4.45±0.05 |
| QCBR | 9.66±1.22 | 2.82±0.10 | 3.97±0.90 | 2.24±0.10 |

**Table 2.** Pasting properties different rice samples

| Sample | Cold paste viscosity, cP | Pasting time, min | Pasting Temp. °C | Peak viscosity, cP | Peak time, min | Hot paste viscosity, cP | Breakdown viscosity, cP | Final viscosity, Cp | Setback viscosity, cP |
|---|---|---|---|---|---|---|---|---|---|
| WR | 23.6 | 3.1 | 74 | 2119 | 4.99 | 1291.6 | 828.1 | 2751.4 | 632.4 |
| BR | 25.4 | 3.1 | 74 | 1044 | 4.99 | 856.8 | 187.5 | 2049.5 | 1005.5 |
| QCWR | 89.9 | 2.4 | 61.9 | 1091 | 7.15 | 1091 | 0 | 2085.3 | 994.3 |
| QCBR | 50.4 | 3.1 | 74 | 726 | 7.15 | 726.1 | 0 | 1490.3 | 764.3 |

**Table 3.** Bio-chemical parameters of rice samples

| Sample | Phenolic content, mg GAE/100 g d.m. | Amylose content, % | GABA content, mg/100g d.m. | Mineral content, mg/100 g d.m. | | | |
|---|---|---|---|---|---|---|---|
| | | | | Ca | Fe | Mg | Zn |
| WR | 122.55 | 26.88 | 6.82 | 2.244 | 0.446 | 1.453 | 0.073 |
| BR | 370.2 | 23.81 | 11.91 | 2.343 | 0.926 | 2.958 | 0.084 |
| QCWR | 42.3 | 19.95 | 4.66 | 2.446 | 0.348 | 1.143 | 0.076 |
| QCBR | 107.7 | 19.12 | 5.21 | 2.413 | 0.715 | 2.742 | 0.081 |

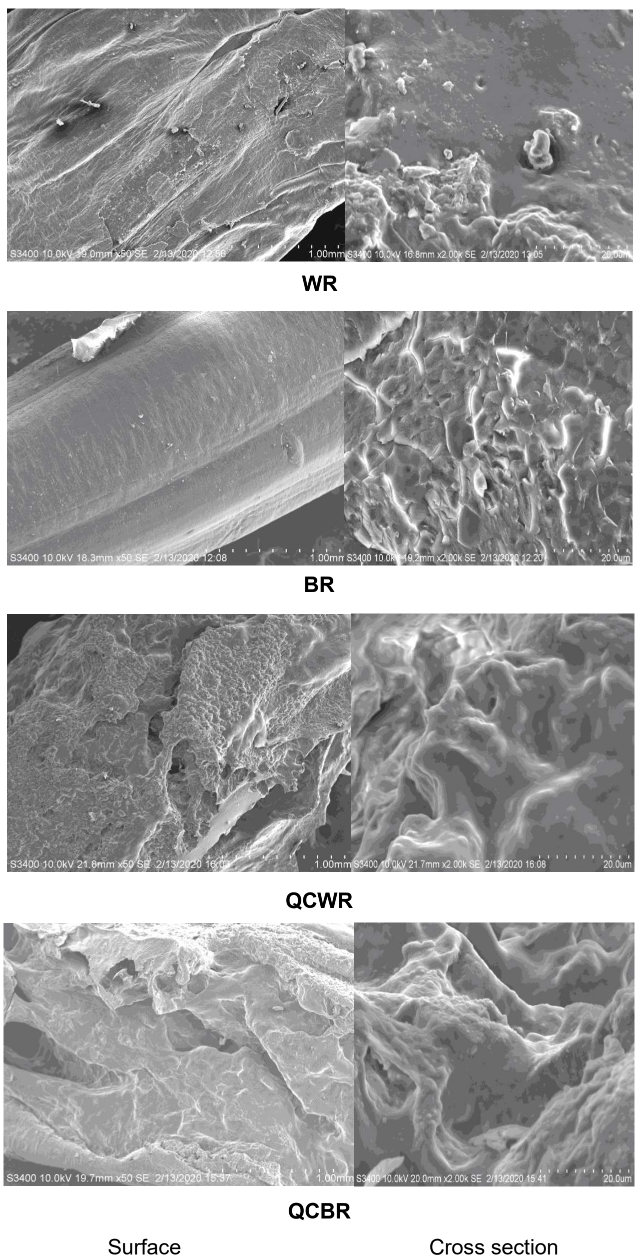


**Fig. 2.** Scanning electron micrographs of the surface and cross section of different rice samples

dependent on processing temperature (Komatsuzaki et al 2007) and Sirisoontaralak et al (2015) reported decrease in GABA content during cooking.

**Mineral composition:** Iron, Zinc and Magnesium content were more in BRdue to the presence of the bran layer. There was no significant difference in Calcium and Zinc content among the rice samples. Less mineral content in QCBR as compared to BR might be due to the loss during cooking process. Though mineral content of QCBR were less than BR, they were found to be more than WR and QCWR and presented in Table 3. Brown rice is rich source of minerals which are important for human health.

**Amylose content:** Amylose content of BR was less than WR due to the presence of bran layer. The lower values of amylose content in QCWR and QCBR samples were probably due to the leaching loss of amylose during cooking process (Table 3).

**Phenolic content:** The phenolic content of BR was highest (370.2mg GAE/100g) followed by WR, QCWR and QCBR. The lower value in WR was due to the removal of bran layer. However, lower value of phenolic content in QCBR and QCWR as compared to corresponding BR and WR samples was probably due to leaching loss during cooking process (Table 3).

## CONCLUSION

When compared to brown rice, quick cooking brown rice took less time to cook. In comparison to the WR and BR samples, the QCWR and QCBR samples had higher water uptake ratios and volumetric expansion ratios, as well as decreased solid loss. White rice has the highest viscosity values, but breakdown viscosity was missing in the QCWR and QCBR samples. The net structure between starch and protein were destroyed, reconstructed and internal texture of rice was changed greatly with fusion of starch granules into a coherent mass in QCBR and QCWR. Though mineral content of QCBR were less than BR, they were found to be more than WR and QCWR. Phenolic content and GABA content of QCBR were higher than QCWR.

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# Production of Rice Bran Wax based Biodegradable Film

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***Abstract***: Biodegradable films produced from plant source with binding agents to reduce the negative effects of non-degradable waste materials on the environment and human health. An attempt was made to prepare films by using corn starch, rice starch and rice bran wax solutions. Glycerol was added as plasticizer. The study was conducted to compare the cornstarch and rice starch films prepared with and without addition of rice bran wax. Film thickness of the treatments increased with the increase in binding agent. Highest value of thickness was observed for treatment, CS-10 g + glycerol (5 ml) as 1.21 mm. Similar trends was observed for thickness for the films prepared with rice starch. Moisture content of the films without addition of rice bran wax was higher than that of treatments added with rice bran wax. The transparency values for both corn starch and rice starch samples with and without addition of rice bran wax were reasonably less. The folding endurance test indicated that maximum number of double folds were 0.60. Biodegradability test reported that the films prepared using rice starch with addition of rice bran wax degraded faster than corn starch films with addition of rice bran wax.

***Keywords***: Rice bran wax, Corn starch, Rice starch, Biodegradable film

Most degradable plastics are made from polyethylene and contain an additive to speed up the decomposition. Depending on the composition and thickness of the material, some biodegradable plastics disintegrate quickly, whilst others take longer (Le 2020). Though many types of plastic films are available for packaging, very few with certain level of gas permeability are suitable for MAP and CAP for storage of fruits and vegetables (Gopalaswamy et al 2016). Starch is an agricultural and biodegradable feed stock biopolymer in a variety of plants such as wheat, corn, rice and potato. The starch granules consist of amylose and branching points of amylopectin molecules. A semi-crystalline granule of starch is converted into a homogeneous material with hydrogen bond broken between the starch molecules. This process is called gelatinization and it leads to loss of both crystallinity and double helices (Talja et al 2007). Starch-starch interactions are replaced by starch plasticizer interactions to strengthen the linkages in bonds.

Lipid biopolymer based coatings include waxes or long chain fatty acids and they are the most efficient compounds to reduce moisture permeability due to their high Hydrophobicity. This characteristic is justified by their high content in esters of long-chain fatty alcohols and acids along with long-chain alkanes (Khwaldia et al 2010). Glycerol is a molecule that has ability to attract water. Addition of glycerol to the starch mixture increases holding capacity of water in the starch chain making it less crystalline and thus less brittle (Le 2020). Waxes are the esters of long chain carboxylic acid and long chain alcohol (Kolattukudy 1976). Wax content in rice bran oil may vary with oil extraction conditions such as the source of the rice bran, solvent used for extraction, temperature at which extraction occurs. These waxes can be used for preparation of films. The formation of wax-in-water emulsion is enhanced by the addition of arabic gum, which serves as an emulsifier (Kim and Ustunol 2001). The added rice bran wax acts as a function modifying agent for improved water vapour barrier properties of the composite films. In view of these, the project was undertaken to produce a biodegradable film from plant source with binding agents to reduce the negative effects of non-degradable waste materials on the environment and human health with the following objectives, to prepare film solutions from plant based materials in combination with rice bran wax, to produce a biodegradable film with plant based material with binding agents, and to analyze the physico-chemical properties of the films.

## MATERIAL AND METHODS

Corn starch, rice starch glycerol was collected from the local shop in Bodhan, Nizamabad dist, Telangana state. Rice bran wax was collected from an oil refinery located at Vijayawada, Andhra Pradesh state. Glassware was used for casting of films.

**Preparation of film solutions from the rice starch (RS) and corn starch (CS):** The rice starch and cornstarch solutions were prepared for casting of films. The rice starch and corn starch solutions with and without addition of rice bran wax were studied to analyse barrier properties.

Different combinations of films were shown in Table 1. The procedure for preparation of film solutions was explained in Figure 1 and 2.

**Preparation of film solutions using rice starch with and without addition of rice bran wax:** Rice starch solutions were prepared by dissolving 2, 5 and 10g of rice starch in 100 ml, 250 ml, and 500 ml of distilled water. Glycerol was added as plasticizer. The solutions were made to gelatinize at 85˚C for 30 min and mixed thoroughly. The solutions were poured through sieve to avoid colloidal formations in the solution and subsequently cooled to ambient temperature. After preparation of rice starch solutions, 2g rice bran wax was added to some of the samples to analyse barrier properties.

**Preparation of film solutions using corn starch with and without addition of rice bran wax:** Similarly, corn starch solutions were prepared by addition of 2, 5 and 10 g of corn starch 100, 250, 500ml of distilled water (Fig. 1 and 2). Glycerol (1, 2.5, 5 ml) was also added. The solutions were made to gelatinize at 85˚C for 30 min and mixed thoroughly. 2g of rice bran wax added to samples to analyse the barrier properties.

**Preparation of casting films from rice starch and corn starch film solutions:** The rice starch and corn starch film solutions with and without addition of rice bran wax were casted by pouring the solutions into Petri dishes. The films casted with different compositions were shown in plate 3.3. A sample of 50 ml was poured in each petri dish uniformly and dried at 55 °C for 10 hours in hot air oven. After drying, the films were peeled gently and stored in desiccators.

**Physico-chemical Analysis**

**Film thickness (mm):** Film thickness was measured by the procedure given by Brodnjak et al (2018) at 5 random locations on each film.

**Moisture content (%):** Moisture content of the films was determined by assessing the weight loss upon drying. Initial weight of the films was taken, and then the films were dried at 105°C for 24 h in a laboratory oven (Nordin et al 2020). Then, the dried films were weighed to obtain the final weight**.**

**Solubility test:** Solubility test determines the ability of dissolution of the sample. In this work, solubility of film was analysed using ethanol, chloroform, diethyl ether and distilled water till five days.

**Folding endurance:** The folding endurance was calculated as (Sharmila et al 2021).

$$F = \log_{10} d$$

Where F=Folding endurance, D=Number of double folding

**Transparency (%mm$^{-1}$):** The transparency of film was recorded at 600nm by cutting the films into a rectangular piece (15 × 50 mm) and placed inside a UV-Vis spectrophotometer.

Transparency (%mm$^{-1}$)= $\frac{-\log T_{600}}{x}$, Where T600 is light transmission at 600 nm

**Biodegradability in soil:** Biodegradation was tested in soil

Take distilled water of known volume (eg: 100ml)
↓
Add starch powder (eg:2%w/v)
↓
Add the glycerol (eg:1ml)
↓
Add vinegar (eg:1ml)
↓
Gelatinize the mixture at 85˚C for 30min
↓
Pour 50ml of sample in petridish
↓
Dry the mixture in hot air oven at 55˚C for 10h
↓
Gently peel the film and store in desiccator

**Fig. 1.** Flow chart for preparation of films without addition of rice bran wax

Take distilled water of known volume
↓
Add starch powder (eg:2%w/v)
↓
Add vinegar (eg:1ml)
↓
Add 2g of rice bran wax and 0.35% of Arabic gum
↓
Gelatinize the mixture at 85˚C for 30min
↓
Pour 50ml of sample in Petri dishes
↓
Dry the mixture in hot air oven at 55˚C for 10h
↓
Gently peel the film and store in desiccator

**Fig. 2.** Flow chart for preparation of films with addition of rice bran wax

**Table 1.** Different composition of films

| Treatment | Binding agent (g) | Plasticizer (ml) |
|---|---|---|
| Without addition of rice bran wax | | |
| T1 | CS–2 | 1 |
| T2 | CS-5 | 2.5 |
| T3 | CS-10 | 5 |
| T4 | RS-2 | 1 |
| T5 | RS-5 | 2.5 |
| T6 | RS-10 | 5 |
| With addition of Rice bran wax | | |
| T7 | CS–2 | 1 |
| T8 | CS-5 | 2.5 |
| T9 | CS-10 | 5 |
| T10 | RS-2 | 1 |
| T11 | RS-5 | 2.5 |
| T12 | RS-10 | 5 |

*0.35%w/v Arabic gum was added to all samples added with rice bran wax under controlled laboratory conditions (25˚C, Relative humidity 25% and pH=7). The film samples were placed in plastic container filled with soil.

## RESULTS AND DISCUSSION

**Thickness (mm):** The highest thickness was observed for $T_3$; CS-10g + glycerol (5ml) as 1.21 mm. The lowest f thickness in $T_1$; CS-2g + glycerol (1ml) as 0.50 mm. Similar trend was observed for thickness for the films prepared with rice starch. The thickness increased as the quantity of binding agent increased. Similar results was obtained by Brodnjak et al (2018) while preparation of films. The thickness of corn starch and rice starch films prepared with addition of rice bran wax was measured (Fig. 2). Among all the treatments, highest value of thickness was observed for $T_{12}$; RS-10g+glycerol (5ml)+rice bran wax (2g) as 1.78 mm. The lowest thickness observed for $T_{10}$; RS -2 g+ glycerol (1ml) + rice bran wax (2g) as 1.02 mm. In all the treatments, the thickness increased upon increase in binding agent. The amylose content in corn starch is high compared to rice

**Table 3.** Solubility test in distilled water for different composition of films with and without addition of rice bran wax

| Solvent (Distilled water) | Cornstarch + glycerol ($T_1$) | Rice starch + glycerol($T_4$) | Cornstarch + glycerol + rice bran wax ($T_7$) | Rice starch + glycerol + rice bran wa ($T_{10}$) |
|---|---|---|---|---|
| Day 1 | Insoluble | Insoluble | Insoluble | Insoluble |
| Day 2 | Insoluble | Insoluble | Insoluble | Insoluble |
| Day 3 | Insoluble | Insoluble | Insoluble | Insoluble |
| Day 4 | Partially soluble | Partially soluble | Partially soluble | Partially soluble |
| Day 5 | Partially soluble | Partially soluble | Partially soluble | Partially soluble |

**Table 4 .** Solubility test in chloroform for different composition of films with and without addition of rice bran wax

| Solvent (chloroform) | Corn starch + glycerol ($T_1$) | Rice starch + glycerol ($T_4$) | Corn starch + glycerol + rice bran wax ($T_7$) | Rice starch+glycerol +rice bran wax ($T_{10}$) |
|---|---|---|---|---|
| Day 1 | Insoluble | Insoluble | Insoluble | Insoluble |
| Day 2 | Insoluble | Insoluble | Insoluble | Insoluble |
| Day 3 | Insoluble | Insoluble | Insoluble | Insoluble |
| Day 4 | Partially soluble | Partially soluble | Partially soluble | Partially soluble |
| Day 5 | Partially soluble | Partially soluble | Partially soluble | Partially soluble |

**Table 5.** Solubility test in ethanol for different composition of films with and without addition of rice bran wax

| Solvent (ethanol) | Cornstarch + glycerol ($T_1$) | Rice starch+ glycerol ($T_4$) | Corn starch +glycerol+ rice bran wax ($T_7$) | Rice starch+ glycerol +rice bran wax ($T_{10}$) |
|---|---|---|---|---|
| Day 1 | Insoluble | Insoluble | Insoluble | Insoluble |
| Day 2 | Insoluble | Insoluble | Insoluble | Insoluble |
| Day 3 | Insoluble | Insoluble | Insoluble | Insoluble |
| Day 4 | Partially soluble | Partially soluble | Partially soluble | Partially soluble |
| Day 5 | Partially soluble | Partially soluble | Partially soluble | Partially soluble |

**Table 6.** Solubility test in diethyl ether for different composition of films with and without addition of rice bran wax

| Solvent (diethyl ether) | Cornstarch + glycerol ($T_1$) | Rice starch+ glycerol ($T_4$) | Corn starch +glycerol+ rice bran wax ($T_7$) | Rice starch+ glycerol +rice bran wax ($T_{10}$) |
|---|---|---|---|---|
| Day 1 | Insoluble | Insoluble | Insoluble | Insoluble |
| Day 2 | Insoluble | Insoluble | Insoluble | Insoluble |
| Day 3 | Insoluble | Insoluble | Insoluble | Insoluble |
| Day 4 | Partially soluble | Partially soluble | Partially soluble | Partially soluble |
| Day 5 | Partially soluble | Partially soluble | Partially soluble | Partially soluble |

starch, which may have accounted for strong, close binding among the corn starch molecules that led to decrease in thickness of films (Ali et al 2014). The addition of plasticizers also led to the increase in thickness of films (Nordin et al 2020). Higher values of thickness were recorded for treatments with addition of rice bran wax than the treatments without addition of rice bran wax. Regardless of rice bran wax content, the corn starch and rice starch films with the addition of rice bran wax were translucent.

**Moisture content (%):** Moisture content of the corn starch and rice starch film prepared without addition of rice bran wax is evaluated (Fig. 3). The highest moisture content was observed for treatment $T_6$; RS-10 g + glycerol (5ml) as 11.4% and lowest was for $T_1$; CS-2g + glycerol (1 ml) as 9.5%. Similar results was obtained by Brodnjak et al (2018) while preparation of chitosan and starch films. The lower moisture content which is desirable is because of the presence of rice starch and corn starch in the films. These starch molecules form highly cross-linked systems, preventing water molecules from penetrating into composite films (Thakur et al 2016). The moisture content values of the films with addition of rice bran wax were presented in Figure 4. The highest moisture content was observed for $T_9$; CS-10 g + glycerol (5ml)+ 2 g rice bran wax as 10 % (Fig. 4). The lowest moisture content was in $T_7$; CS-2g+glycerol (5ml)+ 2g rice bran wax as 9%. Similar results was obtained while preparation of films by Brodnjak et al (2018). The moisture content of the films without addition of rice bran wax was higher than of added rice bran wax. Hence, the added rice bran wax is a function modifying agent for improved moisture absorption of the composite films (Abhirami 2019).

**Transparency (% mm$^{-1}$):** The transparency of the films was higher in $T_3$; rice starch (10 g)+ glycerol (5ml) as 1.3 % mm$^{-1}$ and the lower value for $T_4$; corn starch (2 g) + glycerol (1ml) + rice bran wax (2g) as 1.2%mm$^{-1}$ (Fig. 4). The transparency values for both corn starch and rice starch samples were reasonably less. Xu et al (2005) worked on starch films with grape pomace extract, emphasized that opacity is directly related to the degree of film homogeneity. In present study, the presence of glycerol in CS-glycerol and RS-Glycerol film may block or lower the intensity of the scattering light passing through the film resulting in higher opacity values. The corn starch and rice starch samples with addition of rice bran wax shown similar trend of decrease in transparency as compared to samples without addition of rice bran wax (2g). Although rice bran wax (2g) reduced the film transparency, this could be advantageous for food packaging, especially for foods that are light-sensitive since it provides barrier against UV.

**Solubility test**: Test was conducted for five days by

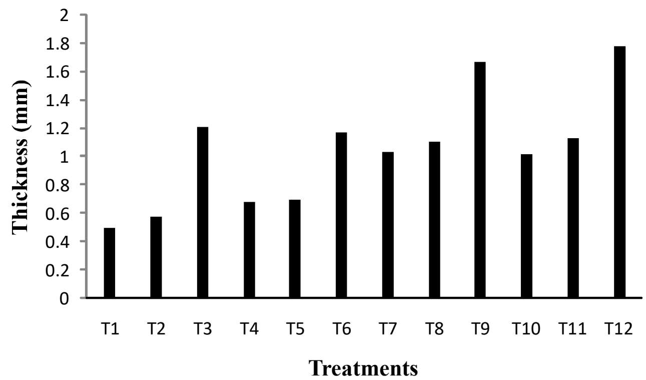


**Fig. 1.** Changes in thickness of corn starch and rice starch films prepared without addition of rice bran wax

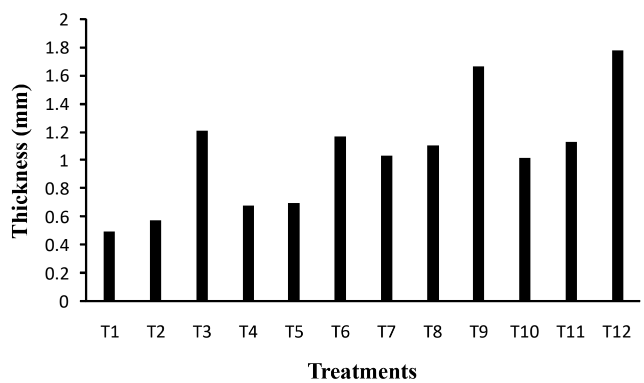


**Fig. 3.** Changes in moisture content of corn starch and rice starch films with and without addition of rice bran wax

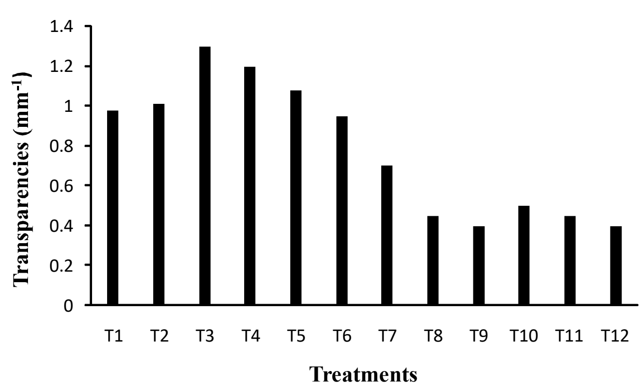


**Fig. 4.** Changes in transparency (%mm$^{-1}$) of corn starch and rice starch films without addition of rice bran wax

**Table 7.** Folding endurance for different composition of films with and without addition of rice bran wax

| Treatments | No. of double folds | Endurance |
|---|---|---|
| Cornstarch + glycerol ($T_3$) | 4 | 0.60 |
| Rice starch + glycerol ($T_6$) | 4 | 0.60 |
| Corn starch + glycerol +rice bran wax ($T_9$) | 3 | 0.47 |
| Rice Starch + glycerol +rice bran wax ($T_{12}$) | 4 | 0.60 |

dissolving films in distilled water, diethyl ether, ethanol, and chloroform (Table 3). $T_{1;}$ Corn starch (2g) + glycerol (1ml), $T_4$; Rice starch (2g)+glycerol (1ml), $T_7$; Corn starch (2g)+glycerol (1ml)+rice bran wax (2g), $T_{10}$**;** Rice starch (2g)+glycerol (1ml)+rice bran wax (2g) was dissolved in chloroform for five days. Similarly, all the treatments are insoluble for three days and partially soluble on day-4and day-5 in chloroform. These exhibited no change for 5 days in ethanol and di-ethyl ether. All the films were insoluble for first three days in all solvents. Due to hydrophilic nature of the plasticizer and binding agent, the films were partially soluble in water. The result confirms that the films were easily and naturally degradable by water.

**Folding endurance:** Maximum number of double folds is for $T_3$;corn starch(10g) + glycerol (5ml), $T_{6;}$ rice starch (10g) + glycerol (5ml), $T_{12;}$ rice starch (10g) + glycerol (5ml)+rice bran wax (2g) were recorded as 0.60. The minimum folding endurance was reported for $T_{9;}$ Corn starch(10g) +glycerol(5ml)+rice bran wax (2g) as0.47. Slight increase in relative humidity causes decrease in folding endurance. It may be due to an increase in ductility (Sharmila et al 2021).

**Biodegradability:** The film prepared using rice starch with addition of rice bran wax degraded faster than corn starch film with addition of rice bran wax. The surface of samples included cracks, holes and colour changes. Both films with rice bran wax were completely degraded after 15days in soil.

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# Effect of Pre-treatment on Aggregation, Biochemical Quality and Membrane Clarification of Pomegranate Juice

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***Abstract*:** Pomegranate (*Punica granatum* L., Punicaceae) is the most popular tropical non-citrus fruits, mainly because of their attractive aroma, refreshing flavour and Brix/acid ratio. The research was carried out on the physicochemical analysis and membrane clarification of pomegranate juice after pretreatment. Pretreatment of pomegranate juice was performed using egg albumin with different concentrations and observed that 2 g/L concentration gave effective removal of colloidal substances of both juices. The biochemical analysis of pomegranate juice after pretreatment revealed the that of TSS, colour intensity, browning index, turbidity, titrable acidity, pH, viscosity, total antioxidant activity, total phenolic content, total anthocyanin content, reducing sugars, non-reducing sugars, total sugars and colour as 12.985%, 7.695, 4.726, 0.751%, 0.784%, 4.753, 2.326 cP, 37.221 mg/g, 57.225 (mg of GAE/g of dry material), 12.461 mg/100mL, 5.754%, 2.671%, 8.425% and 3.842, respectively. There were significant differences among all the treatments of pomegranate juice. Permeate flux generally declined with time for both microfiltration (MF) and ultrafiltration (UF). However, increase in permeate flux was achieved with increase in TMPs and feed flow rates. The permeate flux was high during MF of pomegranate juice than UF. The decrease in pore size and MWCO also decreased the permeate flux. In MF and UF of pomegranate juice, the initial fluxes were high but gradually decreased.

***Keywords*:** Membrane clarification, Microfiltration, Ultrafiltration, Egg albumin, Permeate flux, MWCO, Pore size

Pomegranate is an important fruit crop grown in India. It is originated in Iran and extensive pomegranate farming is done in the Mediterranean countries like Spain, Morocco, Egypt, Iran, Afghanistan, and Baluchistan. India ranks first in pomegranate cultivation in the world. Ganesh, Bhagwa, Ruby, Arakta and Mridula are the important commercial cultivars. Maharashtra is leading with 147.9 thousand ha area with annual production of 1789 thousand MT and productivity of 12.10 MT/Ha. Andhra Pradesh and Telangana states record the productivity of pomegranate with 14.69 and 13.36 MT/Ha, respectively. India ranks sixth in the production of pineapple among the world countries.

Pomegranate (*Punica granatum* L., Punicaceae) is the most popular tropical non-citrus fruits, mainly because of their attractive aroma, refreshing flavour and Brix/acid ratio. This juice have been used in fruit based beverages individually, in the form of mixture or combined with other fruit juices. As an ingredient, the concentrated juice from pomegranate blends well with other aromas of fruits resulting in a pleasant product with a competitive market price. Pomegranate, mainly produced in the middle east have a number of nutritional and health benefits and is a potential source of anthocyanins, ellagic acid, phytoestrogenic flavonoids, tannins and organic acids, some of which are antioxidants. Further, as reported in biological studies, pomegranate juice is rich in anti-atherosclerotic and anti-atherogenic compounds which have been shown to reduce blood pressure and low density lipoprotein oxidation (Aviram and Dornfeld 2001). Due to these characteristics and increasing public awareness about nutritional food, the demand for the pomegranate fruit has significantly increased in the last years. Consequently, many industries producing pomegranate fruit juice as well as pharmaceutical companies extracting health beneficial compounds from the fruits have been developed. There is a worldwide increasing tendency for the consumption of tropical fruits, juices and fruit drinks due to the interest in ready to consume healthy products. Fruit juices are liquid foods that provide vitamins, sugars, mineral compounds and water. Consumers have individual preferences for specific appearance, consistency and flavor characteristics. Traditional methods of processing fruits limit the possibility to retain freshness as much as possible and its health-beneficial compounds. For instance, conventional juice clarification processes are based on the use of clarifying agents (gelatin, bentonite, diatomaceous earth, etc.) which create serious problems on the juice quality and freshness. Similarly, the concentration of fruit juices by thermal evaporation results in color degradation and reduction of most thermally sensitive compounds. Membrane technology is an alternative to produce a juice with good nutritional characteristics as it does not destroy the vitamins and other nutrients. It is also an alternative because of its operational advantages such as mild temperature, ease of scale-up and simplicity.

Introduction of membrane processing enables production of additive-free juices with high quality and natural fresh like taste. Juice clarification, stabilization, depectinization and concentration are typical steps in which membrane processes such as microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO) can be potentially utilized. Clarification based on membrane processes, particularly UF and MF, have replaced conventional clarification, resulting in elimination of chemical clarifying agents and simplified process for continuous production. Purpose of the membrane processing is to remove suspended solids as well as haze-inducing and turbidity causing substances to obtain a clear juice after storage. Keeping in view of the above points, a study was undertaken on membrane processing of pomegranate juice after pretreatment with egg albumin. The study also constituted the analysis of physicochemical characteristics of juice and establishing operational parameters to achieve high permeate flux.

## MATERIAL AND METHODS

Pomegranate of (cv. *Ganesh)* variety were obtained from local market, Bapatla, Guntur dist. Andhra Pradesh. These varieties were chosen as a good juice. Sodium Benzoate, egg albumin powder, glass bottles of 250 mL were procured from National Scientific, Guntur, Andhra Pradesh. The fruits procured were properly sorted to discard fruits of mechanical damage while transportation. Pomegranate fruits were peeled, seeds were collected and juice was extracted.

**Pre-treatment on aggregation and clarification of pomegranate juice:** The pomegranate juice of was used to determine the effect of pre-treatment on aggregation and clarification parameters. The pre-treatment was performed using a fining agent called egg albumin. The juice was subjected to four concentration levels *i.e.,* 0.25, 0.5, 1 and 2 g/L and effect of pretreatment was analysed. After the collection of juice, the egg albumin powder was added and mixed thoroughly. The juice samples were muslin cloth filtered and centrifuged at 4000 rpm (2147 g) for 5 min (Domingues et al 2011). The supernatant was used for biochemical quality analysis to determine the effect of pretreatment. The concentration of egg albumin which resulted in better clarification was determined by biochemical quality analysis. This concentration was subsequently used for pre-treatment of both pineapple and pomegranate juices in all the experiments. The pre-treatment was performed to remove the colloidal substances present in the juices. Colloids can decrease the permeate flux during filtration of the juice due to presence of pectinases, cellulase, hemicellulase, xylanase, carbohydrase, glucanase or arabinose. Removal of aggregates of these species via pretreatment may increase the permeate flux due to the reduction in the size of the particles and the subsequent decrease in viscosity (Valero et al 2014). The results of the biochemical analysis were expressed statistically with complete randomised block design (CRD). The details of independent and dependent variables for pretreatment on aggregation and clarification of juices were as shown below

| Independent variables | Dependent variables |
|---|---|
| Concentrations of egg albumin: 0.25, 0.5, 1 and 2 g/L | Total soluble solids (TSS)<br>pH<br>Turbidity<br>Viscosity<br>Titrable acidity<br>Colour<br>Colour intensity<br>Browning index<br>Total antioxdant activity (TAA)<br>Total phenolic content (TPC)<br>Total anthocyanin content (TAC)<br>Reducing and non-reducing sugars<br>Total sugars |

The pre-treated pomegranate juice with egg albumin was subjected to physicochemical analysis. Total soluble solids (TSS) of juice were measured by Refractometer (ATAGO make, range 58-90%) and expressed in terms of % Brix. The pH measurement was performed using a digital pH meter (Systronics digital pH meter 355). The colour intensity was measured using a Systronics PC based Double Beam Spectrophotometer at absorbance of 510 nm. Similarly, Browning index was expressed as the ratio of 420 nm to 520 nm using Systronics PC based Double Beam Spectrophotometer (Valero et al 2014). The turbidity and color was also measured using Systronics PC based Double

Beam Spectrophotometer at absorbance of 700 nm and 420 nm respectively. The turbidity values of both juices were measured according to the procedure given by Valero et al (2014).Titrable acidity of both juices are determined by the procedure of AOAC (2005). Titrable acidity is expressed as the amount of free acid mainly as anhydrous citric acid present in fruit, conveniently in g acid per 100 g or 100 ml.

$$\%\text{ acidity} = \frac{a \times b \times c \times d \times 100}{e \times w \times 1000} \quad (1)$$

where, a = titre value (volume of 0.1N NaOH)

b = Normality of the alkali (0.1N), c = volume made up, d = equivalent weight of the acid, w = weight or volume of sample taken (g or ml) , e = aliquot

Viscosity of the fruit juice was determined by using Digital Viscometer (Brookfield, Model: DV1MLV). Lane and Eynon method (Ranganna, 1986) was used for determination of total, reducing and non – reducing sugars.

$$\text{Reducing sugars \%} = \frac{\text{(factor (0.052)×dilution ×100)}}{\text{(titre×wt. of sample)}} \quad (2)$$

$$\text{Total sugars \%} = \frac{\text{(factor (0.052)×dilution ×100)}}{\text{(titre×wt. of sample)}} \quad (3)$$

Non-reducing Sugars % = Total Sugars – Reducing Sugars (Ahmmed et al 2015)

The antioxidant assay was estimated by ferric reducing antioxidant power method using ascorbic acid as standard and total Phenolic content by Folin Ciocalteu's method using gallic acid as standard (Kametkar et al 2014). Anthocyanins are water soluble phenolic glycosides belonged to flavonoid pigments having $C_{15}$ skeleton of flavones as basic structural unit.

$$\text{Total O.D./100 ml} = \frac{\text{O.D. ×Volume made up ×100}}{\text{ml of juice taken}} \quad (4)$$

$$\text{Total anthocyanin (mg/100 ml)} = \frac{\text{Total O.D./100 ml}}{87.3} \quad (5)$$

**Membrane clarification of pomegranate juice:** Membrane clarification (MF and UF) of pomegranate juice after pretreatment was carried out at Dr. N.T.R. College of Agricultural Engineering, Bapatla in hollow fibre membrane module setup (Model: HFM – 01, Technoquips Seperation Equipments, Kharagpur). The term membrane processing in this thesis is essentially clarification of juices using membranes.

**Hollow fibre membrane module setup:** The schematic of hollow fiber membrane set up is shown in Figure 1 and Plate 1. The heart of the setup is the hollow fiber module (F). The feed is drawn by the booster pump (C) and fed to the module by 6 mm polyurethane tube via a Perspex flange. Two pressure gauges in the range of 0 to 60 psi (4.1364 bars) are attached to the upstream and downstream of the module. A22.5*cm* needle valve (J) of stainless steel has been fitted in the retentive line after the module. This valve is used for fine tuning of pressure and flow rate through the module. A rotameter (K) of range 0 to 50 L/h is attached to the retentive line and the retentive stream is recycled back to the feed tank (A). A bypass line is connected from the pump to the feed tank and 15 cm stainless steel needle valve (B) is attached to the bypass line. The permeate flows through a 5 mm polyurethane pipe into permeate collector (G). By controlling the bypass valve (B) and retentive valve (J), one can control the flow rate and the trans membrane pressure drop across the module, independently. The trans membrane pressure drop is the arithmetic average of the readings in the pressure gauges E and I. The physical dimension of the setup is 70 mm in length, 48 mm in width and 65 mm in height. The weight of the setup is approximately 10 kg. One power point of domestic line 220 V is required to run the pump.

where,

A: Feed tank, B: Bypass valve, C: Booster pump, D: Short piece, E: Upstream pressure gauge (0 – 4.21 kg/cm$^2$(60 psi)), F: Hollow fibre module, G: Permate collector, H: Short piece, I: Downstream pressure gauge (0 – 4.21 kg/cm$^2$(60 psi)), J: Pressure valve (Needle type), K: Rotameter (0 – 50 Lph)

Membrane processing of pomegranate juice was carried out in the membrane module setup with different hollow fibre

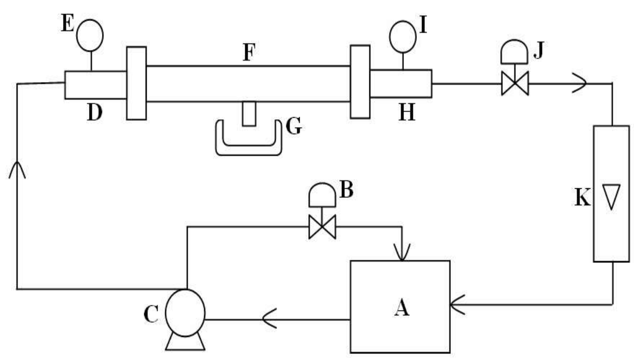


**Fig. 1.** Schematic diagram of the hollow fibre membrane module setup


**Plate 1.** Hollow fibre membrane setup

cartridges. The container was filled with 250 mL of juice. The operation was done in total recycle mode. The suction, retentate, by-pass lines were kept in feed solution and continuous operation was carried out. The permeate was collected at permeate line separately. All microfiltration (MF) and ultrafiltration (UF) experiments were carried out at trans membrane pressures (TMPs) of 0.3447 bar (5 psi), 0.6894 bar (10 psi), 1.0342 bar (15 psi) and 1.3789 bar (20 psi). The pore sizes of hollow fibre cartridges used for microfiltration and ultrafiltration experiments were 0.1 and 0.2 μm and 120, 70, 44 and 120 kDa (MWCO), respectively. The permeate was collected at regular intervals of time and tabulated. Initially the membranes were compacted at 1.0342 bar 15 psi, 30 Lph with distilled water for 2 hours in total recycle mode. The technical specifications of MF and UF membrane were given in Table 1 and Table 2, respectively. Further, pure water flux data was collected both for MF and UF membranes using distilled water. After each run, the set up was flushed with distilled water and then cleaned with 0.1 N hydrochloric acid (HCl) for 30 mins in total recycle mode according to the washing protocol given by the manufacturer. After thorough washing, the permeability of the cartridges was analysed to measure the change in permeability of the hollow fibres. All the experiments were conducted in triplicate at room temperatures (30±2 °C). After every experiment, the membranes were cleaned properly and stored in the 1% formalin solution for future use.

Permeate flux was calculated as

$$J^* = \left(\frac{1}{A}\right) \times \left(\frac{dv}{dt}\right) \qquad (6)$$

Where, J*= Permeate flux (L/h $m^2$), A= Area of the membrane ($m^2$), dv= Volume of flow rate (L), dt= Time of flow rate (h)

The permeate collected was stored in glass bottles. The experiments were performed according to the different conditions laid down in the Table 3 and analysed to obtain high permeate flux.

## RESULTS AND DISCUSSIONS

**Pre-treatment of pomegranate juice:** In pomegranate juice after the pre-treatment, 2 g/L concentration level recorded highest removal of colloidal substances. There was a decrease in all the constituents of the juice. However, the decrease of constituents was not high to loose the essential components of juice. Pomegranate juice resulted in effective decrease in constituents at 2 g/L concentration of egg albumin. The decrease in complex colloidal components might increase in permeate flux of the juice decreasing the fouling colour intensity of pomegranate juice. This was in accordance with Mirsaeedghazi et al (2010). The pomegranate juice presented a significant decrease in all the biochemical attributes as the concentration level of egg

**Table 3.** Operating variables for microfiltration and ultrafiltration of pomegranate juices

| Operating variables | |
|---|---|
| Membrane poresizes: | MF - 0.1 and 0.2 μm<br>UF – 120, 70, 44 and 10 kDa |
| Transmembrane pressures (TMP): | 0.3447 bar (5 psi), 0.6894 bar (10 psi), 1.0342 bar (15 psi) and 1.3789 bar (20 psi) |
| Crossflow Velocities/ Feed flow rates: | 0.024 m/s (20 Lph), 0.037 m/s (30 Lph) and 0.049 m/s (40 Lph) |

**Table 1.** Technical specifications of MF membranes

| Membrane material | Pore size (μm) | Water permeability as claimed by the manufacturer (m / Pa.s) |
|---|---|---|
| Poly acrylonitrile (PAN) (Make: M/s Technoquips seperations equipments Pvt.Ltd., Kharagpur) | 0.2 | $53.4\times10^{-11}$ |
| Poly acrylonitrile (PAN) (Make: M/s Technoquips seperations equipments Pvt.Ltd., Kharagpur) | 0.1 | $44.5\times10^{-11}$ |

**Table 2.** Technical specifications of UF membranes

| Membrane material | Pore size (kDa) | Water permeability as claimed by the manufacturer (m / Pa.s) |
|---|---|---|
| Poly SuLphone (PS)<br>(Make : M/s. Technoquips Seperations Equipments Pvt Ltd., Kharagpur) | 120 | $29.7\times10^{-11}$ |
| Poly SuLphone (PS)<br>(Make : M/s. Technoquips Seperations Equipments Pvt Ltd., Kharagpur) | 70 | $24.3\times10^{-11}$ |
| Poly SuLphone (PS)<br>(Make : M/s. Technoquips Seperations Equipments Pvt Ltd., Kharagpur) | 44 | $20.5\times10^{-11}$ |
| Poly SuLphone (PS)<br>(Make : M/s. Technoquips Seperations Equipments Pvt Ltd., Kharagpur) | 10 | $13.4\times10^{-11}$ |

albumin increased which enhanced the filtration process while membrane processing by high permeates flux.

Browning index decreased in pomegranate juice upon using egg albumin as pre-treatment (Valero et al 2014). Pomegranate juice recorded the low BI values. BI values were high prior to the pre-treatment in non- clarified juice. Similarly, Alper et al (2005) also observed decrease in browning degree for non-clarified juice. A decrease of 49.1% was obtained with gelatine and bentonite combined conventional fining. Browning index values observed as 4.726 for pomegranate juice in 2 g/L concentration level of egg albumin.

The turbidity values decreased as the concentration level increased. The highest clarity was obtained with 2 g/L egg albumin. Similarly turbidity was also decreased with addition of PVPP and bentonite and increased the clarity of the juices (Valero et al 2014, Samreen et al 2020). Titrable acidity (TA) values decreased as the concentration of egg albumin increased. The pH values increased in pomegranate juice. The TA for pomegranate juice was 0.784% expressed as citric acid. Similarly, the pH of pomegranate juice was 4.753. The results were best for 2 g/L concentration level of egg albumin. However, there was a significant difference among all the concentration levels of egg albumin. Similar, results were recorded by Alighourchi et al (2009). Initially the concentration level 0.25 and 0.5 g/L did not show any significant difference in the values. They were approximately same in terms of pH of both the juices (Molina et al 2009).

Viscosity of the juices decreased with increase of concentration level of egg albumin. The mean values of viscosity of pomegranate juice at 2 g/L concentration level were recorded as 2.326±0.05 cP. There was a significant decrease in viscosity of pomegranate juice at different concentration levels of egg albumin. As the pomegranate juice is very light juice with less colloidal substances, the decrease of viscosity was recorded. The antioxidant activity decreased as the concentration level of egg albumin increased. The highest decrease was observed in 2 g/L egg albumin of pomegranate juice as 37.2218 mg/g. The centrifugation and clarification process might aid to the decrease in the antioxidant activity of the juice. Similar results were recorded by Vegara et al (2013) in terms of pomegranate juice. The results pertaining to antioxidant activity obtained in this study were not in accordance to Valero et al (2014) where the antioxidant activity increased upon increase of concentration level of egg albumin.

Total phenolic content of the juice also significantly decreased with increase of concentration level of egg albumin. Similar results were obtained by Valero et al (2014) in decrease of total phenolic content with 2 g/L egg albumin. The decrease of phenolic content might be due to the changes in the different clarification techniques with egg albumin. Total anthocyanin content decreased as the concentration of egg albumin in clarification increased. There was no significant difference for pomegranate juice at 0.25 and 0.5 g/L of egg albumin. The anthocyanin significantly decreased for 1 and 2 g/L egg albumin. Anthocyanin compounds are labile and undergo degradative

**Table 4.** Biochemical characteristics of pomegranate juice after pretreatment with different concentrations of egg albumin

| Property | Concentration of egg albumin (g/L) | | | |
|---|---|---|---|---|
| | 0.25 | 0.5 | 1 | 2 |
| Total soluble solids (%) | 13.783 ± 0.01 | 13.453 ± 0.010 | 13.156±0.010 | 12.985±0.010 |
| Colour intensity | 7.765±0.010 | 7.744±0.021 | 7.714±0.010 | 7.695±0.010 |
| Browning index | 6.944±0.010 | 5.926±0.015 | 5.483 ±0.015 | 4.726±0.015 |
| Turbidity | 0.781±0.050 | 0.775±0.050 | 0.768±0.020 | 0.751±0.050 |
| Titrable acidity (%) | 1.184±0.020 | 1.155±0.010 | 0.927±0.010 | 0.784±0.050 |
| pH | 4.036±0.015 | 4.23± 0.02 | 4.583±0.050 | 4.753 ± 0.050 |
| Viscosity (cP) | 4.826±0.010 | 4.105±0.010 | 3.557±0.010 | 2.326±0.050 |
| Total antioxidant activity (mg/g) | 42.521±0.010 | 40.251±0.010 | 38.532±0.020 | 37.221 ± 0.066 |
| Total phenolic content (mg of GAE/g of dry material) | 79.416±0.010 | 76.844±0.588 | 75.143±0.030 | 57.225±0.050 |
| Total anthocyanin content (mg/100 mL) | 14.493±0.010 | 13.971±0.050 | 13.257±0.010 | 12.461±0.050 |
| Reducing sugars (%) | 7.202±0.017 | 5.992±0.011 | 5.853±0.010 | 5.754±0.010 |
| Non-reducing sugars (%) | 4.052±0.050 | 4.833±0.050 | 3.8±0.05 | 2.671±0.010 |
| Total sugars (%) | 11.254±0.011 | 10.825±0.050 | 9.653±0.010 | 8.425±0.010 |
| Colour | 3.994 ±0.010 | 3.994±0.010 | 3.895±0.010 | 3.842± 0.010 |

$F_{tab}$ = 4.0661

reactions. There are many variations in the stability of the structure of anthocyanins. Anthocyanins remain stable in dried form than in state of high water activity.

Reducing sugars significantly decreased in pomegranate juice. The highest decrease was recorded to 2 g/L concentration level egg albumin. The mean values of decrease obtained for pomegranate was recorded as 5.754%. Similarly, the decrease was obtained for total sugars and non - reducing sugars. A slight increase was observed in non - reducing sugars in pomegranate juice at 1 g/L egg albumin concentration. The increase might be achieved because of conversion of some sugars during hydrolysis. Total sugars significantly decreased in pomegranate juice as the concentration level increased. The decrease of total sugars was achieved due to conversion into simpler sugars while hydrolysis in pomegranate juice.

The colour values significantly decreased for pomegranate juice. Anthocyanins are phenolic compounds responsible for pomegranate juice colour. As, the phenolic content of the juices were in decreasing trend, the anthocyanins also decreased in juices. This might be the reason for the decrease of colour in juice as anthocyanins decreased. The loss of anthocyanin pigments occurred because of addition of egg albumin as it is sequestering agent it removes the colloidal substances in flocks which might have reduced the pigments in turn aided to decrease in colour of juice. Vardin and Fenercioglu (2003) recorded the same decrease with the use of gelatine addition and natural sedimentation. The 2 g/L egg albumin was the best concentration level as flocculating agent to remove the colloidal substances and this was utilized as pre-treatment prior to membrane processing of pomegranate juice to increase permeate flux and reduce fouling.

**Membrane processing of pomegranate juice and establishing operational parameters to achieve high permeate flux:** The pomegranate fruit juice was collected after pre-treatment with egg albumin. According to the pre-treatment analysis, the best concentration was observed at 2 g/L egg albumin. The pomegranate juice after pre-treatment with egg albumin was refrigerated for further membrane processing. In membrane processing, both Microfiltration (MF) and Ultrafiltration (UF) hollow fibre cartridges were used for clarification of pomegranate juice. The different combinations of membrane pore sizes, trans membrane pressures and flow rates were given in table 4.

**MF of pomegranate juice:** Pomegranate juice after pretreatment with egg albumin was subjected to membrane processing using microfiltration with membrane pore sizes of 0.2 and 0.1 µm. The permeate flux declined with time on both the membranes (Fig. 2 and 3). As the membrane pore size increased, the permeate flux increased. Similarly, the increase in TMP also increased the permeate flux (L/m$^2$h). The increase in feed flow rate also resembled the same increase in permeate flux. The highest permeate flux 125.523 L/m$^2$h was for 20 psi pressure and 40 Lph flow rate. Similar results were obtained for pomegranate juice clarified by 0.1µm membrane pore size (Fig. 3). The flux decreases sharply initially due to membrane fouling and gradually thereafter and finally attains a steady state value. Similar results were obtained by Rai et al (2006) for mosambi juice and Karmakar et al (2017) for coconut water. The difference in steady state values for both the pore sizes was marginal. Similar results were observed during MF of Tomato juice (Bottino et al 2002). The processing time increased there was a decline in permeate flux probably because of deposition of colloidal substances while clarification on membrane surface. These colloidal substances offer resistance to flow of permeate which leads to fouling. Fouling may have occurred due to pore narrowing by smaller particles that may have accumulated on the pore walls (Chilukuri et al 2001, Samreen et al 2020) or by pore plugging. High amount of permeate flux was obtained for 0.2 µm pore size probably because of its larger pore size. High fluxes were recorded due to pre-treatment with egg albumin at 2 g/L concentration as large floccs of colloidal substances were removed.

**UF of pomegranate juice:** Ultrafiltration (UF) of pomegranate juice was carried out with four different hollow fibre membranes with different molecular weight cut off (MWCO) *i.e.,* 120, 70, 44 and 10 kDa, trans membrane pressures 0.3447 bar (5 psi), 0.6894 bar (10 psi), 1.0342 bar (15 psi) and 1.3789 bar (20 psi) and three flow rates 20, 30, 40 Lph. After pretreatment with egg albumin at 2 g/L concentration, pomegranate juice was subjected to membrane processing. It was observed through the biochemical quality analysis that large colloidal substances present in the juice was removed in the form large floccs as egg albumin is a good flocculating agent. The permeability of UF membranes was determined using distilled water at different pressures prior to the ultrafiltration of pomegranate juice.

**120 kDa MWCO membrane:** Pomegranate juice when subjected to UF treatment, there was decline in the permeate flux of juice (Fig. 4). The highest flux was obtained at high feed flow rates and high trans membrane pressures. Highest rate of permeate flux obtained was 111.721 L/m$^2$ h. The permeate flux gradually declined and reached a steady state value after prolonged duration of processing (Bottino et al 2002). The lowest value of permeate flux (7.448 L/m$^2$h) was obtained at 20 Lph, 5 psi trans membrane pressures.

However, the permeate flux during UF with 120 kDa MWCO was lesser than both MF 0.1 and 0.2 µm membranes. This might be because of the tighter asymmetric membrane structure of UF compared to MF. Probably, the reason for good permeate flux after long duration of filtration process might be the formation of secondary layer. The secondary layer would have given slightly higher and more sustainable flux because of the permeability of the layer. However, there was gradual decline in flux as the duration of processing increased because of formation of fouling on the membrane surface and also might be because of pore narrowing or pore clogging (Chilukuri et al 2001).

**70 kDa MWCO membrane:** Highest flux obtained for 40 Lph flow rate and 20 psi trans membrane pressure was about 99.388 $L/m^2$ h (Fig. 5). The lowest flux obtained for 20 Lph flow rate, 5 psi (0.3447 bars) TMP was about 7.297 $L/m^2$ h. The permeate flux decreased as the duration of filtration was increased. The TMP and flow rate were the driving forces to increase the permeate flux. The values of permeate flux for 20 psi (1.37890 bar) were high compared to all the remaining TMPs. Similarly lowest values of permeate flux were for 5 psi (0.3447 bar) TMP. All the permeate flux values gradually decreased and attained steady state values in the range from 7.297 to 20.179 $L/m^2$ h for low to high TMPs. Similarly, decline of permeate flux was observed by Cassano et al (2011) during pomegranate juice clarification.

The decline in permeate flux might have occurred because of concentration polarization on the membrane surface. The concentration polarization might have occurred because of the some colloids which could not be removed in the pre-treatment process of egg albumin. These colloids might adhere to the membrane surface causing plugging of pores. This in turn could have reduced permeate flux of the juice. The fouling might be predominant because of the tighter membrane pore size where easy clogging of membrane would have taken place. Initially high amount of flux rates were achieved because of the high TMPs and flow rates but gradually the permeate flux decreased. The increased flux rates initially might also because clean membrane in which the pores were unclogged.

**44 kDa MWCO membrane:** The pomegranate juice clarification was also performed with 44 kDa MWCO membranes at different trans membrane pressures and flow rates. The membrane permeability of the 44 kDa membrane was verified with different TMPs. The membrane permeability for 44 kDa Poly sulphone (PS) membrane was $18.3\times10^{-11}$ $m^3/m^2s$ Pa (Fig. 6). The calculated membrane permeability was in accordance with the membrane permeability given by the manufacturer in operational details of equipment ($20.5\times10^{-11}$ $m^3/m^2$ s Pa). During the membrane processing of pomegranate juice with 44 kDa MWCO membrane, the permeate flux declined gradually. The range of permeate flux obtained was from 94.143 to 5.031 $L/m^2h$. The decrease in permeate flux was probably due to concentration polarization by sediments of pomegranate which could not be removed while aggregation process with egg albumin.

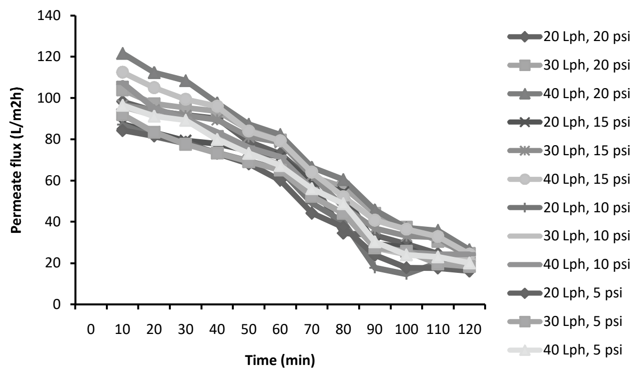


**Fig. 2.** Flux decline during MF of pomegranate juice using 0.2 µm pore size membrane at different TMPs and feed flow rates

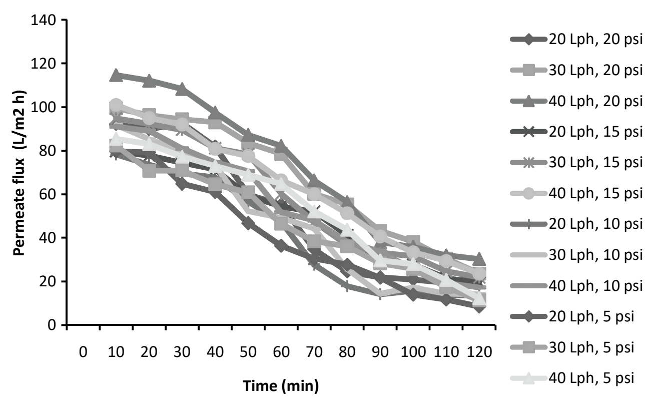


**Fig. 3.** Flux decline during MF of pomegranate juice using 0.1 µm pore size membrane at different TMPs and feed flow rates

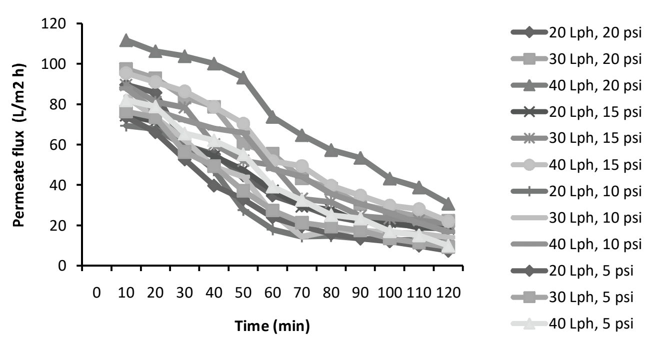


**Fig. 4.** Flux decline during UF of pomegranate juice using 120kDa MWCO membrane at different TMPs and feed flow rates

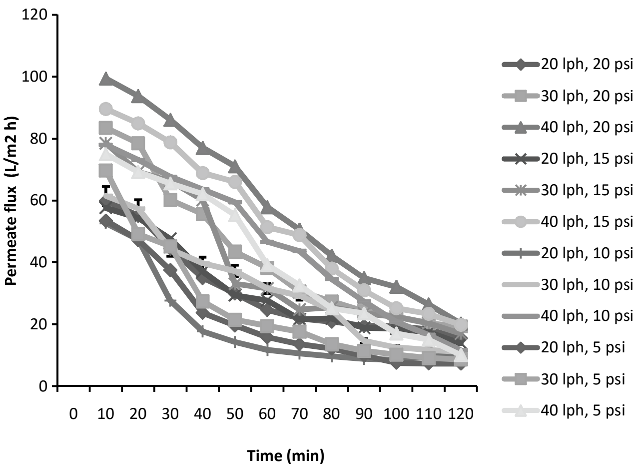


**Fig. 5.** Flux decline during UF of pomegranate juice using 70 kDa MWCO membrane at different TMPs and feed flow rates

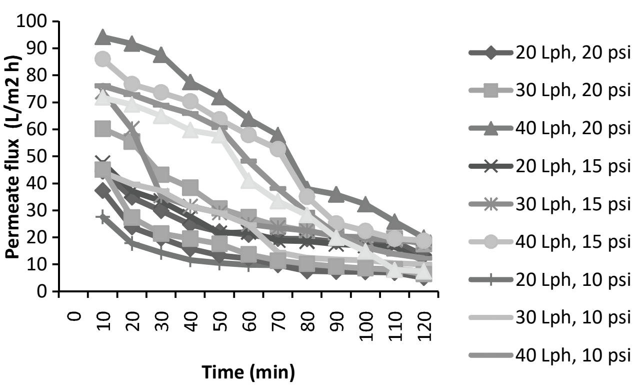


**Fig. 6.** Flux decline during UF of pomegranate juice using 44 kDa MWCO membrane at different TMPs and feed flow rates

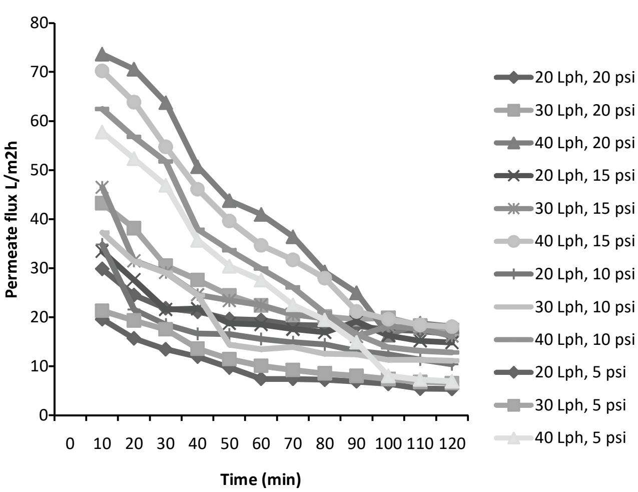


**Fig. 7.** Flux decline during UF of pomegranate juice using 10 kDa MWCO membrane at different TMPs and feed flow rates

**10 kDa MWCO membrane:** The decline in flux was observed in 10 kDa MWCO membrane (Fig. 7). The permeate flux obtained for 10 kDa MWCO membrane was low compared to the 44 kDa MWCO membrane. The lowest permeate flux was recorded among all the membranes. This might be because of tighter membrane where the possibility of chances of fouling was high. Smaller solute particles left after removal of the colloidal particles in the juice could cause pore narrowing.

## CONCLUSIONS

Pre-treatment of pomegranate juice was performed using egg albumin at different concentrations and observed that 2 g/L concentration gave good results in removal of colloidal substances of both juices. Optimum concentration of flocculant *i.e.,* 2 g/L of egg albumin has been found to effectively remove the colloids. The TSS, colour intensity, browning index, turbidity, titrable acidity, pH, viscosity, total antioxidant activity, total phenolic content, total anthocyanin content, reducing sugars, non-reducing sugars, total sugars and colour. The characteristics were analyzed in permissible limits. Permeate flux declined with time in both MF and UF. However, increase in permeate flux was achieved with increase in TMPs and feed flow rates. The permeate flux was high for MF than UF. The decrease in pore size also decreased the steady state permeate flux.

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# Nutritional Status, Level of Trace Metals and Human Health Risk Assessment in Fishes of Central Himalayan River Alaknanda

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***Abstract***: The aim of the present study is to access the human health risk and nutritional status of five common food fishes, *Schizothorax richardsonii, Crossocheilus latius latius, Garra lamta, Schizothorax progastus* and *Barilius bendelisis* found in the river Alaknanda of Central Himalaya. The fish, *G. lamta* was richest in protein (21.22%), *B. bendelisis* in lipid (4.58%) and *C. latius latius* in carbohydrate content (2.03%). Among the macro and trace elements, *C. latius latius* was rich in K (348.41 mg $100g^{-1}$), *B. bendelisis* in Ca (504.78 mg $100g^{-1}$) and Zn (3.163 mg $100g^{-1}$), *G. lamta* in Na (155.89 mg $100g^{-1}$) and *S. progastus* in Fe and Cu (18.24 mg $100g^{-1}$, 0.715 mg $100g^{-1}$). The level of trace metals was well below the highest permissible limit as set by FAO (1983) and WHO (1995). No hazard and carcinogenic risk related to fishes of Alaknanda River was proven on the basis of target hazard quotient (THQ), hazard index (HI) and target cancer risk (TR) estimations. None of the fish species showed HI levels higher than 1 and TR values for Pb were also lower than $10^{-6}$ indicating no possible risk to human health. Thus, fish species may be recommended in daily diet for human consumption.

***Keywords:*** FAO, Omnivorous, Trace metals, THQ, TR

Fish is an important animal food rich in protein, fats and minerals. Mineral elements perform their functional role in metabolism (Belitz et al 2001). The most important mineral elements are sodium (Na), calcium (Ca), potassium (K), iron (Fe), phosphorus (P) and some others are needed in small amounts. Deficiency in the amount of essential minerals (Na, Ca, K, Fe, Cu, Zn *etc*.) causes improper enzyme-mediated metabolic functions which result in malfunctioning of organs, various chronic diseases and ultimately leads to death of the organism (Ozden et al 2010). Even low concentration of trace mineral elements poses a threat to public health, but long-term exposure leads to the accumulation up to toxic levels (Belitz et al 2001). Fishes are also the bioindicators of heavy metals in the water body (Padmini and Kavitha 2005). Some authors indicated that macro and microelements in fish muscle tissue depend on species and their feeding habits (Luczynska et al 2006). The Ganga River is one of the greatest rivers of northern Indian subcontinent which originates in the Himalayas. It is a trans-boundary Himalayan River of Asia, flowing through India and Bangladesh and emptying into Bay of Bengal. The two main headstreams of river Ganga are Alaknanda and Bhagirathi. A vast diversity of flora and fauna flourishes in the Alaknanda river. The various fish species of family Cyprinidae dwell in this river which exhibit different modes of feeding. Although a variety of fish fauna is present in the river Alaknanda (Khanna et al 2013) but now-a-days there is increasing demand of fish food among the human population which makes it difficult to rely only on wild stock. However, no study has investigated the comparative nutritional status of cyprinids from upland Himalayan rivers. Therefore, the present study was elucidated to explore the nutritional value of five different cyprinids from the parent stream of river Ganga. The aim of the study is to know the biochemical composition, level of macro and trace metals in the muscle tissue of fishes and to evaluate human health risk associated with these cyprinid fishes from the Himalayan River Alaknanda of Central Himalaya. Hence, priority can be fixed for their consumption, culture and augmentation.

## MATERIAL AND METHODS

**Study area:** Freshly dead fish samples were procured from local fish market collected by local fishermen from the river Alaknanda (latitude 30°13'30" N; longitude 78°47'33" E) and one of its sub-tributaries, Laster stream (latitude 30°21'05"N; longitude 78°58'15" E). The Alaknanda originates from the confluence of the Satopanth and Bhagirath Kharak glaciers near Vasudhara falls (3650 m a.s.l.) and after covering a course of 191 km it meets with Bhagirathi River at Devprayag (450 m a.s.l) to forms river Ganga. The laster stream originates from Kinkholakhal where it flows in east-south direction before joining the river Mandakini at Tilwara which joins Alaknanda at Rudraprayag (620 m a.s.l.).

**Collection and identification of samples:** The study was conducted on five fish species, of which three were herbivorous, namely *Schizothorax richardsonii*, *Crossocheilus latius latius* and *Garra lamta* and two omnivorous, namely *Schizothorax progastus* and *Barilius bendelisis*. The total of 300 samples (60 samples of each fish species) were collected for a period of one year (2016-17). Samples were then brought to the laboratory for identification, measurements and analysis. Fish samples were identified with the help of standard keys (Jayaram 2002). Samples were degutted, cleaned and stored frozen at -20$^0$C until further analysis.

**Analysis of body composition:** Estimation of total protein, total carbohydrate, and total lipid was done using bovine serum albumin, glucose, and olive oil as a standard, respectively, to make standard curve for calculations. Total moisture content was determined by drying 1g of fish muscle tissue in hot air oven at 105$^0$ C for 24 h. The difference in initial and final weight represents the amount of moisture present and results were expressed as percentage of wet weight of tissue (AOAC 2000). Five replicates were taken for the analysis of biochemical composition and three replicates for mineral composition. Minerals were determined by digesting the tissue samples (0.5-0.6 g) in 1:3 HCl and HNO3 in a closed digestion system at 150$^0$ C for about 1-2 h until completely digested (AOAC 2000). Samples were then cooled and filtered. By using millepore water, the volume of filtrate was made up to 100 ml. Samples were allowed to run on ICP-OES (Thermo Scientific, iCAP 6000 Series) and the concentration of mineral elements was determined.

**Statistical analysis:** Whisker's plot was displayed using STATISTICA 64 *ver*. 12.0 and Cluster analysis was performed using PAST 3. Bray-Curtis clustering was performed using Wards method to group the fish species on the basis of mineral composition.

**Health risk assessment**

**Daily intake of metals:** The estimated daily intake of metals, Fe, Cu, Zn and Pb, was calculated according to the equation of US EPA (1989):

$$\text{EDI} = \frac{\text{MC} \times \text{FIR}}{\text{BW}}$$

Where, MC is the average metal concentration in fish muscle tissue. FIR (Food Ingestion Rate) is the average food ingestion rate which is 0.019 g person$^{-1}$day$^{-1}$ (FAO 2016). BW is the average body weight and was taken as 70 kg for adult (US EPA 2011). The results so obtained were then compared with daily reference dose ($R_fD$) as proposed by US EPA (2011) whose values for Fe, Zn, Cu and Pb are 0.700, 0.300, 0.040 and 0.004 (mg kg$^{-1}$day$^{-1}$).

**Target hazard quotient (THQ):** THQ was calculated by using the following equation (US EPA 2012):

$$\text{THQ} = \frac{\text{EF} \times \text{ED} \times \text{FIR} \times \text{C}}{\text{RFD} \times \text{BW} \times \text{TA}}$$

THQ is non-carcinogenic risk and is dimensionless. EF represents the exposure frequency (365 days/year), ED is the exposure duration which is 70. $R_fD$ represents the reference dose (mg kg$^{-1}$day$^{-1}$), TA is the average time for non-carcinogens exposure which is 365days×ED (US EPA 2012).

THQ>1 indicates negative health risks to the population consuming contaminated fish, but if value of THQ<1, then it gives no adverse effects on human health with consumption of fish (Alipour et al 2015).

**Hazard index (HI):** To determine the additive effect of metals present in food, hazard index (HI) was estimated by summing the THQ value of individual metals (US EPA 2011).

$$\text{HI} = \text{THQZn} + \text{THQFe} + \text{THQCu} + \text{THQPb}$$

**Target cancer risk (TR):** TR was calculated following US EPA (2012):

$$\text{TR} = \frac{\text{EF} \times \text{ED} \times \text{C} \times \text{FIR} \times \text{CSF}}{\text{BW} \times \text{TA}}$$

Where, CSF represents cancer slope factor (mg kg$^{-1}$day$^{-1}$) and CSF value for Pb is 0.0085 mg kg$^{-1}$day$^{-1}$ (US EPA 2010). If the value of TR>$10^{-4}$, then carcinogenic risk is unacceptable. But if value of TR<$10^{-6}$, then carcinogenic risk is negligible. If value is in between $10^{-4}$and $10^{-6}$, then it is an acceptable range of carcinogenic risk (Raknuzzaman et al 2016).

## RESULTS AND DISCUSSION

The samples of *S. richardsonii* selected for the study were having maximum average length (21.58 cm) and weight (88.83 g) while *B. bendelisis* was lowest in length (11.28 cm) and weight (17.43 g) in the present study (Table 1). Moisture followed by protein contributes maximum towards biochemical composition of edible muscle tissue. Highest moisture content (78.02%) was in *S. richardsonii* while lowest (71.95%) in *C. latius latius.* Protein content ranged from 18.40 to 21.22 being highest in *G. lamta* and lowest in *S. richardsonii*. Lipid content varied from 2.04% to 4.58% with maximum amount in *B. bendelisis* and minimum in *S. richardsonii*. Sarma et al (2014) recorded low protein (16%) and high value of fat (7%) and moisture (73%) in *B. bendelisis* collected from Upland Himalaya. Joshi et al (2017) estimated muscle protein of five *Schizothorax* species ranging from 15-17% which is lower than the range of 18-21% in the present study. Highest amount (2.03%) of carbohydrates was in *G. lamta* and lowest (1.89%) in *S. richardsonii*. No significant interspecific variations were observed for protein and carbohydrate contents. However, significant interspecific variations were recorded for moisture and lipid contents (Table 2). All the five studied fish species, namely *S. richardsonii, S. progastus, B. bendelisis, C. latius latius*, and *G. lamta* were low fat (1-5%) fishes, none of the fishes belong to medium (5-10%) and high fat fish (>10%) category.

Among macroelements, the average Na content ranged from 96.31 to 155.89 mg $100g^{-1}$ being highest in *G. lamta* and lowest in *S. progastus*. K content ranged from 238.57 to 348.41 mg $100g^{-1}$ with highest concentration in *C. latius latius* and lowest in *B. bendelisis*. Na and K are needed for proper functioning of nerve, muscle and adrenaline hormone production (Soetan et al 2010). The balance between high level of K and low level of Na is needed for healthy human nutrition (Stoyanova 2018). High K and low Na level was also reported in earlier work (Martínez-Valverde et al 2000, Stoyanova 2018). Similar findings were recorded in the present study. Low amount of Na observed in the edible muscle tissue may be due to the lower level of Na in aquatic medium (freshwater) and less trophic transfer and accumulation in edible muscle tissue. Ca plays a fundamental role in the formation of bones. Average amount of Ca was highest (504.78 $mg100g^{-1}$) in *B. bendelisis* while lowest (321.55 mg $100g^{-1}$) was observed in *S. progastus*. Small fishes have greater amount of Ca content in their muscle tissue is well known (Kawarazuka and Bene 2011, Rebole et al 2015) which confirms our present findings on three fish species namely *B. bendelisis*, *C. latius latius* and *G. lamta* (small indigenous fish species) regarding Ca content. Significant differences were observed in Na, Ca, and K among the studied five fish species. All the selected fish species were found to show similar trend (Ca>K>Na) of macroelements accumulation (Table 3).

Trace metal like Fe has a well-defined role in transporting oxygen around the body. Deficiency of Fe causes anemia and it also leads to haemochromatosis and thalassemia when taken in excessive amount. Among the trace elements, the average Fe content was highest (18.24 mg $100g^{-1}$) in *S. progastus* and lowest (10.62 mg $100g^{-1}$) in *B. bendelisis*. The present study observed optimum Fe in the fish muscle tissue. The omnivorous fish, *S. progastus*, was rich in Fe content as compared to herbivorous fishes, *S. richardsonii, C. latius latius* and *G. lamta*. Zn has role in the synthesis of proteins, DNA and RNA, and gene expression

**Table 1.** Average length, weight, feeding habit and conservation status of collected freshwater fish species of Alaknanda river

| Scientific name | Common name | Mean length (cm) | Mean weight (gm) | Feeding habit | IUCN status (2010) |
|---|---|---|---|---|---|
| *Schizothorax richardsonii* | Snowtrout | 21.58±3.56 | 88.83±33.62 | Herbivorous | Vulnerable |
| *Crossocheilus latius latius* | Gangetic Latia | 19.65±2.38 | 75.16±27.93 | Herbivorous, Detritophagic | Least Concern |
| *Garra lamta* | Lamta Garra | 18.93±1.78 | 92.76±33.62 | Herbivorous, Detritophagic | Least Concern |
| *Schizothorax progastus* | Dinnawah Snowtrout | 20.35±1.79 | 70.64±19.87 | Omnivorous | Least Concern |
| *Barilius bendelisis* | Hamilton's Barila | 11.28±1.55 | 17.43±7.07 | Omnivorous | Least Concern |

**Table 2.** Biochemical composition (%) of muscle tissue of five freshwater fish species (Mean±SD)

| Fishes | Moisture | Protein | Lipids | Carbohydrate |
|---|---|---|---|---|
| *Schizothorax richardsonii* | 78.02±0.73 | 18.40±5.30 | 2.04±0.29 | 1.89±0.51 |
| *Crossocheilus latius latius* | 71.95±3.77 | 20.45±5.10 | 2.15±0.52 | 2.03±0.42 |
| *Garra lamta* | 73.17±3.06 | 21.22±4.74 | 2.13±0.47 | 1.92±0.37 |
| *Schizothorax progastus* | 77.90±1.01 | 18.48±4.63 | 2.06±0.51 | 1.91±0.40 |
| *Barilius bendelisis* | 74.02±2.25 | 19.85±6.51 | 4.58±1.39 | 1.94±0.47 |
| Fisher's values (F) | 0.465 | 7.327 | 19.011 | 0.159 |
| Probability of significance (p) | 0.7609 | 8.36E-05 | 7.25E-10 | 0.9579 |

**Table 3.** Average composition of macroelements in the muscle tissue of five freshwater fish species (Mean±SD)

| Fishes | Na (mg $100g^{-1}$) | K (mg $100g^{-1}$) | Ca (mg $100g^{-1}$) |
|---|---|---|---|
| *Schizothorax richardsonii* | 102.51±41.38 | 304.90±36.84 | 359.37±39.43 |
| *Crossocheilus latius latius* | 125.20±23.53 | 348.41±26.22 | 500.51±31.70 |
| *Garra lamta* | 155.89±32.55 | 263.00±41.91 | 407.11±37.72 |
| *Schizothorax progastus* | 96.31±20.00 | 264.75±33.17 | 321.55±52.35 |
| *Barilius bendelisis* | 122.40±21.12 | 238.57±31.21 | 504.78±40.94 |
| Fisher's values (F) | 8.781 | 37.854 | 15.119 |
| Probability of significance (p) | 5.71E-06 | 1.52E-15 | 6.57E-09 |

(Alloway 2008). Zn was maximum (3.163 mg $100g^{-1}$) in *B. bendelisis* and minimum (2.873 $100g^{-1}$) in *S. richardsonii*. The amount of Cu was highest in *S. progastus* (0.715 mg $100g^{-1}$) and lowest in *C. latius latius* (0.621 mg $100g^{-1}$). Pb content ranged from 0.154 mg $100g^{-1}$ to 0.346 mg $100g^{-1}$ with its lowest and highest concentration in *C. latius latius* and *B. bendelisis*, respectively. Both Zn and Pb showed higher accumulation pattern in omnivorous species than herbivorous. However, no specific bioaccumulation pattern was observed in relation to Cu concentration. Pb is usually a non- essential element and can be toxic to human beings when taken in high doses. High doses of Pb cause liver damage and renal failure in humans (Salem et al 2000). It is responsible for increased mucus formation, reduces survival, growth, development and metabolism of fishes. Pb has no biological role and was in lower amount in fish tissue and also less than the highest permissible amount (FAO 1983) which proves its suitability for consumption.

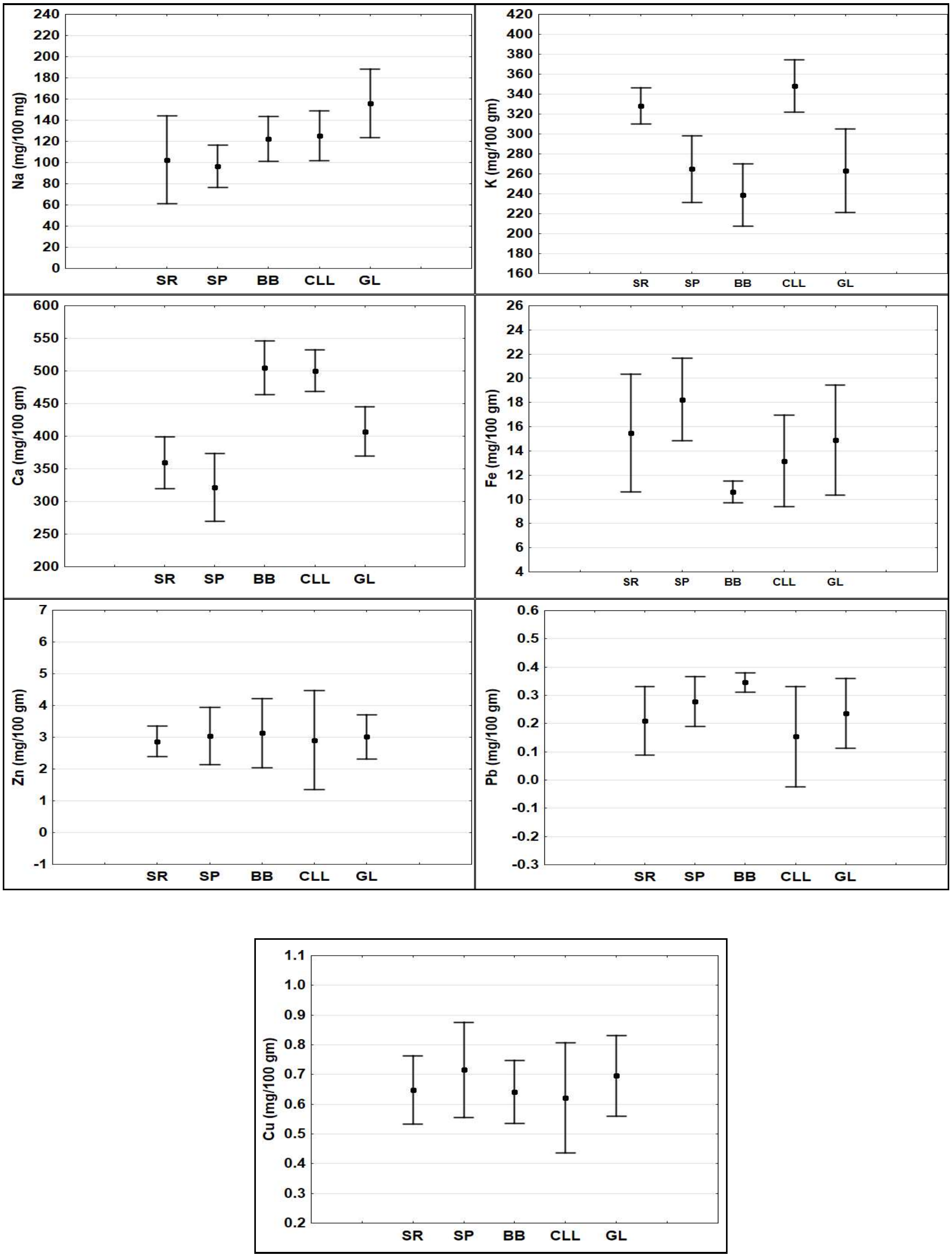
The differences in Zn and Cu levels among analyzed five fishes were insignificant, yet higher Zn level in omnivorous fishes may be attributed to higher trophic level of the fish. However, no specific trend for Cu accumulation with trophic position was observed in the present study. The essential trace elements Fe, Zn and Cu were found in good quantity while Pb was comparatively lower in the muscle tissue of selected fish species. A significant difference was observed in Fe, and Pb content but no significant difference was in Zn among the five fish species (Table 4). The mean concentrations of seven mineral elements in studied fish species of Alaknanda river are shown in Figure 1.

Carnivorous fish species are usually known to be active swimmers. The activities of these fish species are known to accumulate high levels of heavy metals in their body (Karadede et al 2004). Active and fast swimmers usually have high metabolic rate which resulting into higher accumulation of some trace elements in comparison to other bottom dwelling fishes (Canli and Atli 2003). *B. bendelisis* being active and fast swimmer showed higher accumulation of Zn and Pb content. Omnivorous fishes feed upon algae, diatoms, plankton, aquatic insects and their larvae, crustacean, and detritus. The accumulation of Fe, Zn, and Pb in omnivorous fish muscle tissue may be due to their preference for variety of food material intake. However, the accumulation of these three trace elements in herbivorous fish muscle tissue was found lower than omnivorous fishes. This may be due to their preference for specific food items as they are primary consumers and present in lower trophic level. Sediment is also considered a source of trace elements for fishes and their accumulation also depends on feeding habits. Thus, *S. progastus,* an omnivorous bottom-feeder fish, had higher Fe accumulation than *B. bendelisis* which is omnivorous surface-feeder fish. The four fish species namely, *S. richardsonii, S. progastus, C. latius latius*, and *G. lamta* are bottom-feeders and thus, accumulate higher Fe content than *B. bendelisis* which is surface-feeder. Metal accumulation in fish body can be considered as an index of pollution in the aquatic environment (Karadede-Akin and Unlu 2007, Tawari-Fufeyin and Ekaye 2007). Bioaccumulation of trace metals is usually species-specific (Rakocevic et al 2018). The variations observed in the bioaccumulation trend may also be due to different feeding habits, ecological needs and metabolism of fishes (Qiao-qiao et al 2007, Monikh et al 2013).

The bioaccumulation pattern for Zn was observed as *B. bendelisis>S. progastus>G. lamta>C. latius latius>S. richardsonii.* General trend for Pb bioaccumulation was *B. bendelisis>S. progastus>G. lamta>S. richardsonii>C. latius latius* and for Cu it was *S. progastus>G. lamta>S. richardsonii>C. latius latius>B. bendelisis*. However, the accumulation pattern of trace elements in the muscle tissue was Fe>Zn>Cu>Pb in all the studied fish species (Table 4). The abundance pattern of macroelements was as Ca>K>Na while trace elements as Fe>Zn>Cu>Pb in the present study. Similar trend was reported earlier researchers (Shantosh

**Table 4.** Average composition of trace elements in the muscle tissue of five freshwater fish species (Mean±SD)

| Fishes | Fe (mg $100g^{-1}$) | Zn (mg $100g^{-1}$) | Pb (mg $100g^{-1}$) | Cu (mg $100g^{-1}$) |
|---|---|---|---|---|
| *Schizothorax richardsonii* | 15.48±4.88 | 2.873±0.47 | 0.209±0.12 | 0.670±0.09 |
| *Crossocheilus latius latius* | 13.16±3.77 | 2.907±1.56 | 0.154±0.18 | 0.621±0.18 |
| *Garra lamta* | 14.89±4.55 | 3.019±0.70 | 0.236±0.12 | 0.696±0.14 |
| *Schizothorax progastus* | 18.24±3.42 | 3.048±0.90 | 0.278±0.09 | 0.715±0.16 |
| *Barilius bendelisis* | 10.62±0.91 | 3.163±1.09 | 0.346±0.03 | 0.641±0.11 |
| FAO, 1983 (mg $kg^{-1}$) | - | 50.0 | 5 | 10 |
| WHO, 1995 (mg $kg^{-1}$) | - | 100 | 2 | 30 |
| Fisher's values (F) | 6.601 | 0.169 | 5.948 | 0.907 |
| Probability of significance (p) | 9.5E-05 | 0.9729 | 0.0002 | 0.4846 |




**Acronyms:** SR- *Schizothorax richardsonii*; SP- *Schizothorax progastus*; BB- *Barilius bendelisis*; CLL-*Crossocheilus latius latius*; GL- *Garra lamta*.

**Fig. 1.** Whisker plots showing mean concentrations of Na, K, Ca, Fe, Zn, Cu, and Pb in five fish species of Alaknanda river

and Sarojnalini 2018, Khitouni et al 2018. Sharma and Singh 2019). However, Bhouri et al (2010) and Abdul and Sarojnalini (2012) recorded the abundance pattern as K>Na>Ca and Zn>Fe>Cu for macro and trace elements in muscle tissue of some fishes. Sarma et al (2019) found more Zn than Fe in muscle tissue of six small indigenous fish species. Similar results were also recorded in earlier studies (Hei and Sarojnalini 2012, Njinkoue et al 2016).

Cluster analysis grouped the fish species into three groups having high similarity percentage (79%). *B. bendelisis* and *C. latius latius* formed the first group, *S. richardsonii* and *S. progastus* formed second group and *S. richardsonii, S. progastus* and *G. lamta* formed the third group based on 94, 95 and 90% average similarity, respectively (Table 5, Fig. 2). Highest (79%) similarity between three groups in Bray-Curtis cluster reveals that all selected fishes have more or less similar profile of mineral content which might be due to similar habitat conditions in the central Himalayan region.

The observed level of trace element concentration (Zn, Pb, Cu) in the muscle tissue of analysed fish species were below the maximum permissible limit set by FAO (1983) and WHO (1995). The studied fish species were free from

**Table 5.** Fishes rich in essential mineral elements in their tissues

| Minerals | Species rich in specific mineral element |
|---|---|
| Macroelements | |
| Sodium | *Garra lamta, Crossocheilus latius latius* |
| Potassium | *Crossocheilus latius latius, Schizothorax richardsonii* |
| Calcium | *Barilius bendelisis, Crossocheilus latius latius, Garra lamta* |
| Microelements | |
| Iron | *Schizothorax progastus, Schizothorax richardsonii, Garra lamta* |
| Zinc | *Barilius bendelisis, Schizothorax progastus, Garra lamta* |
| Copper | *Schizothorax progastus, Garra lamta, Schizothorax richardsonii* |

**Table 6.** Estimated daily intake (EDI), Target hazard quotient (THQ), Hazard index (HI) and Target cancer risk (TR) of metals through consumption of fishes from Alaknanda river

| Fish species | Metals | Average Conc. | $R_fD$ (mg $kg^{-1}$ $day^{-1}$) | EDI (mg $day^{-1}$ $70kg^{-1}$ body weight) | THQ | HI | TR |
|---|---|---|---|---|---|---|---|
| *S. richardsonii* | Cu | 0.641 | 0.040 | 0.00017 | 0.0044 | 0.027 | - |
| | Fe | 15.48 | 0.700 | 0.0042 | 0.006 | | - |
| | Zn | 2.873 | 0.300 | 0.00078 | 0.0026 | | - |
| | Pb | 0.209 | 0.004 | 0.00006 | 0.014 | | 0.00000048/ $4.8\times10^{-7}$ |
| *C. latius latius* | Cu | 0.670 | 0.040 | 0.00018 | 0.0045 | 0.023 | - |
| | Fe | 13.16 | 0.700 | 0.0036 | 0.005 | | - |
| | Zn | 2.907 | 0.300 | 0.00079 | 0.0026 | | - |
| | Pb | 0.154 | 0.004 | 0.00004 | 0.011 | | 0.00000036/ $3.6\times10^{-7}$ |
| *G. lamta* | Cu | 0.621 | 0.040 | 0.00016 | 0.0042 | 0.029 | - |
| | Fe | 14.89 | 0.700 | 0.0040 | 0.0058 | | - |
| | Zn | 3.019 | 0.300 | 0.00082 | 0.0027 | | - |
| | Pb | 0.236 | 0.004 | 0.00006 | 0.016 | | 0.00000054/ $5.4\times10^{-7}$ |
| *S. progastus* | Cu | 0.696 | 0.040 | 0.00019 | 0.0047 | 0.034 | - |
| | Fe | 18.24 | 0.700 | 0.005 | 0.0071 | | - |
| | Zn | 3.048 | 0.300 | 0.00083 | 0.0028 | | - |
| | Pb | 0.278 | 0.004 | 0.000076 | 0.019 | | 0.00000064/ $6.4\times10^{-7}$ |
| *B. bendelisis* | Cu | 0.715 | 0.040 | 0.00019 | 0.0049 | 0.034 | - |
| | Fe | 10.62 | 0.700 | 0.0029 | 0.004 | | - |
| | Zn | 3.163 | 0.300 | 0.00086 | 0.0029 | | - |
| | Pb | 0.346 | 0.004 | 0.000094 | 0.023 | | 0.0000008/ $8\times10^{-7}$ |

$R_fD$= Recommended doses of heavy metals as established by the United States Environmental Protection Agency (2011).

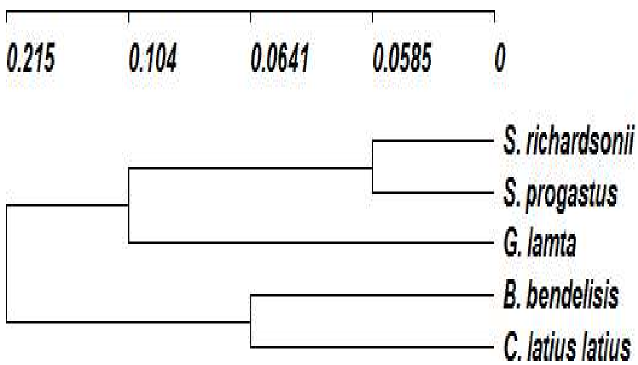



**Fig. 2.** Bray-Curtis cluster grouping of the fish species on the basis of mineral composition

pollution load and toxicity hence may be recommended safe for human intake and should be included in daily meals. The present findings also reflected that these fishes are valuable bio indicator to screen the health of aquatic ecosystem. The conservation, augmentation, and culture of these valuable species will be instrumental for ameliorating malnutrition problem of the countries like India, Pakistan, Afghanistan, Bangladesh, Bhutan, Nepal, China, Turkey, Srilanka, Myanmar and Thailand.

**Health risk assessment by estimation of EDI, THQ, HI and TR of heavy metals in adult person (70 kg body weight) on consuming fishes from Alaknanda River:** The EDI values of studied fishes were recorded below the R*FD* values. EDI for Fe, Zn, Pb, and Cu were still lower than $R_fD$ indicating lower probability for risk to occur. THQ values are potential risk assessment parameters of metals related to the consumption of contaminated fish and shellfish (Chien et al 2002, Zheng et al 2007, Storelli 2008). HI value was in the following sequence, *B. bendelisis* = *S. progastus* >*G. lamta* >*S. richardsonii* >*C. latius latius*. HI values for *B. bendelisis* and *S. progastus* were observed to be 0.034 each while for *S. richardsonii*, *C. latius latius*, *G. lamta*, were 0.027, 0.023, and 0.029, respectively (Table 6). In all the studied fish samples HI value for all the studied fish species were found below 1 which indicates that intake of metals by consuming these fishes will not result in hazard risk for humans. TR values for studied fishes, S. *richardsonii*, *C. latius latius*, *G. lamta*, *B. bendelisis* and *S. progastus* were observed to be lower than $10^{-6}$ which indicates no possible carcinogenic risk for consumers. Hence, Alaknanda river still represents a good and healthy riverine ecosystem. Also, the fish species are free from any toxicity and thus may be recommended in daily diet. Regular monitoring of heavy metals in fishes as well as in river water should be performed to prevent more accumulation of metals in humans.

## CONCLUSION

In spite of the variations in mineral elements, all the studied five fish species were abundant source of animal protein, macro and trace elements. The trace metal concentrations were below the highest permissible limits hence safe for human consumption. Risk assessment parameters, THQ, HI and TR associated with fish consumption clearly indicates that fishes of the Alaknanda river are still suitable for long-term consumption and will not cause any harmful effects in humans. Based on the nutritional status and negligible toxicity, the nutritional information will be helpful in dietary counseling, consumer guidance and prioritization of fish species for their culture and augmentation on large scale to combat hunger and malnutrition.

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# Proximate, Minerals and Microbial Properties of Chickpea Nuggets Supplement with Green Leaf Powder

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***Abstract***: This study was undertaken with the objectives to prepare nuggets with improved nutritional value and better utilization of underutilized green leaf. The proximate composition of green leaf powder blended chickpea nuggets, moisture content, crude protein content and crude fat content decrease with the increase in the level of green leaf powder while as the total ash content of nuggets increased with the increased in incorporation level of green leaf powder. The highest mean crude fiber total ash and available carbohydrate content of 3.57 , 6.05, 67.51 per cent, respectively were recorded in $T_7$(82:18::chickpea flour**:** green leaf powder).The calcium and iron content of green leaf powder blended chickpea nuggets increased with the increasing level of green leaf powder. The highest mean calcium and iron content of 236.08 and 10.00 mg per 100g was recorded in $T_7$(82:18::chickpea flour**:** green leaf powder).The microbial load of green leaf powder blended chickpea nuggets was within the permissible limits of BIS ($4 \times 10^4$ cfu $mL^{-1}$) throughout storage period of three months.

***Keywords*:** Proximate, Nuggets, Incorporation, Permissible limits, BIS, Chickpea flour**,** Green leaf powder

Today's health-conscious consumers demand for high quality, shelf-stable and ready-to-use processed food products that are convenient and promote health (Joshi et al 2019). Nugget is a convenience food that is healthy, sensory acceptable and convenient to consumed. Pulse flours and fractions have been used as ingredients in the formulation of meat products (e.g., sausages, nuggets, burgers, etc.) successfully (Boye et al 2010). The use of green leaf powder as a dietary supplement is thus increasing in parallel with the research on its multitudinous effects on human health and designer foods. Amaranthus have been domesticated as leaf vegetables, potherbs, ornamentals or as fodder (Kachiguma 2015) and is available abundantly during rainy season and are very good source of calcium ranging from 300-800 mg/100 gm. The amaranth being rich in protein, calcium and iron can be used as supplement in cereal based diets and consumption of these nutrient rich products can contribute significantly towards improving the nutritional status of the population, (Singh et al 2014). Radish (*Raphanus sativus* L) is the one of the most ancient, cool season and cold tolerant root vegetable of *Brassicaceae* family. The leaves of radish are good source of protein and found to have biological value of 76.6 with the digestibility co-efficient of 73.5% may be due to the presence of nitrogenous fraction of t twenty-two amino acids (Ankita and Prasad 2015). Chickpea (*Cicer arietinum* L.), commonly known as Bengal gram or gram, belongs to the family *Fabaceae,* is one of the most important and widely consumed leguminous crop in India. Chickpea is known to be a good source of carbohydrates, proteins, vitamins and minerals and contains high protein (20.3-24.5%) and the protein quality is considered to be better than other pulses. It is low in fat and sodium content and as such, beneficial for diabetics and hypertensive individuals. It is considered as a 'functional food' along with its role in providing protein and fiber (Alrayyes 2018). Keeping in view the consumers demand and overall health benefits of chickpea and green leaf powder (Amaranthus and radish), this study was undertaken with the objectives to prepare nuggets with improved nutritional value which requires less time for preparation and better utilization of underutilized green leaf.

## MATERIAL AND METHODS

**Preparation of raw materials:** The healthyradish and amaranth leaves were washed, blanched (80°C for 3min), dried (5-6 hrs at 55°C, tray dryer), crushed and mixed to prepared green leaf powder in the ratio of 50:50::radish: green leaf powder. The split dehulled chickpea was cleaned, washed and soaked for 10-12 hrs. The soaked chickpea was steamed (80°C for 10 min), dried (cabinet dryer, 55-60°C) and then finally ground into flour.

**Formulation of nuggets:** Seven formulations of nuggets with different percentage of chickpea flour and green leaf powder have been formulated in this study. Nuggets preparation was started by blending chickpea flour and green leaf powder in different ratios (100:0, 97:3, 94:6, 91:9, 88:12, 85:15, 82:18) along with 30g corn flour (as binder) and coarse ground spice blend (1gm coriander, 1.5gm black pepper, 1gm zeera, 1.5gm coarse red chilli powder, 5gm salt). A chickpea nugget (100:0) was chosen as reference and control sample (Fig. 1).

**Analysis of proximate composition:** Moisture content in the samples was determined by following the oven drying method as the loss in weight due to evaporation from sample at a temperature of 105±1°C. The crude protein content was determined by micro Kjeldahl method, using the factor 6.25 for converting nitrogen content into crude protein (Sadasivam and Manickam 2008). Crude fat (Soxhlet extraction technique) and total ashwere estimated as per methodology given in AOAC (2005). The available carbohydrate content was estimated by the difference method. It was calculated by subtracting the sum of percentage of moisture, crude fat and crude protein and ash contents from 100 according to AOAC (2005).

**Mineral content:** The mineral contents were determined after the ash determination. The ash residue of each formulation was digested with perchloric acid and nitric acid (1:4) solution. The samples were left to cool and contents were filtered through Whatman filter paper 42. Each sample solution was made upto a final volume of 25 ml with distilled water (AOAC, 2005). The aliquot was used separately to determine the mineral contents of calcium and iron by using an Atomic Absorption Spectrophotometer (Spectra AA 220, USA Varian).

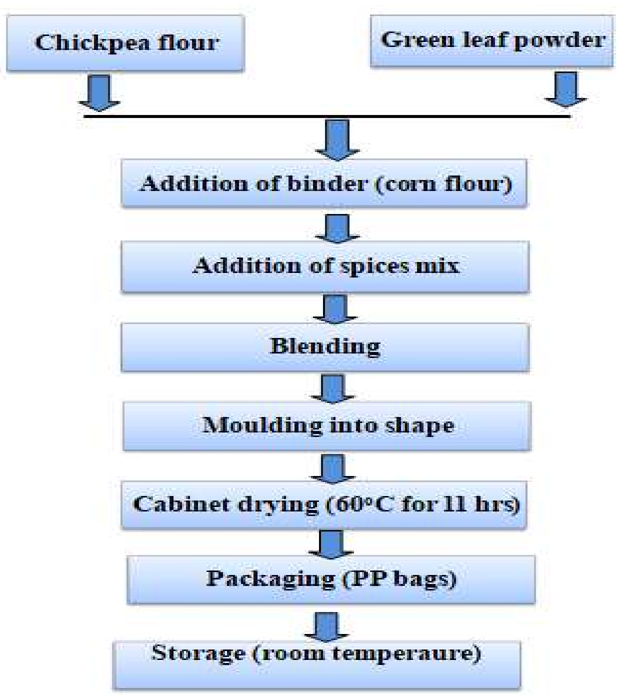



**Fig. 1.** Flow chart for preparation of green leaf powder blended chickpea nuggets

**Microbial analysis (Total microbial count):** Spread plate technique, described by Palczar and Chan (1991) was followed. 1g of sample was aseptically transferred into test tube containing 9 ml of sterile water and was mixed vigorously. After mixing, 1ml of this mixture was again transferred to a test tube containing 9 ml sterile water for further dilution. The process was continued until 4th dilution ($10^{-4}$). Nutrient agar was inoculated with 0.1 ml of diluted sample ($10^{-4}$), by spread plating technique and incubated at 37°C for 24 hours. Colonies were counted and multiplied by dilution factor.

**Statistical analysis:** The results obtained were statistically analyzed using completely randomized design (CRD) and CRD factorial.

## RESULTS AND DISCUSSION

**Proximate composition of green leaf powder blended chickpea nuggets:** The maximum mean moisture content of 9.76 percent was in $T_1$ (Control nuggets) while as least of 7.78 percent for $T_7$ (Table 1). The supplementation of green leaf powder decreased the moisture content of green leaf powder blended chickpea nuggets. The decrease in moisture content might be because of low moisture content in green leaf powder in comparison to chickpea. Elhadi et al (2017) reported decreased in moisture content of chicken patties with the increase of moringa leaf powder is in line with our findings. Similar to present observation the moisture content of raw beef patties decreased as the percentage of moringa flour increased (Al-juhaimi et al 2017). Hawashin et al (2016) reported that the moisture content of raw beef patties gradually decreased as the concentration of defatted olive cake increased. The mean moisture content of green leaf powder blended chickpea nuggets increased from 7.81 to 9.72 percent during three months of storage. Khatoniar et al (2018) observed gradual increase in moisture content of dehydrated greens incorporated value added products.. Similarly, Bashir et al (2019) and Slathia et al (2016) also mentioned the increase in the moisture content of meat analog nuggets incorporated with flaxseed powder and noodles made with wheat flour supplemented with germinated mung bean flour during storage.

The maximum and minimum mean crude protein content of 21.49 and 17.90 percent were $T_1$ control and $T_7$, respectively. The supplementation of green leaf powder decreased crude protein content of green leaf powder blended chickpea nuggets and is attributed due to the fact that crude protein content of chickpea is more than the greens. Mendiratta et al (2013) reported lower protein content in vegetable nuggets than control due to lower protein content of vegetables. Similar finding has been reported by Bhosale et al (2011) for carrot and meshed potato incorporated chicken nuggets.During storage period of three months, the crude protein content decreased from 20.10 to 18.35 percent in green leaf powder blended chickpea powder. Verma et al (2010) and Kassem and Emara (2010) also reported a reduction in protein content during storage.

The highest mean crude fat content of 2.98 per cent was in $T_1$ (Control nuggets) while as least of 2.21 percent in $T_7$ as reflected. The supplementation of green leaf powder decrease the crude fat content of green leaf powder blended chickpea nuggets. The decrease in crude fat content might be because of low crude fat content in green leaf powder in comparison to chickpea. Sharma et al (2015) reported a decreased in crude fat of nuggets with the increase in mushroom fortification. Similar to present observation, the crude fat content of *dhokla* decreased as the percentage of dehydrated *Celosia argentea* increased (Gupta and Prakash 2011). The mean crude fat content of green leaf powder blended chickpea nuggets decreased from 3.61 to 1.76 percent during three months of storage. Khursheed (2014) also reported a decreased in crude fat content of high fiber chicken meat ball blended with knol khol. Similar trend was also observed by Sanchez-Escalante et al (2001) and Fernández-López et al (2004). Ash content is the measure of total amount of minerals present within a food. The maximum and minimum mean ash content of 6.05 and 3.88 percent were in $T_7$ and $T_1$ respectively (Table 2). The supplementation of green leaf powder increased ash content of nuggets and is due to the fact that ash content of vegetables added in the product is high as compare to chickpea.The ash content of moringa muffin showed an increase which indicate higher amount of minerals in it attributed by dried moringa leaf powder incorporation (Srinivasamurthy et al 2017). Mouminah (2015) observed significance enhancement in ash content of moringa cookies. During storage period of three months, the ash content decreased from 4.88 to 4.59 percent in green leaf powder blended chickpea nuggets. The decrease in ash content might be due to increase in moisture content and mineral loss by Millard reaction during storage (Nadarajah and Mahendra 2015). Hasanuzzaman et al (2014) also reported a reduction in ash content of tomato candy during storage. The results are in accordance with Bashir (2019) who reported a decrease in total ash content during storage period of six month in meat analog nuggets.

The highest mean crude fiber content of 3.67 percent was in $T_7$ while as least of 2.32 percent recorded for treatment $T_1$ (control nuggets) (Table 3). The supplementation of green leaf powder increase the crude fiber content of green leaf powder blended chickpea nuggets. The increase in crude fiber content might be attributed to high crude fiber content in green leaf powder in comparison to chickpea. Hernandez et al (2016) reported that pastas with both amaranth flour and leaves demonstrated the highest crude fiber content. Singh et al (2009) reported increase in crude fiber content of amaranth powder supplemented biscuits. The mean crude fiber content of green leaf powder blended chickpea nuggets decreased from 3.61 to 1.76 percent during three months of storage period. Rathod (2015) also reported a decrease in crude fiber content of multigrain cookies formulated from partially defatted soy and oat flour. The least mean available carbohydrate content of 62.72 per cent was for $T_1$ control while as $T_7$ reflected highest mean available carbohydrate

**Table 1.** Effect of treatment and storage on moisture content (%), crude protein content (%) and crude fat (%) of green leaf powder blended chickpea nuggets

| Treatment | Storage periods (Months) | | | | Mean | Storage periods (Months) | | | | Mean | Storage periods (Months) | | | | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | | 0 | 1 | 2 | 3 | | 0 | 1 | 2 | 3 | |
| $T_1$ (100:00::CP:GLP) | 8.88 | 9.39 | 9.92 | 10.83 | 9.76 | 22.25 | 21.97 | 21.10 | 20.63 | 21.49 | 4.07 | 3.12 | 2.62 | 2.09 | 2.98 |
| $T_2$ (97:3::CP:GLP) | 8.27 | 8.80 | 9.32 | 10.12 | 9.13 | 21.46 | 21.05 | 20.57 | 19.60 | 20.67 | 3.92 | 2.95 | 2.46 | 1.91 | 2.81 |
| $T_3$ (94:6::CP:GLP) | 8.00 | 8.55 | 9.13 | 9.91 | 8.90 | 20.55 | 20.10 | 19.45 | 18.10 | 19.55 | 3.77 | 2.73 | 2.31 | 1.80 | 2.65 |
| $T_4$ (91:9::CP:GLP) | 7.82 | 8.36 | 8.94 | 9.74 | 8.72 | 19.87 | 19.50 | 18.81 | 18.01 | 19.05 | 3.61 | 2.66 | 2.24 | 1.73 | 2.56 |
| $T_5$ (88:12::CP:GLP) | 7.53 | 8.03 | 8.59 | 9.42 | 8.39 | 19.29 | 19.01 | 18.53 | 17.75 | 18.65 | 3.46 | 2.50 | 2.09 | 1.67 | 2.43 |
| $T_6$ (85:15::CP:GLP) | 7.30 | 7.84 | 8.42 | 9.28 | 8.21 | 18.85 | 18.58 | 17.97 | 17.21 | 18.15 | 3.31 | 2.46 | 2.06 | 1.65 | 2.37 |
| $T_7$ (82:18::CP:GLP) | 6.88 | 7.50 | 8.02 | 8.72 | 7.78 | 18.45 | 18.20 | 17.81 | 17.15 | 17.90 | 3.16 | 2.29 | 1.90 | 1.49 | 2.21 |
| Mean | 7.81 | 8.35 | 8.91 | 9.72 | | 20.10 | 19.77 | 19.18 | 18.35 | | 3.61 | 2.67 | 2.24 | 1.76 | |

| Effects | C.D. (p=0.05) | Effects | C.D. (p=0.05) | Effects | C.D. (p=0.05) |
|---|---|---|---|---|---|
| Treatment | 0.05 | Treatment | 0.08 | Treatment | 0.02 |
| Storage | 0.02 | Storage | 0.10 | Storage | 0.01 |
| Treatment × Storage | 0.03 | Treatment × Storage | 0.05 | Treatment × Storage | 0.03 |

CP: Chickpea flour; GLP: Green leaf powder content of 67.51 (Table 3). The available carbohydrate increased with increasing the level of green leaf powder this might be attributed to higher available carbohydrate in green leaf powder. During storage period of three months, the available carbohydrate content increased from 63.59 to 67.57 percent in green leaf powder blended chickpea nuggets. The increase in available carbohydrate content might be due to degradation of polysaccaharide into simple sugar (Jan, 2018). Similar findings were reported by Chukwu and Abdullahi (2015) while analyzing the effects of storage period on proximate composition of cassava flour.

**Minerals composition of nuggets:** The highest mean calcium content of 238.06 mg per 100g was in $T_7$ while as least of 139.00 mg per 100g in $T_1$(control nuggets) (Table 3). The supplementation of green leaf powder increased the calcium content of green leaf powder blended chickpea nuggets. The increase in calcium content might be attributed to high calcium content in green leaf powder in comparison to chickpea. The maximum and minimum mean iron content of 10.00 and 5.49 mg per 100g were in $T_7$ and $T_1$ control respectively (Table 4). The supplementation of green leaf powder increased iron content of green leaf powder blended chickpea nuggets. The increase in iron content is attributed due to the fact that iron content of green leaves powder added in the product is high than the chickpea. Sengev et al (2013) reported a remarkable increase in mineral content upon increasing the level of supplementation of wheat flour with moringa leaf powder. An increased iron content of blended flour (wheat and Amaranthus) with increased incorporation level of amaranth was also reported by Emire

**Table 2.** Effect of treatment and storage on total ash content (%), crude fiber (%) and available carbohydrate content (%) of green leaf powder blended chickpea nuggets

| Treatment | Storage periods (Months) | | | | Mean | Storage periods (Months) | | | | Mean | Storage periods (Months) | | | | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | | 0 | 1 | 2 | 3 | | 0 | 1 | 2 | 3 | |
| $T_1$ (100:00::CP:GLP) | 3.53 | 3.49 | 3.42 | 3.33 | 3.44 | 2.45 | 2.38 | 2.25 | 2.18 | 2.32 | 61.27 | 62.10 | 63.25 | 64.26 | 62.72 |
| $T_2$ (97:3::CP:GLP) | 3.98 | 3.93 | 3.85 | 3.76 | 3.88 | 2.75 | 2.50 | 2.37 | 2.10 | 2.43 | 62.37 | 63.54 | 64.60 | 66.22 | 64.18 |
| $T_3$ (94:6::CP:GLP) | 4.43 | 4.39 | 4.20 | 4.11 | 4.28 | 3.06 | 2.85 | 2.45 | 2.17 | 2.63 | 63.25 | 64.48 | 65.69 | 66.73 | 65.04 |
| $T_4$ (91:9::CP:GLP) | 4.88 | 4.74 | 4.65 | 4.56 | 4.71 | 3.36 | 2.97 | 2.58 | 2.34 | 2.81 | 63.82 | 65.16 | 66.53 | 67.83 | 65.84 |
| $T_5$ (88:12::CP:GLP) | 5.33 | 5.18 | 5.12 | 5.03 | 5.17 | 3.67 | 3.29 | 2.76 | 2.46 | 3.05 | 64.39 | 65.81 | 67.22 | 68.64 | 66.52 |
| $T_6$ (85:15::CP:GLP) | 5.78 | 5.64 | 5.57 | 5.47 | 5.62 | 3.97 | 3.56 | 2.99 | 2.65 | 3.29 | 64.76 | 66.01 | 67.98 | 69.44 | 67.05 |
| $T_7$ (82:18::CP:GLP) | 6.23 | 6.07 | 5.99 | 5.90 | 6.05 | 4.28 | 3.82 | 3.20 | 2.96 | 3.57 | 65.28 | 66.52 | 68.40 | 69.85 | 67.51 |
| Mean | 4.88 | 4.78 | 4.69 | 4.59 | | 3.36 | 3.05 | 2.66 | 2.41 | | 63.59 | 64.80 | 66.24 | 67.57 | |

| Effects | C.D. (p=0.05) | Effects | C.D. (p=0.05) | Effects | C.D. (p=0.05) |
|---|---|---|---|---|---|
| Treatment | 0.08 | Treatment | 0.03 | Treatment | 0.03 |
| Storage | 0.02 | Storage | 0.02 | Storage | 0.02 |
| Treatment × Storage | 0.02 | Treatment × Storage | 0.05 | Treatment × Storage | 0.05 |

CP: Chickpea flour; GLP: Green leaf powder

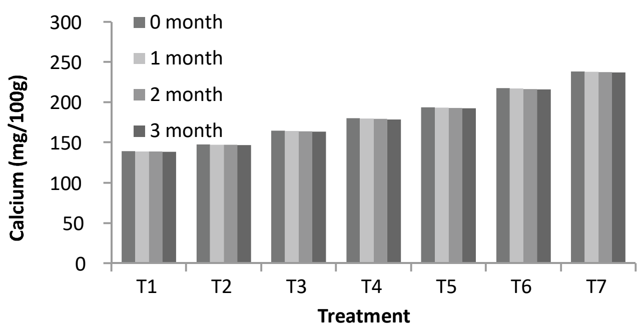
**Table 3.** Effect of treatment and storage on calcium (mg/100g), iron content (mg/100g) and microbial count (□$10^4$ c.f.u/g) of green leaf powder blended chickpea nuggets

| Treatment | Storage periods (Months) | | | | Mean | Storage periods (Months) | | | | Mean | Storage periods (Months) | | | | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | | 0 | 1 | 2 | 3 | | 0 | 1 | 2 | 3 | |
| $T_1$ (100:00::CP:GLP) | 139.10 | 139.02 | 138.86 | 138.51 | 139.00 | 5.82 | 5.71 | 5.40 | 5.02 | 5.49 | ND | ND | 0.240 | 0.831 | 0.536 |
| $T_2$ (97:3::CP:GLP) | 147.56 | 147.31 | 147.08 | 146.85 | 147.23 | 6.91 | 6.82 | 6.53 | 6.13 | 6.60 | ND | ND | 0.231 | 0.786 | 0.509 |
| $T_3$ (94:6::CP:GLP) | 164.48 | 164.30 | 163.93 | 163.51 | 164.23 | 7.42 | 7.29 | 6.92 | 6.64 | 7.07 | ND | ND | 0.218 | 0.719 | 0.469 |
| $T_4$ (91:9::CP:GLP) | 179.86 | 179.54 | 179.06 | 178.37 | 179.64 | 7.79 | 7.08 | 6.76 | 6.50 | 7.03 | ND | ND | 0.205 | 0.653 | 0.429 |
| $T_5$ (88:12::CP:GLP) | 193.70 | 193.32 | 192.70 | 192.31 | 193.44 | 8.35 | 8.20 | 7.87 | 7.32 | 7.94 | ND | ND | 0.190 | 0.590 | 0.390 |
| $T_6$ (85:15::CP:GLP) | 217.34 | 216.93 | 216.27 | 215.79 | 217.33 | 9.21 | 9.05 | 8.75 | 8.18 | 8.80 | ND | ND | 0.175 | 0.484 | 0.330 |
| $T_7$ (82:18::CP:GLP) | 238.30 | 237.88 | 237.36 | 236.80 | 238.06 | 10.45 | 10.34 | 9.89 | 9.33 | 10.00 | ND | ND | 0.150 | 0.452 | 0.301 |
| Mean | 182.93 | 182.79 | 182.62 | 182.48 | | 7.99 | 7.78 | 7.45 | 7.02 | | ND | ND | 0.201 | 0.645 | |

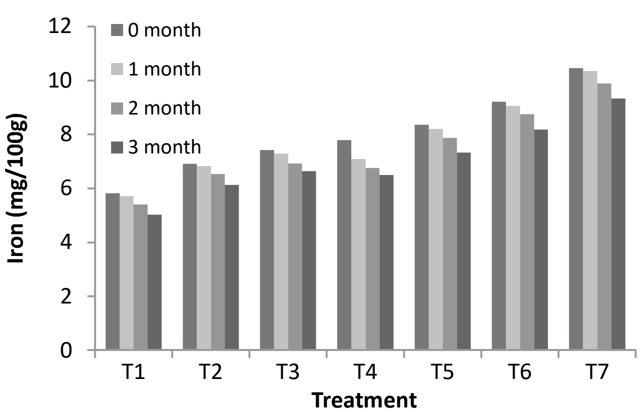
| Effects | C.D. (p=0.05) | Effects | C.D. (p=0.05) | Effects | C.D. (p=0.05) |
|---|---|---|---|---|---|
| Treatment | 1.03 | Treatment | 0.10 | Treatment | 0.04 |
| Storage | NS | Storage | 0.01 | Storage | 0.02 |
| Treatment × Storage | 0.05 | Treatment × Storage | 0.03 | Treatment × Storage | 0.05 |

CP: Chickpea flour; GLP: Green leaf powder and Arega (2012). Veena et al (2019) also reported increased iron in beetle leaf incorporated pasta. The mean calcium and iron content of green leaf powder blended chickpea nuggets decreased from 182.93 to 182.48 and 7.99 to 7.02 mg per 100g, respectively during three months of storage periods (Fig. 2). The decrease in minerals content of green leaf powder blended chickpea nuggets might be due to interaction of these minerals with protein and carbohydrate (Millard reaction products) making them unavailable(Akhtar et al 2010). Sharma et al (2017) observed decrease in mineral content of flaxseed blended cracker throughout storage.

**Microbial evaluation of nuggets (Total microbial count):** The microbial load of green leaf powder nuggets was significantly affected by treatment (Table 3). The highest mean total microbial count of $0.536 \times 10^4$ (c.f.u/g) was in $T_1$ (100:00::CP:GLP) whereas the lowest of $0.301 \times 10^4$ (c.f.u/g) in $T_7$ (82:18::CP:GLP).The supplementation of green leaf powder decreased the microbial load of green leaf powder blended chickpea nuggets because low pH value inhibit the growth of microorganism and reduce the content of biogenic amines. Ahn et al (2019) and Mendiratta et al (2013) also reported that the addition of dried radish leaves and roots reduce the pH, prevents microbial growth and affects lipid oxidation. Shinde (2006) observed antimicrobial effect of radish in pork patties are in line with our findings. With the advancement of storage period the total microbial count of green leaf powder blended chickpea nuggets increased significantly from 0 to $0.645 \times 10^4$ (c.f.u/g). The increase in microbial count during storage may be due to increase in moisture content of nuggets that provides favourable environment for microbial growth (Chakroborty and Chakroborty 2017). Nisha (2008) also reported an increase in microbial load during storage of green gram-based meat analog. The microbial load of green leaf powder blended chickpea nuggets was within the permissible limits of BIS ($4 \times 10^4$ cfu $mL^{-1}$) throughout storage period of three months.




a) Calcium content (mg/100g)




b) Iron Content (mg/100g)

**Fig. 2.** Effect of treatment and storage on (a) calcium content (mg/100g) and b) iron content (mg/100g) of green leaf powder blended chickpea nuggets

## CONCLUSION

The increase in level of green leaf powder in the nuggets formulation resulted in nuggets with a higher ash, fibre, calcium and iron content which was an objective of this study. Thus, nutritionally rich nuggets can be prepared from blending underutilized green leaf powder. The green leaf powder blended nuggets formulated in this study being highly nutritious can be recommended for malnourished children.

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# Growth Relationship between Capital Investments and Paddy-Wheat Productivity in Punjab

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***Abstract***: Capital investment is a vital aspect of economic development. The behaviour of farm operators towards the investment in fixed farm assets is dependent on farm location, farm size and the product-mix. Timeliness and accuracy in farm operations through farm machinery is the dire need for obtaining optimal yield levels. Thus, an investigation on the extent of capital investment implicit for these farm assets is of paramount importance. An attempt has been made to establish relationship between capital accumulation and paddy-wheat productivity on Punjab agro-farms. The secondary data were procured from various sources and regression analysis was attempted to find out the correlations. The increase in investment on farm machinery and equipment showed a rise in productivity of main crops of paddy and wheat. Because of the indivisible nature of these assets in relation to the area under command there was a simultaneous increase in related fixed cost. An overview of the study indicated that investments in fixed farm assets, fixed cost of cultivation and yield levels of paddy and wheat continuously grew almost on all farm situations in the state over the period from 1970-71 to 2018-19. Investment on draught animals decreased considerably on all farms of the state during the study period because the bullock labour got substituted by tractors and other machines. Further, it was found that capital investment in fixed assets being the important component could enhance the productivity of paddy and wheat within increase in these investments.

***Keywords***: Growth, Investments, Productivity, Trend, Mechanization

The growth and development of an enterprise as well as of an economy are determined ostensibly by the level of technology and the efficiency of the market mechanism. But it is the use of capital that makes the above two factors operational. Hence, capital is the most vital input required for achieving the much desired goal of growth both in the micro and macro units of the economy and the agriculture sector is no exception. All countries have reported significant growth in agricultural productivity during the period 1980-2013, highest in Bangladesh @1.05% p.a. followed by India (0.52%), Pakistan (0.38%) and Nepal (Asif Reza Anik et al 2017). After independence, the development of agriculture sector was the main focus of government of India. The rate of capital investment, share of agriculture in total GDP and productivity of food grains was reported to be the highest in post green revolution period (Salgotra et al 2018). The farm sector, because of its special characteristics implying higher degree of risk, low productivity, seasonal nature of production coupled with fluctuations in input and output prices, lacked lustre to allure the investors as compared to the other sectors of the economy. However, the advent of new farm technology was witnessed during the late sixties and the early seventies of the last century. It promised higher returns as well as a fillip to the farmers to make investments in irrigation structures and farm machinery and equipment such as tractors and accessories. Lately, the combine harvesters found inclusion in this list. This process of incurring in technology needed capital investment in the above mentioned assets and has not been a one-time phenomenon but a continuous process. It has occurred doubtlessly, the investments in irrigation structures, draught power, harvesters and threshers helped achieving precision and timeliness in operations faster in some areas and slower in the others. Resultantly there was a noticeable increase in the productivity of paddy and wheat, being the major crops. This phenomenon needs an analysis on relationship between growth of capital investments and productivity of these crops. Lately, there has been an impression that the investment in the capital components on the farms, particularly in the agriculturally developed states like Punjab has decreased due to the stagnation in the yields of major crops and the rising capital costs of the farm machinery and equipment. The present study has therefore been conducted to examine the growth in capital investment and paddy-wheat productivity during the post-green revolution periods.

## MATERIAL AND METHODS

The secondary data were used for this study. The data used in the present study were collected from various issues of statistical abstract, Punjab and the Commission on

Agricultural Costs and Prices (CACP), India. The data relating to fixed farm investment on per hectare basis for paddy and wheat pertaining to Punjab state for different periods were collected from CACP reports. The data with respect to net sown area, total cropped area, paddy and wheat area, production and productivity for the period of 1970-71 to 2018-19 were taken from various issues of Statistical Abstract, Punjab. The data regarding farm inventory i.e. farm machinery and implements were also collected from various issues of these statistical abstracts. The data were analyzed by using following statistical tools:

**Annual growth rate (AGR):** Annual rates were computed by taking 1970-71 as a base year with formula, Growth rate = {(current year – base year)/(base year) × 100}÷ total number of reference years

**Correlation analysis:** Correlation analysis was carried out to determine the relationship between farm capital investment on the production of paddy and wheat in the Punjab.

## RESULTS AND DISCUSSION

**Net sown area, total cropped area and cropping intensity:** The perusal of the Figure 1 showed an annual growth rate 0.03 per cent of net sown area, 0.78 per cent of total cropped area and 0.73 per cent in case of cropping intensity over the period of 1970-71 to 2018-19.

The net sown area increased from 4053 to 4250 thousand ha, total cropped area increased from 5678 to 7911 thousand ha and cropping intensity increased from 140 to 187 per cent in Punjab during the period of 1970-71 to 2000-01. Contrary to this, there was decrease in net sown area from 4158 to 4118 thousand ha and in total cropped area from 7882 to 7839 thousand ha during the period of 2010-11 to 2018-19, but cropping intensity increased to 190 per cent. This decrease showed the saturation in farm investments on machinery and equipment.

**Production of paddy and wheat:** Production of the crop relates to the main and by-product of the crop and productivity relates to the per unit production of crop being cultivated on all farms in Punjab. The area, production and productivity level of paddy and wheat crops are discussed in this part of study and given in Table 2. The perusal of the table showed that annual growth rate of wheat remained 1.08, 5.20 and 2.69 per cent, respectively in case of area, production and yield over the period of 1970-71 to 2018-19. On the other hand, this growth rate for paddy remained 14.20, 35.99 and 2.74 per cent in case of area, production and yield, respectively, during the corresponding periods.

The Table 1 depicts an increase in area under wheat from 2299 to 3520 thousand hectares, production from 5145 to 18262 thousand mt and its yield from 2238 to 5188 kg ha$^{-1}$ in Punjab during the period 1970-71 to 2018-19. Also, the area under paddy increased from 390 to 3103 thousand hectare, production from 688 to 12822 thousand mt and its yield increased from 1765 to 4132 kg ha$^{-1}$ during the corresponding period. The continuum increasing trend of area, production and yield of paddy and wheat crops explicitly indicated the

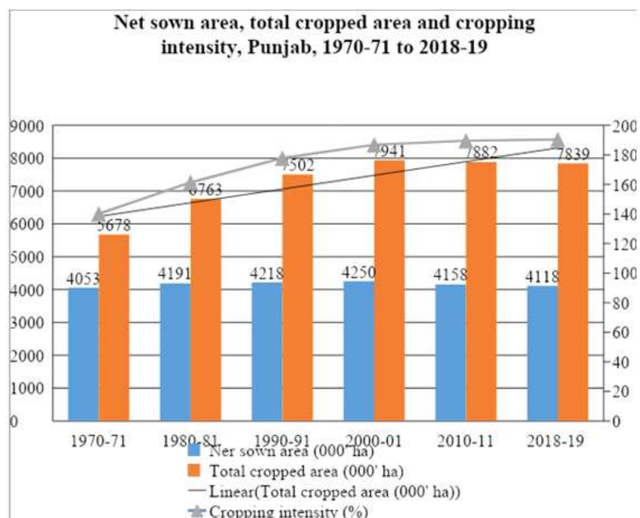


**Fig. 1**. Area sown and cropping intensity in Punjab state

**Table 1.** Area, production and yield of paddy and wheat in Punjab, 1970-71 to 2018-19

| Year | Area (000'ha) | | Production (000'Mt) | | Yield (kg ha$^{-1}$) | |
|---|---|---|---|---|---|---|
| | Wheat | Paddy | Wheat | Paddy | Wheat | Paddy |
| 1970-71 | 2299 | 390 | 5145 | 688 | 2238 | 1765 |
| 1980-81 | 2812 | 1183 | 7677 | 3233 | 2730 | 2733 |
| 1990-91 | 3273 | 2015 | 12159 | 6506 | 3715 | 3229 |
| 2000-01 | 3408 | 2612 | 15551 | 9157 | 4563 | 3506 |
| 2010-11 | 3510 | 2826 | 16472 | 10819 | 4693 | 3828 |
| 2018-19 | 3520 | 3103 | 18262 | 12822 | 5188 | 4132 |
| AGR | 1.08 | 14.20 | 5.20 | 35.99 | 2.69 | 2.74 |

**Source:** Statistical Abstract of Punjab, Economic Adviser, Government of Punjab impact of massive capital investment on farm machinery, implement, irrigation structures etc. during the post green revolution decades. No doubt, better seeds, fertilisers and plant protection measures have a significant role in increasing the yield levels. However, farm machinery and equipment played a vital role in providing timeliness and precision in farm operations thus contributing to crop yields. The combine harvesters had a role in raising yield levels by saving grain losses occurring through use of traditional methods of harvesting and threshing.

**Status of farm machinery:** The increase in farm machinery and implements has a taken place sharply since the inception of green revolution in Punjab agriculture. The role of machinery has transformed the agriculture from subsistence farming to mechanized commercial farming. This section comprises of the status and growth of investment in farm machinery and equipment in Punjab.

As shown in Table 3, there was a substantial growth in the number of machines such as tractors, electric motors and diesel engines, self-propelled and tractor drawn combines. Over a span of last few decades a glimpse of table indicated that the number of machines has increased in each span of five years except seed-cum fertilizer drills and threshers. The total number of tractors rose from 22345 in 1970-71 to 450213 in 2018-19. Electric tube wells increased from 97000 to 1335700 and diesel engine run tube wells from 101000 to 140000. The number of self-propelled combines increased from 10 to 7980, the tractor drawn combines increased from 10 to 4200 during the corresponding period.

**Growth rate of farm machinery:** Table 3 revealed that the highest growth rate was reported in the case of combines during the study period. The annual growth rate indicated that self-propelled combines increased about sixteen times and tractor drawn combines by eight times during the period of 1970-71 to 2018-19. Tractors, electric motors, diesel engine run tube-wells showed 39.08, 26.06 and 0.79 per cent annual growth during the study period.

Various other implements such as disc harrows, seed-cum-fertilizer drills, threshers, tillers, reapers, laser levelers and rotavators have witnessed the highest increase over the period from 1970-71 to 2018-19. Disc harrows showed the highest increase from 6200 to 262500 and tillers, reapers, laser levelers, rotavators from 18210 to 394278 during the corresponding period. Seed-cum-fertilizer drills showed the highest increase from 16000 to 195000 from 1970-71 to 2000-01 but started to decline from 166489 in 2010-11 to 141460 in 2018-19. In case of threshers, the highest increase was 76024 in 1970-71 to 740000 in 2010-11 followed by a substantial decline to 88000 during 2018-19.It was because of their replacement by combine harvesters.

**Growth rate of farm implements:** Table 2 revealed that the annual growth rate of disc harrows, seed-cum fertilizer drills, threshers and tillers, reapers, laser levelers, rotavators were 84.36, 16.00, 0.32 and 42.15 per cent, respectively during the

**Table 3.** Fixed cost for cultivation of paddy and wheat in Punjab (Rs. $ha^{-1}$)

| Year | Wheat | Paddy |
|---|---|---|
| 1996-97 | 9466 | 7772 |
| 1999-2000 | 11312 | 9704 |
| 2004-05 | 12524 | 15006 |
| 2010-11 | 24864 | 27363 |
| 2014-15 | 28873 | 39213 |
| 2015-16 | 32152 | 39814 |
| 2016-17 | 35315 | 40135 |
| 2017-18 | 39179 | 43911 |
| AGR | 14.27 | 21.14 |

**Source:** Directorate of Economics and Statistics, Department of Agriculture, Cooperative and Farmers Welfare, Govt. of India

**Table 2.** Status of farm machinery in Punjab, 1970-71 to 2018-19

| Year | Farm machinery (No) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Tractors | Electric tube wells | Diesel engine tube wells | Self-propelled combines | Tractor drawn combines | Disc harrows | Seed cum fertilizer drills | Threshers | Tillers, reapers, laser levellers, rotavators |
| 1970-71 | 22345 | 97000 | 101000 | 10 | 10 | 6200 | 16000 | 76024 | 18210 |
| 1980-81 | 110000 | 323000 | 320000 | 80 | 110 | 70600 | 45800 | 245000 | 95200 |
| 1990-91 | 265000 | 610000 | 200000 | 1900 | 3100 | 215000 | 100000 | 297000 | 198100 |
| 2000-01 | 405000 | 765000 | 170000 | 5000 | 5200 | 305000 | 195000 | 350000 | 299300 |
| 2010-11 | 434000 | 1141606 | 240000 | 8130 | 6056 | 210000 | 166489 | 740000 | 345000 |
| 2018-19 | 450213 | 1335700 | 140000 | 7980 | 4200 | 262500 | 141460 | 88000 | 394278 |
| AGR | 39.08 | 26.06 | 0.79 | 1626.53 | 855.10 | 84.36 | 16.00 | 0.32 | 42.15 |

AGR= Annual growth rate
**Source:** Statistical Abstract of Punjab, Economic Adviser, Government of Punjab.

period of 1970-71 to 2018-19.

**Fixed cost of cultivation:** The fixed cost included repair and maintenance, interest and deprecation cost of fixed assets and was calculated on per hectare basis. Similarly, its average growth rate was calculated on annual basis and shown in Table 3. The perusal of the table showed that the annual growth rate of fixed cost of cultivation was 14.27 and 21.14 per cent in case of paddy and wheat crops, respectively from 1996-97 to 2017-18. It was also observed that annual growth rate of fixed cost of cultivation of paddy is higher than wheat during the corresponding years.

Figure 2 indicated that the per hectare fixed cost of cultivation of wheat ranged from Rs. 9466 to 39179 during 1996-97 to 2017-18. Likewise, in case of paddy it ranged between Rs. 7772 to 43911 during the corresponding years. It was seen that the per hectare fixed cost of cultivation was higher for wheat than paddy during 1996-97 and 1999-2000. Contrary to this it was also seen that this cost of cultivation was higher on paddy than wheat during 2004-05 to 2017-18. However, the fixed cost of cultivation of both crops increased from 1996-97 to 2017-18.

**Growth relationship for paddy and wheat:** Table 5 showed the growth relationship between farm assets accumulation and productivity of paddy and wheat in Punjab.

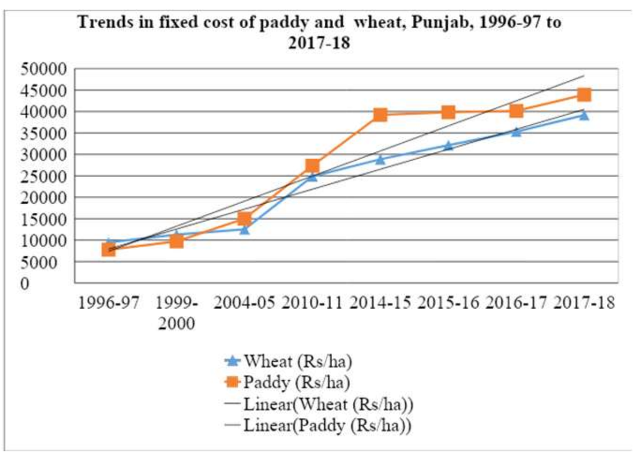


**Fig. 2.** Fixed cost of cultivation of paddy- wheat, Punjab, 1996-97 to 2017-18

**Paddy:** Table 5 showed that the explanatory variables expressed the correlation for tractors (0.911), electric tube wells (0.887), self-propelled combines (0.924), tractor drawn combines (0.894), disc harrows (0.773), seed cum fertilizers drills (0.876) and tillers and reapers (0.955), was positive and significant. This indicated that an increase in the number of machinery and implements could increase productivity of paddy as per the value of coefficients.

It was also observed that upto the last nineties the acquisition of needed farm machinery and equipment reached the saturation point on Punjab farms, thus there remained a little new demand for further additions. Simultaneously the existing farm machinery and equipment faced depreciation. As a result, there was a slowdown in new investments and the net capital investments in these assets followed a declining path. Consequently, the result showed the increasing trend followed by declining trend during the study period.

**Wheat:** The perusal of the Table 4 indicated that the selected independent variables explained the correlation for tractors (0.813), electric tube wells (0.902), self-propelled combines (0.896), tractor drawn combines (0.601), disc harrows (0.534), seed cum fertilizers drills (0.636) and tillers and

**Table 4.** Relationship between capital farm investment and the productivity of paddy and wheat

| Farm machinery and implements | Wheat | Paddy |
|---|---|---|
| Tractors | 0.813** | 0.911** |
| Electric tube wells | 0.902** | 0.887** |
| Self-propelled combines | 0.896** | 0.924** |
| Tractor drawn combines | 0.601* | 0.894** |
| Disc harrows | 0.534 | 0.773** |
| Seed cum fertilizer drills | 0.636* | 0.876** |
| Tillers and reapers | 0.728** | 0.955** |

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

**Table 5.** Pattern of investment on different components of capital assets (excluding land) in Punjab, 2017-18

| Particulars | Zone-I | Zone-II | Zone-III | Overall |
|---|---|---|---|---|
| Farm-buildings (%) | 12.20 | 16.69 | 22.15 | 17.87 |
| Irrigation (%) | 32.65 | 13.27 | 16.14 | 18.61 |
| Machinery (%) | 37.45 | 46.80 | 39.79 | 42.00 |
| Livestock (%) | 17.70 | 23.24 | 21.92 | 21.52 |
| Total capital assets (Rs ha$^{-1}$) | 172496 (100.00) | 176405 (100.00) | 178284 (100.00) | 176271 (100.00) |

**Source:** A study into the economics of farming and the pattern of income and expenditure distribution in the Punjab Agriculture (2019). Department of Economics and Sociology, Punjab Agriculture University, Ludhiana reapers (0.728). It was positive and significant in case of wheat crop. This indicated that an increase in the number of machinery and implements could increase the productivity of wheat in the state as per the coefficient value.

**Pattern of capital assets:** To examine the pattern of investment on all components of capital assets (excluding land), the per hectare pattern of investment for the state was worked out as depicted in Table 5. The table showed that the investment on all components of capital assets was Rs.176271 on overall farms. Out of this total amount, the highest per hectare share of investment was made on farm machinery being 42 per cent followed by livestock, irrigation structures and farm buildings, claiming 21.52, 18.61 and 17.87 per cent respectively. The zone-wise figure for this aspect ranged from Rs.172496in zone-I to Rs.178284 in zone-III. It was also observed that around 33 per cent of total investment was on irrigation Zone-I. This was because of ground water table being comparatively low in this zone. It was also depicted in the table that investment on machinery was more in zone-II i.e. 46.80 per cent of total investment on capital assets as compared to zone-I (37.45%) and zone-II (39.79%) which indicates that zone-II was more mechanized. Investment on livestock was also more in zone-II as compared to other zones.

## CONCLUSION

From the foregoing analysis it could, therefore, be concluded that investment on farm assets (except on draught animals), fixed cost of cultivation and yield levels of paddy and wheat have grew continuously on Punjab farms. Lately, low increase in investment on farm machinery and equipment indicated the saturation stage as these farms were already mechanized and there was a little scope for making more investments on these items. Investment on draft animals decreased considerably on all farms in the state during the study period because the bullock labour got substituted by tractors and other machines like combines and planters. It was seen that the farm capital investments being the important component could enhance the productivity of paddy and wheat. An overview of the study indicated that upto the last nineties the acquisition of needed farm machinery and equipment reached the saturation point on Punjab farms, thus there remained a little new demand for further additions. Simultaneously the existing farm machinery and equipment faced depreciation. As a result, there was a slowdown in new investments and the net capital investments in these assets followed a declining path. Consequently, the results showed an initial increasing trend followed by declining trend during the study period.

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# Statistical Evaluation of Regional Level Agricultural and Socio-Economic Development in Haryana

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***Abstract***: The present study examines inter-district development inequalities in Haryana and identifies key agricultural and socio-economic dimensions. More than fifty indicators for development use Composite index and main component analysis were used to access the development status (PCA). In addition, main component analysis (PCA) has been used to identify key agricultural and socio-economic development indicators. The study showed a considerable degree of inequality among all the districts, with Nuh being behind in both development sectors, but Gurugram and Faridabad were socioeconomically developed despite being behind in agriculture. Population densities in cities, industrial infrastructure and educational facilities have been identified as major factors in socioeconomic development. Karnal, Kurukshtera and Yamunanagar were agriculturally developed and percentage of cereals and food grain areas, yield, irrigation facilities and livestock were observed as major factors contributing to the development of the farming sector.

***Keywords***: Composite index, Normalized index, Principal component analysis, Factor loadings

Development status in any sector cannot be measured by a single indicator because it is a multidimensional phenomenon. The quality of life depends on the state of development in different industries; socio-economic, farming and infrastructure, etc. But a single indicator cannot fully grasp the development process (Muthumurugan and Christina 2021). In addition, many separately examined indicators do not provide an easy to understand picture of genuine patterns of development. India is an agricultural country of great significance in the field of agriculture development because nearly half of India's workforce is involved in farming for their livelihood. Agriculture provides the majority of low-income, disadvantaged and vulnerable people with a source of income and food security. Only by placing agriculture at the top of its agenda can India meet its targets of poverty reduction, malnutrition and inclusive growth, as India remains the world's largest population of poor and malnourished people (Singh et al 2020). Agriculture also provides the basis for a number of agro-based companies and agro-services. Apart from agriculture, the socio-economic sector is also an important sector which contributes greatly to improving the lives of citizens (Van et al 2015). In underdeveloped countries as well as in rich countries around the world, socio-economic development has picked the interests of policy makers. The aim of the economic planning of a country is to achieve balanced regional development and reduce regional differences in development rates. In India, most countries are purely dependent on agriculture for their livelihood, including Haryana (Hooda et al 2017). Agriculture plays an important role in the socioeconomic growth of the state (Chander 2017). This research paper objectives on Haryana's inter-district development disparities and on the key characteristics of regional inequality in agriculture and the socio-economic sector in Haryana, which has a major influence on the state's developmental disparities.

## MATERIAL AND METHODS

The unit of analysis were single district in the state of Haryana. The relevant data on agriculture and socioeconomic sectors was gathered from several issues of the Haryana government's Statistical Abstractson 27 agricultural and 25 socio-economic developments for all the districts of Haryana. To access the status of socio-economic development indicators were collected under different sections like; population, transport and educational facilities, infrastructure, finance and labour. The agricultural development status indicators of various sections like; area, yield, mechanization, human labour, other inputs and livestock were selected. Triennium average of area and yield related agricultural variables have been used in the study (Mishra et al 2017 & 2021).

**Construction of composite development index (Narain et al, 1991, Das et al 2017):** Let $X_{ij}$ denote be the value of *jth* indicator of development for the *ith* district, where *i = 1,2,....,n* and *j = 1,2,....,p.* The methodological steps for construction of CI given by Narian et al (1991) are summarized below:

**Step-1:** Standardize data for each indicator using the transformation

$$Z_{ij} = \frac{X_{ij} - \overline{X}_j}{s_j} \text{ where } s_j^2 = \frac{1}{n}\sum_{i=1}^{n}\left(X_{ij} - \overline{X}_j\right)^2 \text{ and } \overline{X}_j = \frac{1}{n}\sum_{i=1}^{n} X_{ij}$$

From $z_{ij}$, identify the best value of each indicator. Let it be denoted as $z_{oj}$. The best value will be either the maximum value or the minimum value of the indicator depending upon the direction of the impact of indicator on the level of development. For obtaining the pattern of development $c_i$ of *ith* districts

$$\text{development } C_i \text{ of } ith \text{ districts} C_i = \left[\sum_{j=1}^{p}\left(Z_{ij} - Z_{oj}\right)^2\right]^{1/2}$$

Composite index of development (C. I.) is given by:

$$D_i = C_i / \left(\overline{C} + 2SD_i\right), \text{where } \overline{C} = \text{Mean of } C_i \text{ and } SD_i = \text{Standard deviation of } C_i.$$

According to Narian et al (1991) the value of composite index is non-negative and lies between 0 and 1. Also, a value closer to zero indicates the higher level of development while the value closer to 1 indicates the lower level of development.

**Identification of key indicators using principal components:** Principal component analysis (PCA) reduces to a smaller number of linear combinations the original set of variables which capture the maximal variation of the data. The main component analysis mainly explores the variance and covariance structure through some linear combinations of original variables. The usual PCA results ensure that keeping the top few main components with the highest associated variance provides a subset of linear combinations of the other main component that is closest to the source data. The first main component (PC1) is a weighted linear combination of the most variable variables in the data. The

**Table 1.** Selected socio-economic indicators

| Section | Indicator | Notation |
|---|---|---|
| Population | Percentage of rural population male to total population | X1 |
| | Percentage of rural population female to total population | X2 |
| | Percentage of urban population male to total population | X3 |
| | Percentage of urban population female to total population | X4 |
| | Population density | X5 |
| | Rural sex ratio of births (male per 100 female) | X6 |
| | Urban sex ratio of births (male per 100 female) | X7 |
| | Decennial population growth 2001-11 | X8 |
| Transport and other | Number of registered factories per lakh population | X9 |
| | Road length per lakh population | X10 |
| | Number of non-transport vehicle registered total per lakh population | X11 |
| | Total transport per lakh population | X12 |
| | Number of medical institutions allopathic per lakh population | X13 |
| Educational services and infrastructure | Literacy percentage male | X14 |
| | Literacy percentage female | X15 |
| | Total senior secondary/high schools per lakh population | X16 |
| | Total recognised middle schools per lakh population | X17 |
| | Total recognised primary schools per lakh population | X18 |
| | Teacher pupil ratio primary | X19 |
| | Teacher pupil ratio middle | X20 |
| | Teacher pupil ratio senior sec/high school | X21 |
| Financial | Total cooperative societies and banks per lakh population | X22 |
| | Credit deposits ratio (%) | X23 |
| Labour | Percentage of workers employed in working factories to total population | X24 |
| | Main workers as percentage to total population | X25 |

second main component, the weighted linear combination (PC2), is not related to PC1 and represents the majority of the remaining data variations and so on.

## RESULTS AND DISCUSSION

**Socio-economic status of development:** Development indicators selected for socio-economic sector are given in Table 1. Gurugram (0.58) took first place in socio-economic development followed by Faridabad, Panchkula Panipat and Rewari. The least developed socio-economic districts were Jind, Sirsa, Bhiwani and Kaithal. The first major component to the socio-economic sector explained 45.07% of the overall variance and up to 5 PCs almost 85% of the overall variation (Fig. 1). Gurugram, Faridabad, Panchkula and Panipat districts have high main PC1 and PC2 component values. The districts of Nuh, Sirsa, Mahedragarh, Bhiwani and Fatehabad on the other hand have low scores in both the main components of the indicators of the agricultural sector. Socio-economic sector loadings indicators percentage of urban population male and female to total population, population density, number of registered factories per lakh population, number of non-transport vehicle and total transport per lakh population, teacher pupil ratio primary and percentage of workers employed in working factories to total population were the most important variables for first principal component from the socio-economic sector. The other indicators literacy percentage male and literacy percentage female were also having higher values.

**Agriculturalstatus of development:** The details of the development indicators selected for agricultural sector (Table 4). Karnal, Kurukshetra, Yamaunangar, Jind, Kaithal and Sirsa were highly developed districts in agricultural sector. Nuh, Gurugram, Faridabad, Rewari and Jhajjar were among the least developed districts in agricultural sector. The first key part of the agriculture sector was 30.74% of the total variance and almost 80% of the total variance was captured by up to 5 PCs (Fig. 2). Yamaunagar, Karnal, Kurukshetra, Kaithal and Jind districts have high main PC1 and PC2 component ratings. The Nuh, Rewari, Mahendragarh and Jhajjar districts, on the other hand, have low values for both of the principal components of farm indicators. The lower PC2 values are Panchkula, Faridabad, and Gurugram. The development differences indicated by PC1 and PC2 are consistent with the disparities reflected in the standardized

**Table 2.** Socio-economic development status

| Rank | District | Composite index (↓) | Normalized index (↑) | PC value (↑) | District | Rank |
|---|---|---|---|---|---|---|
| 1 | Gurugram | 0.583 | 1.000 | 9.115 | Gurugram | 1 |
| 2 | Faridabad | 0.654 | 0.787 | 9.080 | Faridabad | 2 |
| 3 | Panchkula | 0.743 | 0.523 | 2.419 | Panipat | 3 |
| 4 | Panipat | 0.761 | 0.471 | 1.906 | Panchkula | 4 |
| 5 | Rewari | 0.808 | 0.332 | 0.710 | Ambala | 5 |
| 6 | Jhajjar | 0.824 | 0.282 | 0.646 | Rohtak | 6 |
| 7 | Yamunanagar | 0.827 | 0.275 | 0.593 | Yamunanagar | 7 |
| 8 | Rohtak | 0.828 | 0.272 | 0.164 | Sonipat | 8 |
| 9 | Ambala | 0.852 | 0.199 | -0.532 | Rewari | 9 |
| 10 | Sonipat | 0.855 | 0.190 | -0.547 | Karnal | 10 |
| 11 | Karnal | 0.858 | 0.181 | -0.767 | Palwal | 11 |
| 12 | Palwal | 0.863 | 0.166 | -0.887 | Jhajjar | 12 |
| 13 | Hisar | 0.865 | 0.160 | -1.207 | Hisar | 13 |
| 14 | Mahendragarh | 0.878 | 0.122 | -1.396 | Kurukshetra | 14 |
| 15 | Kurukshetra | 0.883 | 0.106 | -1.919 | Jind | 15 |
| 16 | Bhiwani* | 0.884 | 0.104 | -2.411 | Mahendragarh | 16 |
| 17 | Kaithal | 0.885 | 0.102 | -2.564 | Sirsa | 17 |
| 18 | Fatehabad | 0.900 | 0.058 | -2.654 | Kaithal | 18 |
| 19 | Jind | 0.903 | 0.048 | -3.058 | Nuh | 19 |
| 20 | Sirsa | 0.919 | 0.000 | -3.117 | Bhiwani* | 20 |
| 21 | Nuh | 0.919 | 0.000 | -3.574 | Fatehabad | 21 |

*Bhiwan includes the values of Charkhi Dadri

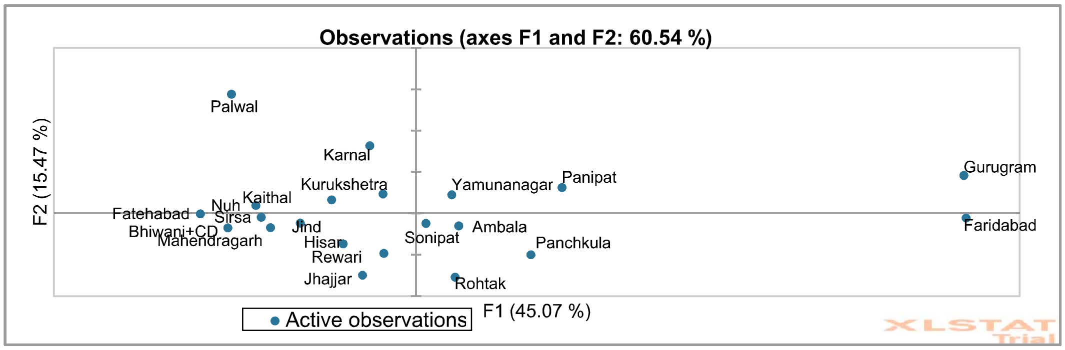


**Fig. 1.**Socio-economic sector principal component plot

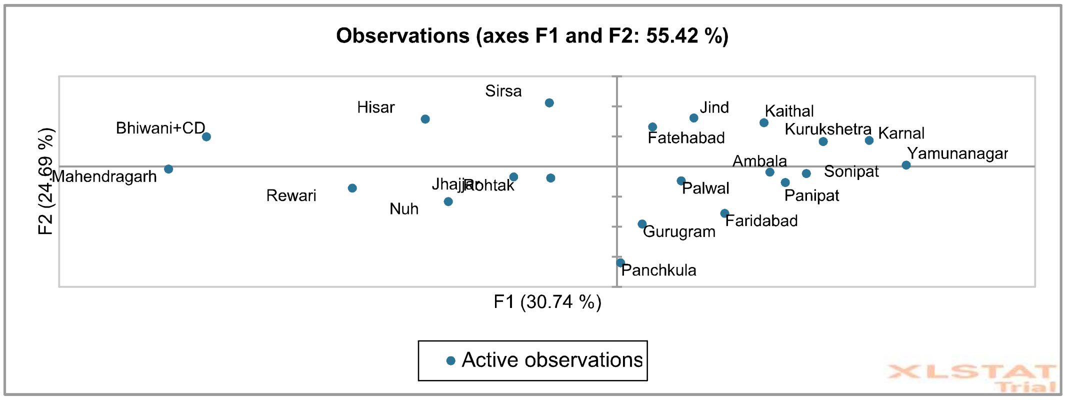


**Fig. 2.** Agricultural sector principal components plot

**Table 3.** Important indicators in socio-economic development

| Indicator | | F1 | F2 | F3 | F4 | F5 |
|---|---|---|---|---|---|---|
| X1 | Rural population male to total population (%) | -0.950 | 0.102 | -0.217 | -0.041 | 0.116 |
| X2 | Percentage of rural population female to total population | -0.948 | 0.131 | -0.201 | -0.053 | 0.139 |
| X3 | Percentage of urban population male to total | 0.952 | -0.116 | 0.206 | 0.046 | -0.117 |
| X4 | Percentage of urban population female to total | 0.946 | -0.116 | 0.214 | 0.048 | -0.138 |
| X5 | Population density | 0.848 | 0.314 | -0.159 | 0.030 | -0.280 |
| X6 | Rural sex ratio of births (male per 100 female) | 0.127 | -0.338 | -0.471 | 0.437 | 0.014 |
| X7 | Urban sex ratio of births (male per 100 female) | -0.172 | -0.094 | -0.556 | -0.260 | 0.283 |
| X8 | Decennial population growth | 0.666 | 0.396 | -0.010 | -0.062 | 0.599 |
| X9 | Number of registered factories per lakh population | 0.911 | 0.000 | -0.121 | 0.096 | 0.092 |
| X10 | Road length per lakh population | -0.777 | -0.311 | 0.154 | 0.205 | 0.173 |
| X11 | Number of non-transport vehicle registered total per lakh population | 0.775 | -0.176 | -0.015 | -0.105 | 0.498 |
| X12 | Total transport per lakh population | 0.844 | -0.023 | -0.135 | -0.085 | 0.468 |
| X13 | Number of medical institutions allopathic total per lakh population | -0.906 | -0.326 | -0.036 | -0.058 | 0.113 |
| X14 | Literacy percentage male | 0.535 | -0.608 | -0.219 | -0.322 | -0.135 |
| X15 | Literacy percentage female | 0.637 | -0.589 | 0.173 | -0.098 | -0.164 |
| X16 | Total senior secondary/high schools per lakh population | -0.179 | -0.634 | -0.597 | 0.077 | -0.211 |
| X17 | Total recognised middle schools per lakh population | 0.205 | 0.838 | 0.085 | -0.270 | -0.230 |
| X18 | Total recognised primary schools per lakh population | -0.522 | 0.000 | 0.459 | -0.452 | 0.188 |
| X19 | Teacher pupil ratio primary | 0.769 | -0.113 | -0.480 | 0.023 | -0.269 |
| X20 | Teacher pupil ratio middle | -0.453 | -0.526 | -0.344 | -0.155 | 0.154 |
| X21 | Teacher pupil ratio senior sec/high school | 0.055 | 0.824 | -0.286 | 0.324 | 0.033 |
| X22 | Total cooperative societies and banks per lakh population | 0.083 | -0.273 | 0.769 | -0.228 | -0.062 |
| X23 | Credit deposits ratio (%) | -0.325 | 0.015 | 0.313 | 0.796 | 0.127 |
| X24 | Percentage of workers employed in working factories to total population | 0.918 | -0.023 | -0.153 | 0.041 | 0.325 |
| X25 | Main workers as percentage to total population | 0.307 | -0.579 | 0.535 | 0.368 | 0.166 |

**Table 4.** Selected agricultural indicators

| Section | Indicator | Notation |
|---|---|---|
| Area | Forest area to total geographical area (%) | X1 |
| | Percentage of net area sown to total cultivable area | X2 |
| | Percentage of area sown more than once to total cultivable area | X3 |
| | Net area irrigated percentage to net area sown | X4 |
| | Percentage of total cereals area to total cropped area | X5 |
| | Percentage of total pulses area to total cropped area | X6 |
| | Percentage of total food-grains area to total cropped area | X7 |
| | Percentage of total oilseeds area to total cropped area | X8 |
| | Average land holding size | X9 |
| Yield | Total cereals yield | X10 |
| | Total pulses yield | X11 |
| | Total food-grains yield | X12 |
| | Total oilseeds yield | X13 |
| Mechanization | Number of tractors 000 $ha^{-1}$ of total cropped area | X14 |
| | Number of tube-wells and pumping sets | X15 |
| Human labour | Percentage of cultivator worker to total workers | X16 |
| | Percentage of agriculture worker to total workers | X17 |
| Other inputs | Irrigation intensity (gross irrigated area x 100/net irrigated area) | X18 |
| | Fertilizer consumption kg $ha^{-1}$ | X19 |
| | Regulated markets | X20 |
| | Rainfall annual (cm) | X21 |
| Livestock | Number of cattle lakh $population^{-1}$ | X22 |
| | Number of buffaloes lakh $population^{-1}$ | X23 |
| | Number of sheep lakh $population^{-1}$ | X24 |
| | Number of goats lakh $population^{-1}$ | X25 |
| | Number of poultry lakh $population^{-1}$ | X26 |
| | Number of veterinary institutions in the state | X27 |

**Table 5.** Agricultural development status

| Rank | District | Composite index (↓) | Normalized index (↑) | PC value (↑) | District | Rank |
|---|---|---|---|---|---|---|
| 1 | Karnal | 0.768 | 1.000 | 1.822 | Yamunanagar | 1 |
| 2 | Kurukshetra | 0.780 | 0.943 | 1.080 | Karnal | 2 |
| 3 | Yamunanagar | 0.788 | 0.902 | 1.070 | Kurukshetra | 3 |
| 4 | Jind | 0.815 | 0.773 | 1.016 | Jind | 4 |
| 5 | Kaithal | 0.816 | 0.769 | 0.963 | Sirsa | 5 |
| 6 | Sirsa | 0.825 | 0.727 | 0.781 | Ambala | 6 |
| 7 | Hisar | 0.825 | 0.726 | 0.563 | Kaithal | 7 |
| 8 | Bhiwani* | 0.830 | 0.703 | 0.325 | Fatehabad | 8 |
| 9 | Ambala | 0.851 | 0.600 | 0.267 | Sonipat | 9 |
| 10 | Fatehabad | 0.865 | 0.533 | 0.202 | Panipat | 10 |
| 11 | Palwal | 0.865 | 0.530 | 0.057 | Palwal | 11 |
| 12 | Sonipat | 0.892 | 0.399 | 0.050 | Hisar | 12 |
| 13 | Mahendragarh | 0.900 | 0.361 | -0.421 | Rohtak | 13 |
| 14 | Rohtak | 0.903 | 0.351 | -0.464 | Bhiwani* | 14 |
| 15 | Jhajjar | 0.931 | 0.214 | -0.471 | Mahendragarh | 15 |
| 16 | Panipat | 0.931 | 0.214 | -0.525 | Panchkula | 16 |
| 17 | Panchkula | 0.933 | 0.204 | -0.968 | Faridabad | 17 |
| 18 | Rewari | 0.936 | 0.192 | -1.099 | Nuh | 18 |
| 19 | Faridabad | 0.961 | 0.069 | -1.222 | Gurugram | 19 |
| 20 | Gurugram | 0.964 | 0.055 | -1.370 | Rewari | 20 |
| 21 | Nuh | 0.975 | 0.000 | -1.656 | Jhajjar | 21 |

*Bhiwan includes the values of CharkhiDadri

**Table 6.** Important indicators in agricultural development

| Indicator | | Component | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| X1 | Percentage of forest area to total geographical area | | | | -.827 | |
| X2 | Percentage of net area sown to total cultivable area | | | | | |
| X3 | Percentage of area sown more than once to total cultivable area | | | | | .786 |
| X4 | Net area irrigated percentage to net area sown | | | | | |
| X5 | Percentage of total cereals area to total cropped area | .918 | | | | |
| X6 | Percentage of total pulses area to total cropped area | -.781 | | | | |
| X7 | Percentage of total food-grains area to total cropped area | .914 | | | | |
| X8 | Percentage of total oilseeds area to total cropped area | -.755 | | | | |
| X9 | Average land holding size | | | | | |
| X10 | Total cereals yield | | .928 | | | |
| X11 | Total pulses yield | | | | | |
| X12 | Total food-grains yield | | .907 | | | |
| X13 | Total oilseeds yield | | | | | |
| X14 | Number of tractors 000 $ha^{-1}$ of total cropped area | | | | | |
| X15 | Number of tube-wells and pumping sets | .821 | | | | |
| X16 | Percentage of cultivator worker to total workers | | | | | |
| X17 | Percentage of agriculture worker to total workers | | | .835 | | |
| X18 | Irrigation intensity (gross irrigated area x 100/net irrigated area) | | | | | |
| X19 | Fertilizer consumption kg per $ha^{-1}$ | | | | | |
| X20 | Regulated markets | | | | | |
| X21 | Rainfall annual (cm) 2019 | | | -.774 | | |
| X22 | No. of cattle per lakh population | | .822 | | | |
| X23 | No. of buffaloes per lakh population | | | .846 | | |
| X24 | No. of sheep per lakh population | | | | | |
| X25 | No. of goats per lakh population | | | | | |
| X26 | No. of poultry per lakh population | | | | -.903 | |
| X27 | Number of veterinary institutions in the state | | | | | |

development index (Tanwar et al 2016). Indicators X5, X7 (percentage of total cereals and food-grains area to total cropped area) and X15 (number of tube-wells and pumping sets) are the most important variables for first PC from the agricultural sector (Table 6). The other five indicators from PC2 and PC3 with higher loadings were X10, X12 (total cereals yield), X12 (total food-grains yield), and X17 (percentage of agriculture worker to total workers), X22 (number of cattle per lakh population) and X23 (number of buffaloes per lakh $population^{-1}$).

## CONCLUSION

The present investigation indicated that inter-district disparities in Haryana in both the sectors. Gurugram, Faridabad and Panchkula were among the highly developed districts in socio-economic sector. Nuh was found lagging behind in both the sectors. It was observed that percentage of urban population to total, population density, number of registered factories, working force in factories and transport related indicators were the important variables in the socio-economic sector development. Percentage of total cultivated land, irrigation facilities, the yield of cereals per acre of cropped area and the percentage of agricultural workers were found to be major contributors to the agricultural sector's growth.

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# Sustainable Public Procurement: Research Trends and Gaps

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***Abstract*:** During the period from 1998 to 2021 there are numerous Sustainable Public Procurement (SPP) discussion. Up to now, the number of research in SPP has increased more than eight times in the past 23 years. In recent years, the implementation of SPP is covering new sectors, and identifying new practices. The aim of this paper is to do an extensive and systematic literature review with the aim to provide qualitative viewpoint of outlining and identifying state-of-the-art research trends and gaps. The literature analyzed here comprises English language papers, which are focused on SPP. In this paper, the 23 years period of SPP discussion disaggregated into several periods of research time. Several findings in this research are: First, most of the articles discuss about the improvement of SPP. Second, SPP has been implemented in many sectors and construction sector is a major subject of discussion in SPP research. Third, most SPP research are in Europe. Finally, we describe conclusion and future research opportunity.

***Keywords*:** Sustainable public procurement, Green public procurement, Socially responsible procurement, Low carbon procurement, Government green procurement, Gender-responsive public procurement, Literature review

Public procurement represents 15-30% of national GDP in global (UNEP 2012). Developed countries spend over 10% of their gross domestic product on public procurement (Zhu et al 2013). As such massive procurement volume, in the last decade, Sustainable Public Procurement (SPP) has become an increasingly used tool policy instrument that potentially play a role in changing unsustainable consumption and production. Tsai (2015) confirms that implementation GPP 2002-2012 in Taiwan from the green-mark products consumption and the renewable electricity purchase reduce CO2 emissions intensity and increase the renewable electricity purchased.

SPP is implemented in different places in different regions. The term Sustainable Public Procurement (SPP) has been broader to Green Public Procurement (GPP), Socially Responsible Public Procurement (SRPP). During the period from 1998 to 2021 there are abundant SPP discussion. Appoloni (2014) states that the research in SPP/GPP is growing fast in terms of number of articles published and the variety of the journals in which this topic is discussed. The 23 years period of SPP discussion will be reviewed to answer these two research questions: What are the research trends in SPP field in the last 23 years and research gaps in the SPP field in the last 23 years? In this research 145 English papers from 1998 up to 2021 were retrieved based on a keyword search on Scopus. The keywords were selected and limited to green or sustainable procurement terminologies include sustainable public procurement, green public procurement, socially responsible procurement, low carbon procurement. All the selected articles specifically focus on the research questions.

## MATERIAL AND METHODS

A thorough content analysis has been used to identify the essential part for grouping the paper selected in this research. There are three major paper groups resulted from the content analysis, first is topic of discussion, second, procurement sector and the third is the geographic location of the research. The three groups are chosen because in the last literature and critical reviews of SPP (Appolloni 2014, Cheng 2017, Sönnichsen 2020, Kundu 2020) has already focus on research method (survey, case studies, theory etc.), type of data (qualitative, quantitative, mixed), impact factor of the papers, area/journal of publication, frequency of government functions, level of government studied by articles, frequency of country studied in the literature.

In order to extent the research in SPP, this article focus to subject areas that has not been discussed in the previous literature reviews. There are eleven major grouping on topic discussion selected based on content analysis with respect to SPP which: literature review, driver of implementation, Improvement of implementation, Criticism, Barrier of implementation, Environmental and/or Social Criteria or Indicators, Standard, Low Carbon Procurement, Importance of implementation, SPP Model, Gender-responsive Procurement. In public procurement sector there are ten sectors identified from the articles. They are transportation services, public health, building and construction, food/catering sector, public university, furniture, waste management, information technology, agriculture, paper, and stationery for geographic location there were five continents as research location in the articles, they are: Africa, Asia, Europe, Australia, and America.

Discussion of SPP/GPP started in 1998 by the concept of lean supply chain for government. Erridge (1998a) and Erridge (1998b) and Murray (1999) has described the concept of lean supply model which include green purchasing that can support development of local economic and environmental sustainability (Table 1). Murray (2000) and Warner (2001) describes the importance of implementation of the green purchasing concept by local government in UK. After 14 years of discussion, start in 2012, there is a criticism of SPP which mainly focus on effectiveness of SPP in supporting Sustainable Development and reducing environment degradation (Lundberg, 2012). The majority of the articles discuss about the improvement of SPP. The number of this topic of discussion increase and reach its top on the last five years with 22 publications. In the latest review by Cheng (2017), the focus of SPP discussion is mainly on the specific impacts of SPP implementation, while discussions about the effectiveness SPP compared to other environmental policy tools is still rare. SPP has been implemented in many sectors (Table 2). Building and Construction is a major subject of discussion in SPP research while transportation, waste management and IT is the minor subject discussed in SPP articles. Most SPP/GPP research are in Europe while articles about SPP in Australia is least one (Table 3).

## RESULTS AND DISCUSSION

Procurement of goods and services that have a large value will also require large natural resources, which can directly or indirectly affect natural sustainability, environmental pollution, biodiversity, and climate change. This effect on nature is not only seen from the significant use of raw materials, but also the emissions resulting from the procurement of goods/services from the production process, transportation, up to the use stage. Issues that occur in the world such as natural resource limitations, food scarcity, population growth is likely to make SPP a global demand to be implemented soon. By 2015, countries in the world incorporated in the United Nations have agreed to implement Sustainable Development Goals (SDG) with 169 targets must be achieved in 15 years (2030). One of the indicators in the target SDG is the goal number 12 is "responsible production and consumption pattern". More specifically on goal 12.7 with the target of "promoting sustainable Government Procurement of Goods/Sustainable Public Procurement, in accordance with national policies and priorities ". In the last decade, Sustainable Public Procurement (SPP) has become an increasingly used tool policy instrument that potentially play a role in changing unsustainable consumption and production. As the extent implementation of SPP in many regions the research for SPP will the extent as well.

In the early discussion of SPP improvement several tools were proposed to ease local authorities implementing SPP (Swanson, 2003; Günther, 2006). Hochschorner (2006) proposed the use Life Cycle Assessment (LCA) as tool that can give guidance for environmentally preferable production and that considers the whole life cycle of the product. In the period of 2008-2012, researchers continue to discuss calculation tool to determine the most economically advantageous tender by life cycle assessment and or the environmental cost calculation method (Lundberg 2011, Larsen 2010, Alhola 2012, Arvidsom 2012). Preuss (2009) and Walker (2012) proposed several ways to improve the implementation of SPP by working with SMEs, contracting with voluntary organization on the social side or including sustainability criteria in contracts such as replacing hazardous materials in products and services on the environmental side. Testa (2012) shows the level of awareness of the existing tools for supporting SPP have a positive and significant effect on the probability to adopt SPP. In the period of 2013-2018, Cerutti (2017) proposed applying a simplified life cycle approach in the assessment of procurement policies. This approach allows the assessment of procurement policies in the catering service that considers all the stages of the process.

Grandia (2015a, 2015b, 2016), Guenther (2013) and Roman (2016) proposed organizational and leadership change to support SPP. The studies show that the degree of sustainable procurement behavior varies across the population of procurers. The change agents are one part of the process to implement SPP, they are important and play a vital role to present and help key actors enact SPP desired behavior. Uttam (2015) mentioned competitive dialogue procedure that allows the contracting authority to embrace discussions with shortlisted contractors regarding the authority's requirements. In the dialogue sessions between procurers and contractors, SPP should be discussed to ensure consistency of the weight for social, economic, and environmental considerations and respective preferences. Witjes (2016) and Wong (2016) concluded that client requirements in tendering as important factor to enhance SPP. This study shows that the government should take a

**Table 1.** Distribution of topic of discussion in SPP articles

| Topic of discussion | Number of articles / Author | | | | |
|---|---|---|---|---|---|
| | 1998-2002 | 2003-2007 | 2008-2012 | 2013-2017 | 2018-2021 |
| Literature review | 3<br>Erridge (1998a), Erridge(1998b), Murray (1999) | | | 3<br>Appolloni (2014), Igarashi (2013), Cheng (2017) | 2<br>Sönnichsen (2020), Kundu (2020) |
| Driver of implementation | | 1<br>Thomson (2007) | | 2<br>Agyepong (2016), Alvarez (2015) | 9<br>Haddadi (2021), Liu (2021), Aldenius (2021), Ciumara (2021), Wang (2020), Leal (2020), Raj (2020), Etse (2021b), Bakir (2018) |
| Improvement of implementation | | 4<br>Swanson (2003), Günther (2006), Hochschorner (2006) | 8<br>Alholla (2012), Arvidsson (2012), Larsen (2010), Lundberg (2011), Preuss (2009), Tarantini (2011), Testa (2012), Walker (2012). | 19<br>Butt (2015), Cerutti (2016), Cerutti (2017), Aldenius (2017), Grandia (2015), Grandia (2016), Gunther (2013), Igarashi (2013), Igarashi (2015), Pacheco-Blanco (2016), Roman (2016), Testa (2014), Trindade (2017), Uttam (2015), Wong (2016), Akenroye (2013) | 22<br>Wang (2018), Grzyl (2018), Liu (2018), Giacomo (2018), Ma (2021), Hamdan (2021), Badell (2021), Miyamoto (2020), Al Nuaimi (2020), Grandia (2020), Stritch (2020), Lindström (2020), Lăzăroiu (2020), Grandia (2019), Fuentes-Bargues (2019), Liu (2019a), De Giacomo (2019), Liu (2019b), Iannone (2019), Etse (2021a), Rosell (2021), Alhola (2019) |
| Criticism o | | | 1<br>Lundberg (2012) | 4<br>Burchard-Dziubinska (2017), Lundberg (2015a ,2015b, Lundberg 2017), Nikolau (2017). | 3<br>Džupka (2020), Burghardt (2021), Halonen(2021) |
| Barrier of implementation | 1<br>Warner (2001) | 6<br>Faith-Ell (2005), Van Asselt (2006), Bouwer (2006), Faith-Ell (2006), Steurer (2007), Walker (2007) | 7<br>Brammer (2011), Erridge (2012), Melissen (2012), Nash (2009), Oruezabala (2012), Walker (2009), Geng(2008) | 6<br>Ahsan (2017), Testa (2015), Rizzi (2014), Schwerin (2013), Zhu (2013), Aragão (2017) | 8<br>Lindfors (2021), Bucea-Manea-țoniș (2021), Vejaratnam (2020), Adjei-Bamfo (2019), Tawfik Alqadami (2020), Da Costa (2019), Plaček (2021) |
| Environmental and/or Social criteria and indicators | | | | 4<br>Bratt (2013), Neto (2017), Rainville (2016), Testa (2015), Fuentes-Bargues (2018) | 4<br>Soto (2020), Braulio-Gonzalo (2020), Welz (2020), Knebel (2021) |
| Standard | | | | 5<br>Smith (2015), Rainville (2016), Chiarini (2017), Witjes (2016), Ahsan (2017) | |
| Low carbon procurement | | | | 2<br>Correia (2013), Rietbergen (2013) | 2<br>Kadefors (2019,2021), |
| Importance of implementation | 2<br>Murray (2000), Warner (2001) | 2<br>Li (2004), McRudden (2004), Preuss (2007) | 7<br>Bala (2008), Bolton (2008), Erridge (2012), Ho (2010), Lacroix (2010), Nissinen (2009), UN (2008) | 6<br>Diófási (2014), Simcoe (2014), Annunziata, (2014), Tsai (2015), Campbell (2017), Prier (2016) | 2<br>Schebesta (2018), Bidin (2019) |
| SPP model | | | | 1<br>Xin (2016) | 1<br>Timm (2021) |
| Gender-responsive public procurement | | | | | 1<br>Orser et.all (2021) |

proactive role in pushing SPP adoption and establish a green material market to promote the SPP by lowering material costs. It is also important to get active engagement of suppliers to provide the performance of construction materials.

Trindade (2017) proposes a new tool-the SPP Toolbox-for guiding public organizations as they re-think the procurement process. This toolbox integrates insights from Green Public Procurement (GPP), Sustainable Public Procurement (SPP) and Public Procurement of Innovation (PPI) objectives and practices, in the context of the emergence of socio-technical transitions. The toolbox allowing flexibility in terms of goals, promoting an increasing complexity of institutionalized practices and skills-from GPP to SPP and then from SPP to PPI, organized in a framework fully integrated into the organizational strategy.

Wang (2018), Etse (2021) and Badell (2021) discuss how government institutions adopt SPP in various ways. Wang (2018) proposes four strategies to implement SPP: establishing a database for small and medium enterprises, developing a grade system and the post-evaluation system, formulating detailed implementation methods for high-tech products (services), and carrying out classification management for imported products. Etse (2021) and Badell (2021) mention that sustainable procurement practices are different from one organization to another organization depends on the regulation and organizational leadership. Miyamoto (2020) reveals that the presence of a GPP is associated with higher implementation and measurement rates of green purchasing. The study shows that green purchasing is advanced in items such as paper or stationery because: Eco labels are available and used. Moreover, it is easy to purchase these items in bulk. However, on contrary, green purchasing is not so common in items such as air conditioners or public works. This due to these items are often tailored, and it is difficult to determine the ecofriendly level.

Alhola (2019) proposes a new term of Circular Public Procurement (CPP) which is defined as: a procurement of competitively priced products, services, or systems that lead to extended life spans, value retention, and/or remarkably improved and no risky cycling of biological or technical materials, making use of and supporting the circular business models and related networks. While SPP and GPP are product or technology-oriented and focus on the tendering process, CPP could go beyond this and pay attention to the complex network of supply chains and other stakeholders. In CPP, the main object of the negotiations between supplier and procurer switches from product orientation to product-service system and from price per product unit to price per delivered service. Alnuaimi (2020) in his research concludes that there is a need for standard practices handbook for SP to be used by public organizations to provide public procurers a clear method for conducting a proper cost–benefit analysis to evaluate and decide on sustainable purchases. The research trends in improvement of SPP mainly focus on creating or implementing tool/procedure for helping implementation of SPP.

In the two decades of implementation of SPP, some researchers reveal that there are still many barriers in implementing SPP (Table 1). Latest from Lindfors (2021) states one barrier of SPP implementation previously identified in literature is related to that the lack of accessible and easy to use tools that help standardize the development of criteria in green tenders. Alqadami (2020) reveals that some challenges in implementing SPP are the higher upfront cost associated with eco-products and services, gap existence between policy formulation and actual project

**Table 2.** Distribution of public procurement sector

| Public procurement sector | Number of article | Articles |
|---|---|---|
| Transportation services | 4 | Lindfors (2021), Aldenius (2021), Aldenius (2014), Parikka-Alhola (2012) |
| Public health | 3 | Ahsan (2017), Diófási (2013), Oruezabala (2012), Etse(2021a) |
| Building and construction | 13 | Kadefors (2021), Timm (2021), Bidin (2019), Annunziata (2014), Uttam (2015), Wong (2016), Alvarez (2015), Rizzi (2014), Tarantini (2011), Faith-Ell (2005), Faith-Ell (2006), Soto (2020), Tawfik Alqadami (2020), Alqadami (2020), Kadefors (2019) |
| Food/Catering sector | 6 | Cerutti (2016), Cerutti (2017), Smith (2015), Neto (2017), Schebesta (2018), Lindström (2020) |
| Public university | 4 | Pacheco-Blanco (2016), Bala (2008), Aragão (2017), Fuentes-Bargues (2018) |
| Furniture | 2 | Parikka-Alhola (2008), Braulio-Gonzalo (2020) |
| Waste management | 1 | Arvidssson (2012) |
| Information technology | 2 | Li (2004), Welz (2020) |
| Agriculture | 1 | Bucea-Manea-ţoniş (2021) |
| Paper and stationery | 1 | Miyamoto (2020) |

delivery, lack of legislation to introduce mandatory influence for green adoption. Placek (2021) have found that the decision-making procurers is affected by the trade-off between stewardship and administrative compliance, which turn out to be mutually conflicting goals. On the one hand, many public procurers do possess a stewardship motivation that shapes their positive attitude to GPP. On the other hand, they are painfully aware of, and seek to forestall, administrative risks and complications attendant on the conscientious, i.e., non-perfunctory, implementation of GPP. Bucea-Manea-țoniș (2021) states that the lack of specific legislation, policies, and procedures in each main area of public procurement interest in one major barrier in implementing SPP. Based on the discussion, it can be concluded that the barriers of SPP mainly in regulation, cost, lack of standard and criteria, and motivation of procurers.

Up to now, the research of SPP has been focused on building and construction sector. Annunziata (2014) discussed the importance of energy efficiency in public buildings. Uttam (2015) discuss a new procedure in SPP in construction of a bridge, tunnel, underpass and pedestrian and bike path. Wong (2016) provide the factors that are important in enhancing green procurement building developments. Alvarez (2005) discuss about carbon footprint in Green Public Procurement can act as a strong stimulus for eco-innovation in construction services sector. Rizzi (2014) discuss factors that hamper GPP opportunities for Small and Medium Enterprises in road construction. Tarantini (2011) discuss about LCA that allowed identifying the main impacts and the critical processes of the window life cycle. Faith-Ell (2005, 2006) discuss about application of environmental requirements in road maintenance contracts. As can be seen from the literature that the research of SPP in construction sector has been last for 16 years (2005-2021). As the implementation of SDG until 2030 there will more construction sector involve in the SPP.

Finally, the research distribution of SPP spread over all continents and most of the research about SPP is in Europe

**Table 3.** Distribution of research location

| Continent | Number of article | Country |
|---|---|---|
| Africa | 7 | South Africa: Agyepong (2016), Bolton (2008)<br>Morocco: Haddadi (2021)<br>Ghana: Adjei-Bamfo (2019), Etse (2021a), Etse (2021b)<br>Nigeria: Akenroye (2013) |
| Asia | 22 | Malaysia: McMurray (2014), Bidin (2019), Tawfik Alqadami (2020), Alqadami (2020)<br>China: Liu (2021), Ma (2021), Liu (2018), Wang (2020), Wang (2018), Wong (2016), Xu (2016), Zhu (2013), Schwerin (2013), Ho (2010), Liu (2019a), Liu (2019b), Geng(2008)<br>Japan: Miyamoto (2020)<br>UAE: Al Nuaimi (2020)<br>Taiwan: Tsai (2015)<br>Korea: Campbell (2017)<br>Singapore: Bakir (2018) |
| Europe | 50 | Sweden: Aldenius (2021), Lindfors (2021), Lundberg (2015), Uttam (2015), Aldenius (2014), Bratt (2013), Arvidsson (2012), Nissinen (2009), Varnas (2009), Parikka-Alhola (2008), Faith-Ell (2006), Faith-Ell (2005), Lindström (2020)<br>Norway: Hamdan (2021), Lundberg (2013), Larsen (2010), Michelsen (2009)<br>Spain: Pacheco-Blanco (2016), Bala (2008), Soto (2020), Fuentes-Bargues (2019)<br>UK: Preuss (2009), Walker (2009), Murray (2000), Preuss (2007), Walker (2007), Erridge (1998), Murray (1999), Murray (2000)<br>French: Oruezabala (2012)<br>Netherland: Rietbirgen (2013), Melissen (2012)<br>Ireland: Erridge (2012)<br>Italy: Annunziata (2014), Testa (2012), Tarantini (2011)<br>Greece: Nikolaou (2017), Lacroix (2010)<br>Finland: Nissinen (2009), Parikka-Alhola (2008)<br>Denmark: Nissinen (2009)<br>Romania: Bucea-Manea-țoniș (2021), Ciumara (2020)<br>Belgium: Grandia (2020)<br>Switzerland: Welz (2020), Knebel (2021)<br>Czech: Plaček (2021)<br>Central Europe: Džupka (2020)<br>EU: Badell (2021), Schebesta (2018), Van Asselt (2011), Steurer (2007), Bouwer (2006), Rosell (2021), Burghardt (2021) |
| Australia | 1 | Australia: Ahsan (2017) |
| America | 9 | USA: Stritch (2020), Simcoe (2014), Li (2004), Swanson (2003), Prier (2016)<br>Canada: Orser et.all (2021)<br>Mexico: Leal (2020)<br>Brazil: Aragão (2017), Da Costa (2019) |

where most of its countries is developed countries. Public authorities are major consumers in Europe: they spend approximately 1.8 trillion euros annually, representing around 14 per cent of the EU's gross domestic product. In Europe Union (EU) there has been a regulation to conduct SPP although this regulation is a voluntary not an obligatory instrument. Rosell (2021) and Lindström (2020) confirms that developed countries and a larger government size impact positively on GPP. However, after 23 years of implementation of SPP in Europe, Lundberg (2018) has found that GPP is neither a cost-effective nor an objectively effective environmental policy instrument especially in Sweden as this country is considered as one of major countries that implement SPP (Bouwer, 2006). Latest critical review by Halonen (2021) also questioning the effectiveness SPP compared to other environmental policy tools in Europe. The topics discussed in the developing countries are about driver of implementation of SPP (Bakir 2018), improvement of SPP implementation (Wang 2018, Liu 2018, Al Nuaimi 2020, Miyamoto 2020) and barriers of SPP implementation (Tawfik Alqadami 2020, Alqadami 2020) and there is no criticism of SPP (Table 3).

This study has identified several SPP research gaps. These are several research gaps that can be defined from the selected 145 reviewed articles: First, to define whether SPP is a good or effective tool for sustainable development there is a need for quantitative research comparing the effectiveness of SPP to others policy (tax for example) in handling environmental issues. Second, since ISO 24000:2017 Sustainable Procurement-Guidance has been published in April 2017, there are opportunities to do research in implementing this guidance in public procurement. Whether this guidance fits for public procurement is still an open question to be answered. Studies of SPP criteria and indicators is very limited while the SPP criteria and indicators are important in optimizing the application of SPP. The indicator is one of the tools to be able to evaluate and monitor the implementation of the principle of sustainability. Indicators can be used as a guide in planning, the selection process, and the performance measures for implementing sustainable procurement. The implementation of the SPP concept requires indicators to assess its effectiveness, in the sense of knowing whether an activity of SPP can be said to be sustainable or unsustainable or to know how sustainable is the SPP process compared to others? Criteria and indicator for implementing SPP is very important to do measurement how sustain a procurement is so it can be compared to other procurement. Another challenge that makes indicators so important is there is a need to differentiate between the companies that only produce nice documents in and those that perform well. Thus, a standard criteria and indicator for SPP is important to standardize future research results in many regions so they can be compared to others. Jatav (2021) in his study of SDGs performance mentioned that different measurement method will have different result and can lead to different conclusions although the indicators use to gauge has been standardize. Therefore, there is a need to standardize the method for measuring SPP.

Construction sector takes a significant portion of public procurement (Mungiu-Pippidi, 2015). As a result of this significant investment, the procurement process has the potential to deliver very significant payoffs for the community and has the potential impact to the environment. Yet, up to now, there is a limited amount of research discussing criteria and indicators for SPP in construction sector. Varnas (2009) mentions the three different steps in the construction process have been suggested for applying environmental criteria: in the preliminary design/architectural competition; in the tendering for the construction contract; and in the tendering for the building services. There is a need to have a standard criteria and indicators for each step to implement GPP. Therefore, there is a significant need to do research in criteria and indicators for SPP in construction sector and method for measuring SPP performance.

## CONCLUSIONS

In the last 23 years SPP has been a growing research subject. SPP in some articles is believed as tool for environment while some argues that SPP is not an effective tool for environment. Beside these two contrary arguments, most of researchers in the last decades put their effort to improve SPP and prove the effectiveness of SPP therefore researcher mainly discuss SPP in the context of importance of implementation. Our findings show that most of the articles discuss about SPP in Europe Union. As the implementation of SDG until 2030, the discussion of SPP will spread across many regions. This opens opportunity for future research of implementing SPP. Finally, creating a standardize criteria and indicator for SPP and a method for evaluating SPP performance are also challenging research areas that need to be solved near the future.

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# Analysis of Climate Parameters Trend over Long Time Horizons and their Probable Impacts in the Beas Basin, H.P., India

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***Abstract***: The present study aims at investigating the climate parameters trends over long time horizons and their probable impacts in the ecology of Beas basin, Himachal Pradesh (H.P), India. In this study, large scale climate variables are downscaled to local scale meteorological variables. For large scale atmospheric modeling, HaDCM3 General Circulation Model (GCM) is used and downscaling is accomplished through SDSM (Statistical Downscaling Model). To detect monotonic trends and their magnitudes Mann-Kendall and Sen's slope test were employed. The study used a 100-years based period data (1901-2001) for A2 (medium to high emission) and B2 (medium to low emission) climate scenarios then an incremental scenarios over wide range climate variables for 2020s (2011- 2040), 2050s (2041-2070) and 2080s (2071-2100) were estimated. The important climate variables over the Beas basin considered for the assessment includes precipitations (PPT), maximum temperature (T-max) and minimum temperature (T-min) that covered four locales/districts -Hamirpur, Kullu, Kangra and Mandi of H.P, India. The paper ends with the concluding remarks with future impending trends and their probable impacts.

***Keywords***: Statistical downscaling, Large scale, SDSM, HaDCM3, Beas Basin

The changes in climate parameters trends can transform the current ecosystem. The disturbances and extreme events within the capacity of ecosystem of a region is a part of climate change impact. In general, climate is the proportion of variety of meteorological parameters such as - temperature, moisture, precipitation, winds and cloudiness in a given locale over significant stretch of time (Cohen et al 2000). Information on climate change is extremely important for every region, nationally and at global scale (Manohar et al 2005). Besides, environmental change can seed enormous consequences for water assets due to alternation in the water cycle. Key points to consider for contemporary examination for climate change may include- factual investigation of chronicled and upcoming atmosphere patterns (Anandhi et al 2008, Dharmaveer et al 2013); application of General Climate Models (GCMs) for reproducing the reaction of atmosphere factors comprehensively and expanding to centralizations of ozone harming substances in the environment (Arora 2001) and application of factual downscaling method (FDM) to demonstrate the hydrology factors (e.g., rainfall, temperature) (Schoof et al 2009). In particular, the changes in the course of two important factors of earth's atmosphere that is the temperature and precipitation greatly influence human wellbeing, financial development and improvement. Fluctuation in precipitation pattern can bring about the changes in the recurrence of inundation, occurrence of dry spells and effect on water standard (Duhan et al 2012). On the other hand, increment in temperature patterns of the earth brings about an expansion in dissipation and arrangement of cloud to happen that builds the rainfall, demonstrating that temperature and rainfall are correlated (Arora et al 2005). Therefore, it is very much important to investigate complete factual examination, especially the patterns of temperature and precipitation which are the two most significant climatic variables (Chakraborty at al 2013).

Climate has a huge tie-in to our livelihoods, health and future, and any change in climate patterns nearly affects every aspect of our lives such as food sources, transport, infrastructure, clothing, etc. It also contributes major influences on the available water resources system which in turn create pressure on agriculture due to variations in rainfall patterns and temperature. In a developing country like India, country's economy mainly depends on the agriculture besides service industry. Furthermore, the country suffers a fragile ecosystem due to increasing population pressure. IPCC (Intergovernmental Panel on Climate Change) reports indicate that India which is one of the most vulnerable countries of the world for global warming is going to face the devastating climate change for the coming years (Down To Earth 2018). The IPCC fourth appraisal report, in particular the SRES (Special Report on Emissions Scenarios) highlights different scenarios which are named as A1, A2, B1 and B2, narratives of subjective (e.g., political, conservative, social, natural and instructive turns of events) discharges drivers (IPCC 2007). These scenarios delineate the connection among the influences owning to ozone depleting substances and airborne discharges and progress during the latest century. For foreseeing the conceivable upcoming atmosphere, these SRES emissions situations are consider helpful. The A2 scenario depicts an extremely various different scenarios. This scenario portrays that there is a nonstop increment in population, financial improvements on territorial levels, monetary development and innovative changes are progressively lopsided and slower in contrast with other three scenarios. In the B2 scenario there is a persistent increment in worldwide population, yet at a decreasing pace than A2 emission scenario. The B2 scenario is additionally coordinated towards ecological security and social value, it focus around both nearby and provincial level (IPCC 2007).The main objectives in the present study is to assess the current and future trends of temperature and rainfall patterns over long time horizons and their probable impacts on Beas Basin, Himachal Pradesh (H.P), India.

**Descriptions of Study Area**

The Beas basin (Fig. 1) falls within the state of Himachal Pradesh (H.P), India which covers major part of Indus River Basin and is one of the major tributary of Sutlej River. It begins at an elevation of 3900m from Beas Kund on the eastern slopes of Rohtang Pass of the Himalayas and flows nearby Larji in the north–south direction where it takes a turn towards the west and flows in the same direction to Pandoh in H.P. The basin covers four districts of H.P. i.e. Kullu, Mandi, Kangra, and Hamirpur. It has a perpetual waterway, beginning from southern face of Rohtang pass in Kullu locale and streaming around 470 km to joins Satluj River in the Punjab province.

In this study the meteorological data was collected from CWC (Central Water Commission) and IMD (Indian Meteorological Department). The data considered for analysis includes - most extreme temperature, least temperature, mean temperature and precipitation data. The data collected from the above agencies covered the periods 1901-2001. Table 1 describes locations of 17 weather stations in different district of the Beas Basin. For downscaling, HadCM3 output and (NCEP/NCAR) data hasbeen successfully taken from CICS (Canadian climate Impact Scenarios). The NCEP/NCAR reanalysis data for SDSM model calibration and validation is from the periods 1961 to 2001acquainted with the HadCM3 having a resolution of 3.75$^{o}$ x 2.7$^{o}$. The variables of HadCM3 are available in A2 and B2 scenarios for the period 1961-2100.

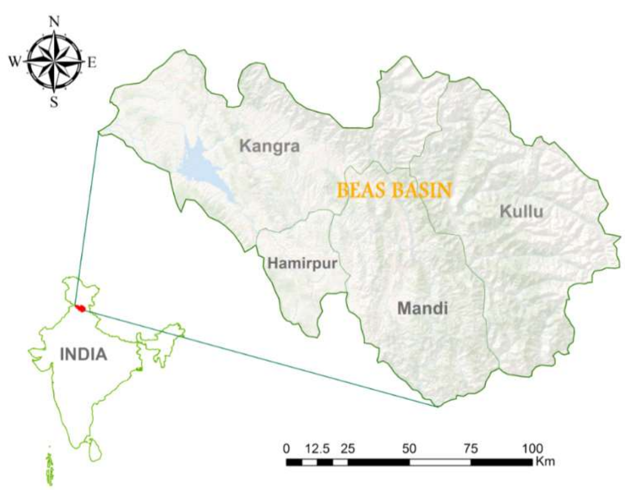


**Fig. 1.** Map of the study area

**METHODOLOGY**

**General Circulation Model**

In this study a GCM model Hadley Centre Coupled Model, version 3 (HadCM3) is considered. It is a coupled atmosphere-ocean general circulation model (AOGCM) developed at Hadley, U.K. It is one of the major models used in the IPCC Third Assessment Report in 2001 and Fourth Assessment Report in 2007. Simulations use a 360 day calendar, where each month is 30 days. HadCM3 is composed of two components: the atmospheric model HadAM3 and the ocean model HadOM3 (which includes a sea ice model). For more details on some GCMs variants, interested readers may find in the works of Houghton (2001), Carter (2007) and Kim et al (2008). Each GCM differ based on model resolution and discretization, domain areas spatial coverage, model parameterization and applied model algorithms.

**Special Report on Emission Scenarios**

The 4th assessment report of IPCC addressed to access the social, economic and technical information according to climate change. It published a report on SRES (Special Report on emission scenarios), which is utilize for prediction of environmental changes in light of ozone emission on the basis of four given scenarios. These are termed as A1, B1, A2 and B2. These four scenarios develop a relation between emissions and future development in upcoming features. Table 2 provides the descriptive SRES scenarios situations.

**Statistical Downscaling Model**

In order to overcome the limitations of GCMs at regional impact studies, downscaling techniques are used (Abdo et al 2009). Although, different downscaling techniques are available, however selection of appropriate downscaling techniques is also a thought-provoking (Dibike and Coulibaly, 2004) and usually depends on the study and availability of data. Statistical Downscaling Model (SDSM) is a decision support tool for assessing local climate change impacts using a robust statistical downscaling technique. SDSM facilitates the rapid development of multiple, low-cost, single-site scenarios of daily surface weather variables under current and future regional climate model. Additionally, the software performs ancillary tasks of predictor variable pre-screening, model statistical analyses and graphing of climate data.

In down scaling, both the predictors and a predict and variables quantitative relationship were established. The difference is such that daily information of state of atmosphere at large scale represents the predictor variables (PEV) while regional scale variables such as rainfall and temperature which are usually observed at weather and/or meteorological stations represent the predict and variables (PV). In other words, the model output of HadCM3 represents the predictor variables that can be avail from CICS on grid basis. The modified SDSM modelling procedure from Wilby and Dawson (2007) (Fig. 2 ).

**Mann-Kendall Test**

Mann-Kendall test (first proposed by Mann 1945)is a nonparametric test used to identify a trend in a series of values. It was further studied by Kendall (1975) and improved by Hirsch et al (1982, 1984) taking into account seasonality. The purpose of the Mann-Kendall (M-K) test is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time (Mann 1945, Kendall 1975, Gilbert 1987). A monotonic upward and/or downward trend means that the variable consistently increases and/or decreases through time, but the trend may or may not be linear. For a time series $x_1, x_2, \ldots x_n$, M-K test can be estimated by the following statistic $S$.

$$S = \Sigma_{i=1}^{n-1} \Sigma_{j=k+1}^{n} sign\ (x_j - x_i)(j > i) \quad (1)$$

Here $n$ denotes the number of data pointsm $x_j$ and $x_i$ are the data values in the series $i$ and $j$ ($j$>$i$) respectively. And sign(1) is the sign function varies in the range -1 to +1; if (.) > 0 then sign (.) = 1, if (.) = 0 then sign (.) = 0 and if (.) < 0 then sign (.)=1.

Here, if S > 0 then later observations in the time series

**Table 1.** District wise weather station locations

| District | Location of weather stations | | Spatial Information | |
|---|---|---|---|---|
| | Station No. | Location | Latitude | Longitude |
| Hamirpur | S1 | Bhoranj | 31.68° | 76.52° |
| | S2 | Hamirpur | 31.70° | 76.50° |
| | S3 | Nadaun | 31.78° | 76.35° |
| Kangra | S4 | Dehra | 31.87° | 76.32° |
| | S5 | Dharmashala | 32.22° | 76.31° |
| | S6 | Nurpur | 32.18° | 75.53° |
| | S7 | Kangra | 32.10° | 76.27° |
| | S8 | Malan | 32.11° | 76.41° |
| | S9 | Palampur | 32.10° | 76.54° |
| Mandi | S10 | Chachiot | 31.39° | 77.20° |
| | S11 | Jogindernagar | 31.99° | 76.79° |
| | S12 | Karsog | 31.38° | 77.20° |
| | S13 | Mandi | 31.70° | 76.93° |
| | S14 | Sarkaghat | 31.70° | 76.74° |
| | S15 | Sundarnagar | 31.53° | 76.90° |
| Kullu | S16 | Banjar | 31.63° | 77.34° |
| | S17 | Bajaura | 31.84° | 77.16° |

**Table 2.** Specification of scenarios

| Scenarios | Characteristics |
|---|---|
| A1 | Quick financial development, across the board social and social cooperation's around the world, fast augmentation of new advancements. |
| A2 | Coordinated world, constantly expanding populace, monetary advancements on local levels. |
| B1 | Fast monetary development as A1, accentuation on worldwide answers for financial, social and ecological solidness, decline in material force, presentation of clean and asset effective innovations. |
| B2 | Persistent expanding populace yet more slow than A2, accentuation on neighborhood as opposed to worldwide answers for financial, social and natural soundness, middle of the road level of monetary turn of events. |

tend to be larger than those that appear earlier in the series, while the reverse is true if S < 0. For n ≥ 10, statistic S is approximately distributed normally as documented by Mann and Kendall with the mean S equal 0 and the variance of S defined as-

M(S) = 0 (2)

$$Var\ (S) = \frac{n(n-1)(2n+5) - \Sigma_{f=1}^{r}(t_f)(f)(f-1)(2f+5)}{18} \quad (3)$$

Where $r$ varies over the set of tied ranks and $t_f$ is the number of times (i.e. frequency) that the rank $r$ appears. The standard normal variable is defined as follows:

$$\begin{aligned} Z &= \frac{S-1}{\{VAR\ (S)\}^{1/2}} & if\ S > 0 \\ Z &= 0 & if\ S = 0 \quad (4) \\ Z &= \frac{S+1}{\{VAR\ (S)\}^{1/2}} & if\ S < 0 \end{aligned}$$

For Z > 0, it shows an increasing trend whereas for Z < 0, there is a decreasing trend. For a given confidence level α, data series would have statistically significant trend if |Z| > Z (1-α/2), where Z(1-α/2) represent the corresponding values of P = α/2 of standard normal distribution. The present study used the confidence level of 95%.

**Sen's slant calculation:** Sen's method (Sen 1968) isemployed to determine the magnitude (increase or decrease) of the current trend slope. It has its wide application in dealing with hydro-meteorological time series (El Nesr et al 2010, Gocic and Trajkovic 2013). For $n$ pairs of sample data with constant time, the residual variance is calculated as-

$V_i = X_k - X_l/k\text{-}1$ *for* $i = 1,2,2,\ldots\ldots.\ n$ (5)

Where $X_k$ and $X_l$ are the data values at times $k$ and $l$, (j > k), respectively. For each time period if there is one datum, then $N = n\ (n\text{-}1)/2$ whereas for multiple observations of one or more time periods, it is $N < n\ (n\text{-}1)/2$. Here $N$ denotes the number of time periods. The $n$ values of $V_i$ is in the range of ascending order, and Sen's slope (or median of slope) is estimated as:

$$V_m = \begin{Bmatrix} V_{\left[\frac{n+1}{2}\right]} & \text{(if } n \text{ is odd)} \\ \dfrac{V_{\left[\frac{n}{2}\right]} - V_{\left[\frac{n+2}{2}\right]}}{2}, & \text{(if } n \text{ is even)} \end{Bmatrix} \quad (6)$$

The value of $V_m$ indicates the steepness of the trendand its sign reflects data trend. With a specific probability, confidence interval ($C_{in}$) of $V_m$ is determine to check whether slope has statistical difference than zero. The $C_{in}$ for time slope can be calculated (Gilbert 1987) as:

$$C_{in} = Z'_{\alpha/2}\sqrt{Var\ (S)} \quad (7)$$

Here $C_{in}$ is calculated with significance level (α) of 95% and 99% and *Var (S)* is defined in Eq. (3).

## RESULTS AND DISCUSSION

The present study is carried out by utilizing chosen shield factors and variety of change in the nearby predict and

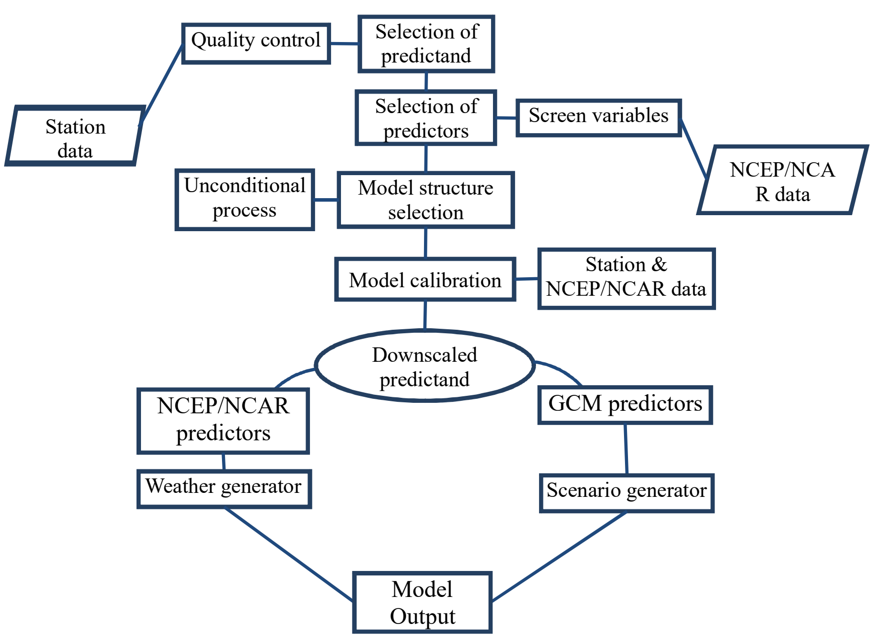


**Fig. 2.** Flowchart of downscaling procedure in SDSM

considering daily rainfall data, most extreme and least temperature for various stations pertaining to 1961-2001. Conditional procedure for precipitation and unconditional procedure for most extreme and least temperature were selected for model calibration. In unconditional procedure, an immediate connection between the predict and predicators are considered whereas conditional procedures are accomplished with intermediate process. Table 3 shown below illustrates the chosen predicators for model alignment at Beas basin. Table 4 depicts the representations of predictor's variables.

**Trend Detection**

The observed trends obtained for four districts of Beas basin (Hamirpur, Mandi, Kullu and Kangra) at different seasonal counts namelyannual, summer, monsoon and winter are summarized in Table 5. In the Hamirpur, the rainfall patterns shows a negative (–ve) trends predominantly for three seasonal counts while positive (+ve) trends exist during summer. Conversely, no trends are detected over the remaining three districts. Besides, others seasonal parameters such as T-min and T-max shows the +ve trends over the four districts at different seasonal counts except for Hamirpur where T-maxin the monsoon and winter are –ve. Figure 3 shows the overall observed rainfall trends over the four prevalent seasonal counts. It is observed that there is an increasing trends in the periodic rainfall, except for winter season where no trend is detected. Conversely, Figures 4 and 5 depict the periodic trends for T-max and T-min over the Beas basin. It is observed that both T-max and T-min follows an increasing trends over all seasonal counts except during the monsoon where both parameters are declining with certain degree.

**Future Projection**

The analysis for climate projections are divided into three time frames each having 30 years of data. These includes 2020s (2011- 2040), 2050s (2041-2070) and2080s (2071-2100), the designations 2020s, 2050s and 2080s are based on the data centering 2025, 2055 and 2085. The observed data periods1961-1985 and 1986-2001 were used for calibration and validation respectively against the projections data. Figure 6 shows the overall variations based on

**Table 3.** Predictors and predict at Beas basin

| Predict and | Predictors |
|---|---|
| T-min | Ncepp 500as, ncepp_zhas, ncepp8_vas, ncepp 8thas, nceptempas,ncepphumas |
| T-max | Ncepp 500as, nceppzhas, nceprhumas, ncepp5_zas, ncepp8thas, ncepshumas, nceptempas |
| Precipitation | Ncepp_uas, ncepp_zas, ncepp_thas, ncepp5_uas, ncepp8_uas, ncepshumas |

**Table 4.** Representation of predictor variables

| Predictors | Description |
|---|---|
| Nceprhumas | Near surface relativehumidity |
| Ncepp5zhas | Divergence |
| Ncepp_uas | Zonal velocity component |
| Ncepp_zas | Surface velocity |
| Ncepp5_uas | Zonal velocity |
| Ncepp_vas | Surface meridional velocity |
| Ncepshumas | Near surface specific humidity |
| Ncepshumas | Surface specific humidity |
| Ncepp_vas | Meridional velocity component |
| Nceptempas | Mean temperature |
| Ncepp500as | Geopotential height |

**Table 5.** Observed trends reported over four districts in Beas basin

| Stations (Beas Basin) | | Seasonal counts and their respective trends | | | |
|---|---|---|---|---|---|
| | | Annual | Summer | Monsoon | Winter |
| Hamirpur | Rainfall | -ve | +ve | -ve | -ve |
| | T-min | +ve | +ve | +ve | +ve |
| | T-max | +ve | +ve | -ve | -ve |
| Kullu | Rainfall | No trend | +ve | No trend | No trend |
| | T-min | +ve | +ve | +ve | +ve |
| | T-max | +ve | +ve | +ve | +ve |
| Kangra | Rainfall | +ve | +ve | +ve | +ve |
| | T-min | +ve | +ve | +ve | +ve |
| | T-max | +ve | +ve | +ve | +ve |
| Mandi | Rainfall | No trend | No trend | No trend | No trend |
| | T-min | +ve | +ve | +ve | +ve |
| | T-max | +ve | +ve | +ve | +ve |

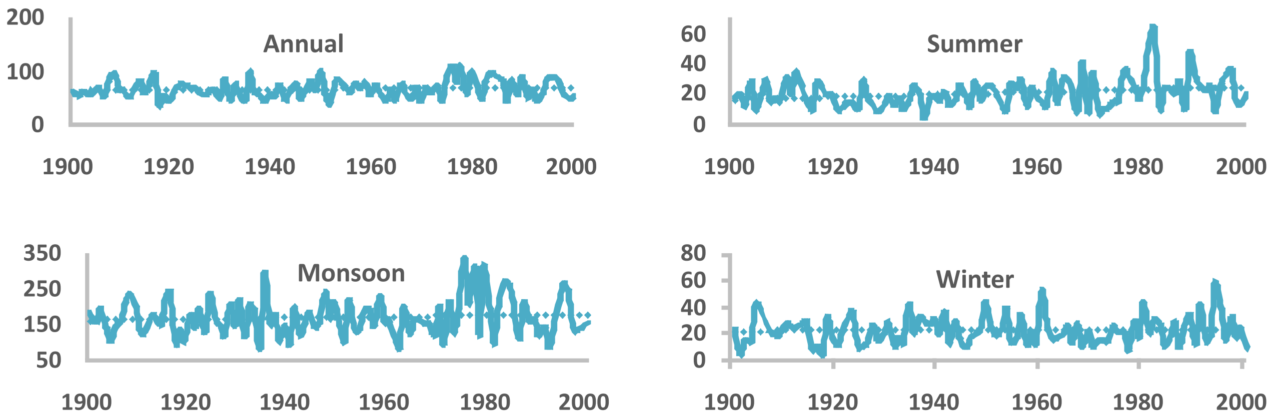


**Fig. 3.** Estimated mean daily rainfall pattern over the period of 101 years (1901 to 2001) in the Beas basin for different seasonal counts

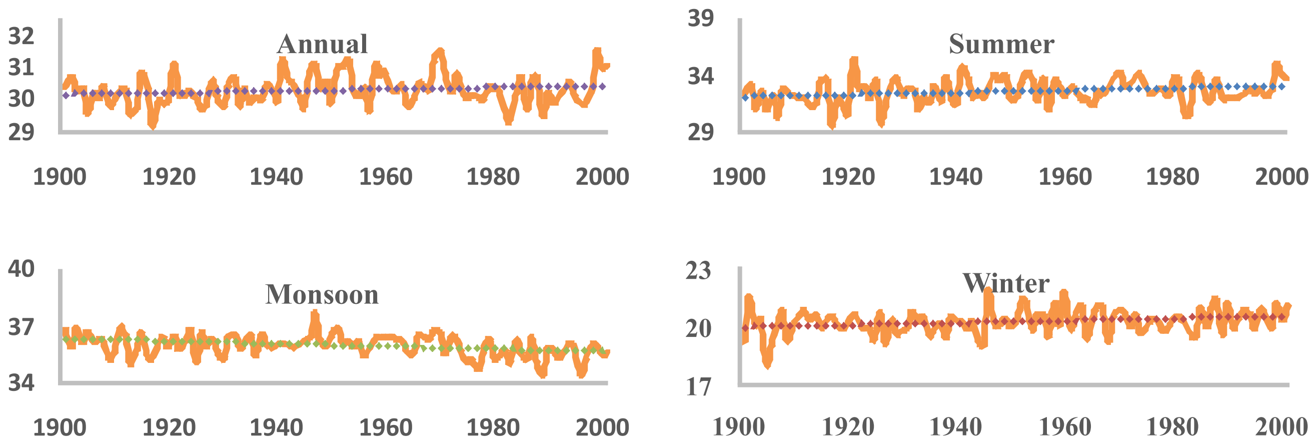


**Fig. 4.** Estimated mean daily pattern of T-max over the period of 101 years (1901 to 2001) in the Beas basin for different seasonal counts

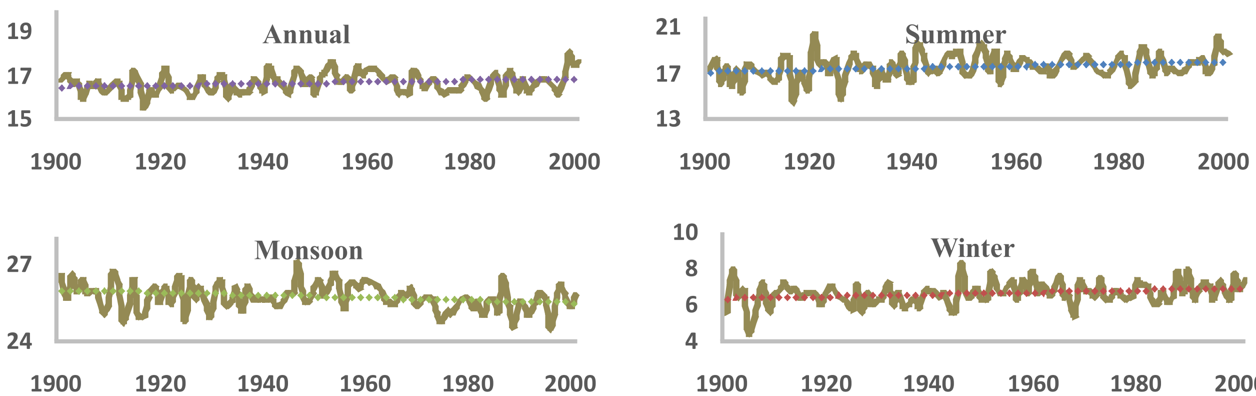


**Fig. 5.** Estimated mean daily pattern of T-min over the period of 101 years (1901 to 2001) in the Beas basin for different seasonal counts

percentage change in PPT for both A2 and B2 scenarios in the Beas basin. For 2020s it was observed that the mean monthly precipitations is decrease for all months excepts for February, September, October and November for both A2 and B2 scenarios, out of which maximum precipitation is observed in September. The magnitude of maximum and minimum percentage rise and fall of the mean monthly precipitation is found to be +19.38 % and -9.68% for 2020s for A2 scenario while for B2 scenario the it is found to be +17.67 % and -11.31% respectively. As shown in Figure 5 the precipitation patterns for summer, monsoon, winter and annual for 2020s, 2050s and 2080s for both the scenarios is expected toshows a declination in the near feature.

As shown in Figure 7, there is a rise in mean monthly maximum temperature (Tmax) for 2020s, 2050s and 2080s against the baseline periods for both the scenarios. Besides, there is an incremental rise in Tmax for 2020s and 2050s except for 2080s where it is reduce in B2 scenario. For 2020s Tmax labels rise by+5.12% and +5.34% respectively during March, and fall by -2.95% and -2.91% in May for A2 and B2 Scenarios. Similarly, the same patterns are observed for 2050s but with further rise and fall i.e. rise by +7.68% (A2 scenario) and +11.53% (B2 scenario) and fall by -3.98% and -4.66% for A2 and B2 scenarios. For 2080s Tmax rise by +9.44% for A2 scenario and +8.24% for B2 scenario. Among seasonal counts, the winter season shows to increase more corresponding to 2050s by +3.84% and +7.24%. Figure 8 displays the percentage trends of mean monthly minimum temperature (Tmin). In the 2020s and based on both the scenarios, it indicates that the pattern of Tmin is more or less close to the baseline periods. However, for 2050s and 2080s the pattern of Tmin is expected to rise particularly during the months of February and December. Overall, the highest change in Tmin is indicated in the 2050s with the rise by +52.56% in December for A2 scenario and by +31.13% in winter season for B2 scenario. Conversely, for all seasonal counts the pattern remains more or less close to baseline periods except for winter season where it indicates to rise in 2050s.

**Rainfall erosivity factor:** The magnitude and intensity of rainfall is subjected to rill soil loss rate and that can be accomplished by an important factor known as rainfall erosivity factor (or R-factor). For accurate estimation of R-Factor, it is essential to calculate at regional scale using the available rainfall data. For more details on R-factor, the readers may find somewhere in the works earlier researchers (Ninyerola et al 2006, Capolongo et al 2008,Calvo-Alvarado et al 2014). In the present study, the method adopted for R-

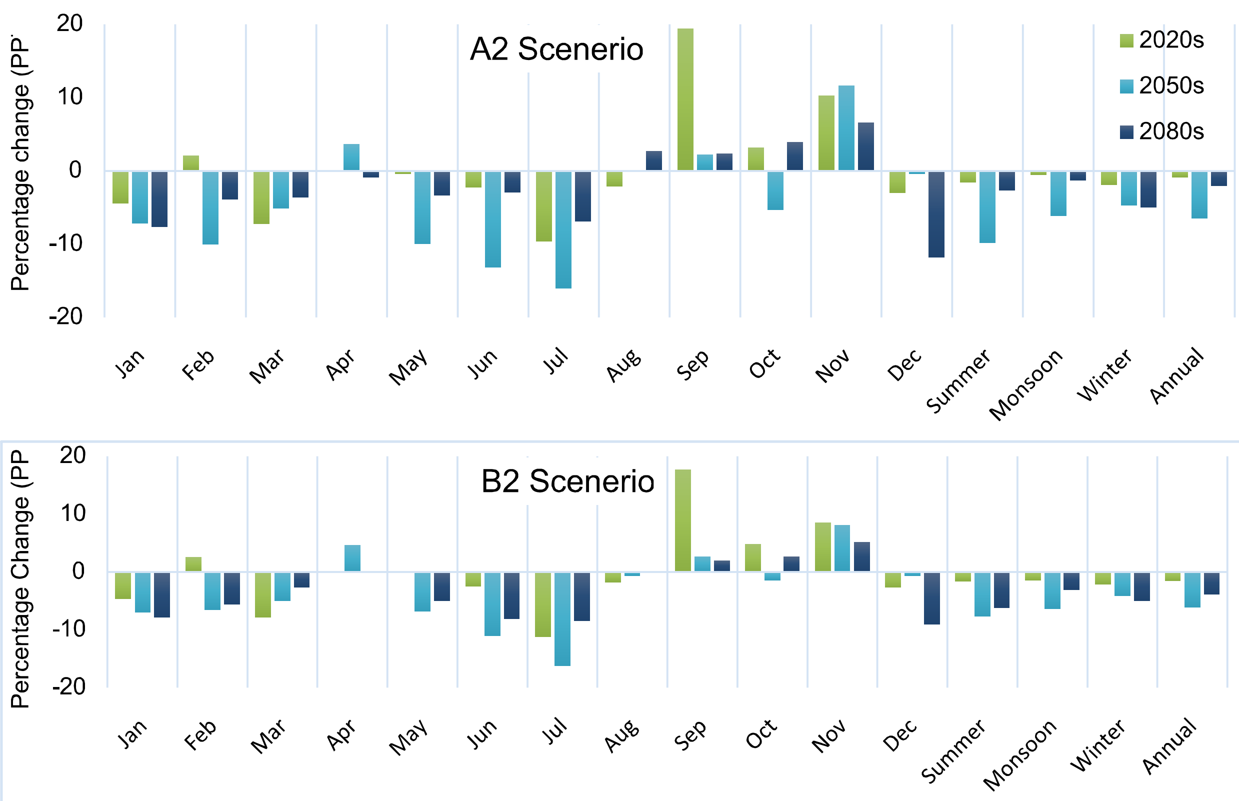


**Fig. 6.** Projected Change in Precipitation (PPT) for mean monthly, summer, monsoon, winter and annually in the Beas basin

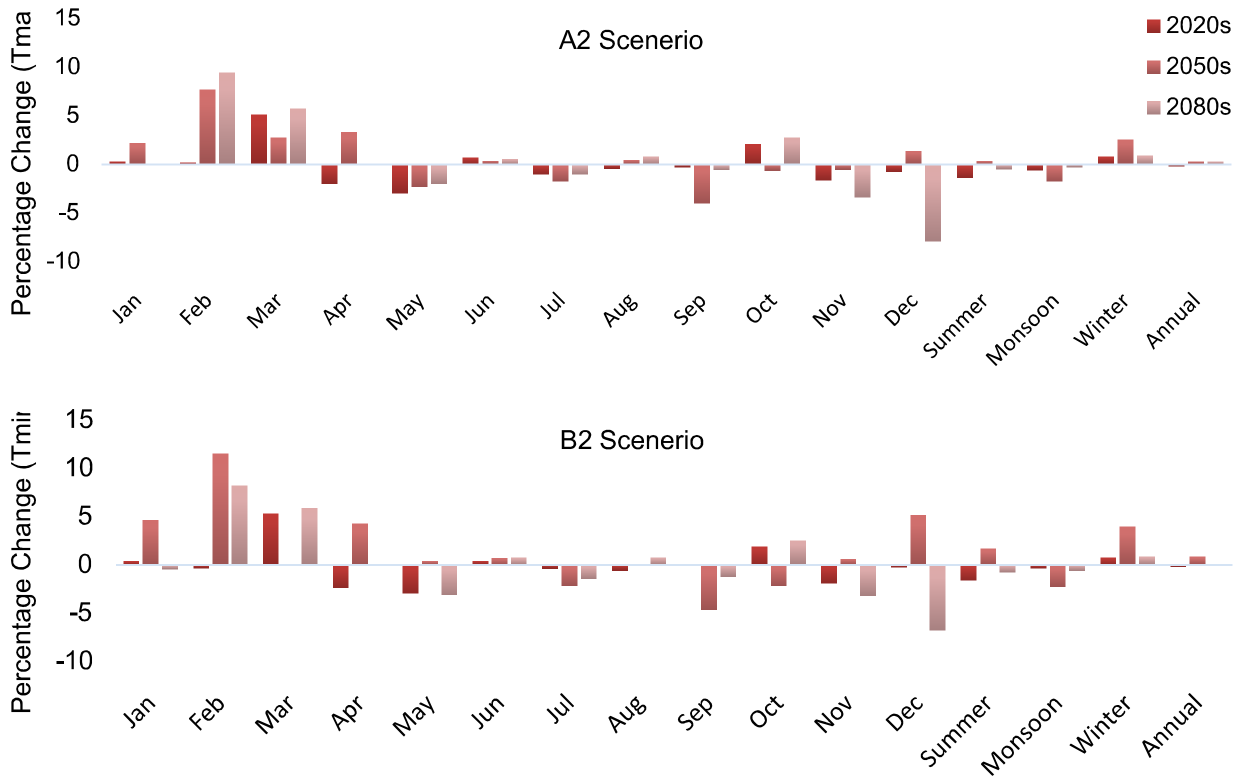


**Fig. 7.** Projected change in maximum temperature (T-max) in for mean monthly, summer, monsoon, winter and annually in the Beas basin

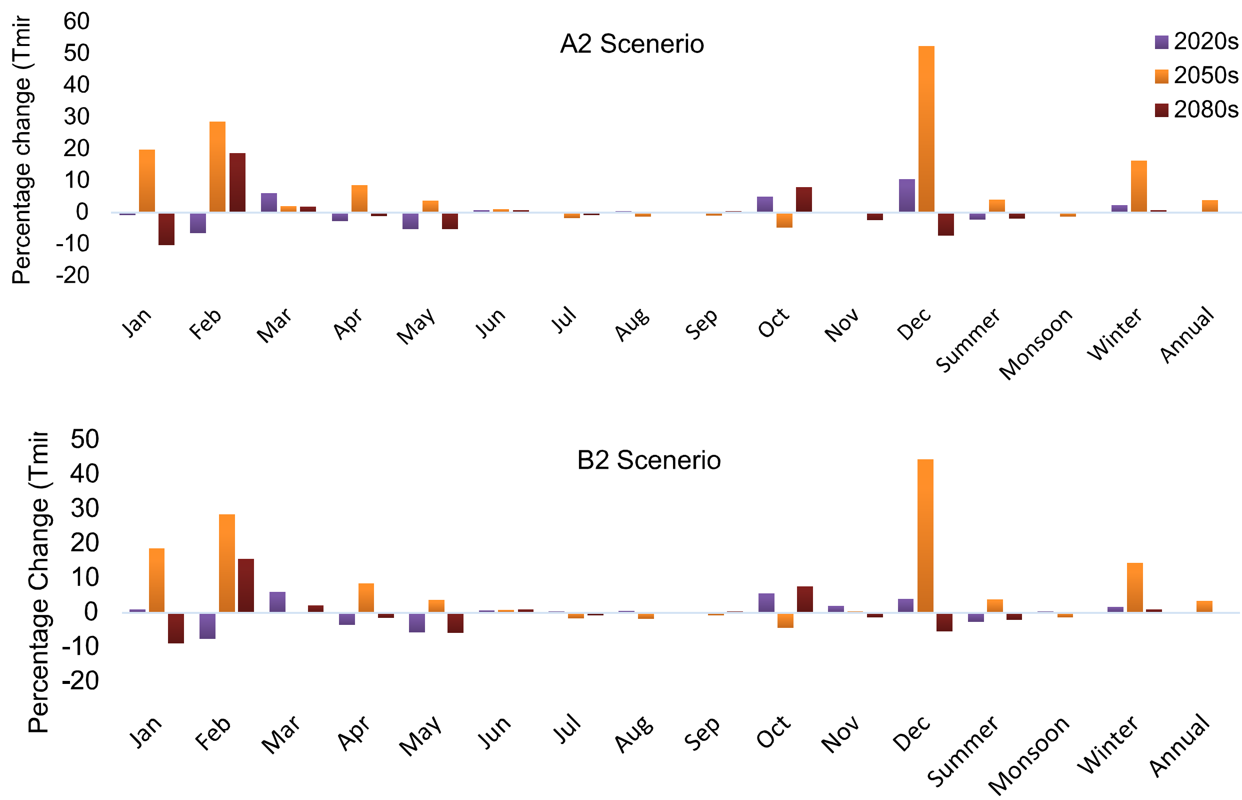


**Fig. 8.** Projected change in minimum temperature (T-min) for mean monthly, summer, monsoon, winter and annually in the Beas basin

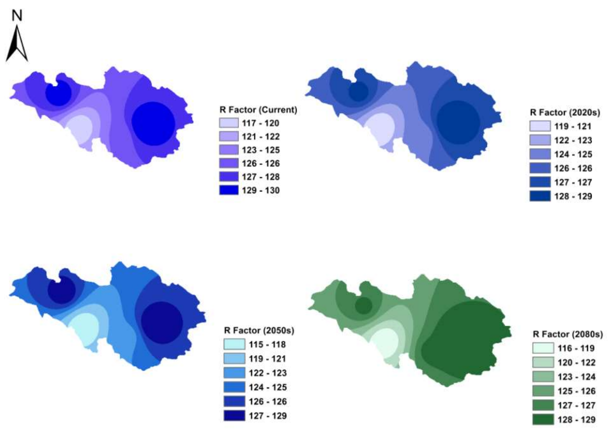


**Fig. 9.** R-factor (MJ.cm/ha$^{-1}$.h$^{-1}$.yr$^{-1}$) for current, 2020s, 2050s and 2080s in the Beas basin, H.P, India

factor estimation is based on the modified Fourier series obtained by Tiwari et al (2015) as it has more or less provides similar rainfall pattern. Figure 9 shows the resultant probability of R-factor trends for 2020s, 2050s and 2080s in corresponds to current trends.

## CONCLUSION

The present study reports on the probable impacts on the environmental shift in the Beas Basin, H.P, India due to impending changes in the patterns of climate parameters. The changes on conditional impacts of PPT, T-max and T-min are predicted over the Beas basin using HadCM3 GCM for A2 and B2 scenarios considering the periods 2011-2100.SDSM indicates a decreasing and increasing trends for rainfall patterns for A2 and B2 emission scenarios, the decrease in trends is higher for 2020s (2011-2040) and an increasing trends is observed for 2050s (2041-2070) while the patterns is more or less were comparatively closer to baseline periods for 2080s (2071-2100). Nevertheless, the T-max is expected to increase by 2050s and 2080s while T-min is comparatively expected to increase rapidly during 2050s only. Furthermore, based on the R-factor (rill in soil rate loss due to change in rainfall pattern is likely to remain more or less consistent by 2100 with the near magnitude of 119 MJ.cm/ha$^{-1}$.h$^{-1}$.yr$^{-1}$. The model results for climate variables shows decent consistency within the IPCC change predictions. The downscaled results is pertinent to uncertainties and were expected to be associated with the downscaled model (SDSM), hence the results are indicative of possible changes in the future rather than actual prediction. Overall, the results presented in the paper can still provide a valuable inputs to decision maker to counteract vulnerability of the ecology in the Beas basin hydrology which is important for mitigation strategies. In future various other downscaling techniques and in-addition other significant operational climate parameters may be investigated for effective prediction accuracy.

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# Population Structure and Habitat Association of Defassa Waterbuck (*Kobus ellipsiprymnus Defassa*, Ruppell, 1835) in Maze National Park, Ethiopia

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***Abstract***: An investigation on population structure and habitat association of *Defassa* waterbuck (*Kobus ellipsiprymnus Defassa*) was carried out in Maze National Park between October 2018 and April 2019 for both wet and dry seasons. Sample counting based on the line-transect method was used. Habitat association was evaluated based on the number of individuals observed in different habitats. A total of 10 representatives transect across four main habitat types were randomly laid, and about 20% of each habitat was surveyed. Data were analyzed using descriptive statistics and compared with the Chi-square test. A total of 93 mean numbers of individuals were observed and 491.5 estimated populations were recorded during the study period. The age composition of *Defassa* waterbuck comprised 39.5 (42.47%) adults, 52.5 (56.45%) sub adults and 1 (1.08%) young. Females were greater than males during both seasons. The highest *Defassa* waterbuck population was observed in the riverine forest habitat in both seasons. However, no *Defassa* waterbuck was observed in the bush land habitat type. The relative abundance of palatable vegetation, the availability of water and the accessibility of vegetation cover for shelter were the major factors governing their distribution in the present study area.

***Keywords***: *Defassa* waterbuck, Habitat association, Maze National Park, Population structure

*Defassa* waterbuck (*Kobus ellipsiprymnus defassa*, Ruppell 1835) is a large antelope found widely in sub-Saharan Africa (Spinage 2013). In Ethiopia, occurs west of the Great Rift Valley in association with most major rivers, lakes and wetlands (Kingdon 2015). Within favorable habitats, populations of waterbuck species can reach relatively higher densities. For instance, more than 10 individuals/km² were recorded in Lake Nakuru National Park, Kenya, while in Ethiopia, particularly in the Chebera Churchura National Park (CCNP) 0.506 individuals/km$^2$ was estimated (Adane et al 2015).

Habitat for mammals is disappearing quickly from the Earth's surface due to human interferences, climate change and habitat destruction (Patterson et al 2003). This condition, particularly affects the distribution patterns of large mammals, including *Defassa* waterbuck as them to depart in search of preferred habitats. Due to these mentioned problems the population status of *Defassa* waterbuck gets declining (Spinage 2013). Even in Ethiopia common waterbuck are extinct and *Defassa* waterbuck is grouped under lists of near threatened subspecies (IUCN SSC Antelope Specialist Group 2017). As a result, information on population status and their habitat association is essential for the species survival, sustainable management and conservation of protected areas (Aramde et al 2011).The presence of *Defassa* waterbuck is only known from the species list documented by the Maze National Park (MzNP). However, their population status, habitat association and other aspects are not scientifically studied. As a result, data on these issues especially on their population status and habitat association give firsthand information for conservationists and managers to safeguard this near threatened subspecies. Based on this understanding, the study was conducted to estimate the current population size and identify their habitat association in Maze National Park, Ethiopia.

## MATERIAL AND METHODS

**Study area**: The Maze National Park is located at 460 km southwest of Addis Ababa on the way of Wolaita Sodo - Sawla road in the Southern Nations, Nationalities People's Region, Ethiopia (Fig. 1). The Park was named after the Maze River which rises from southern parts of the surrounding highland and passes through the park from south to north direction and eventually drains into Omo River. The MzNP was established in 2005 and is serving as one of the last remaining sites for the conservation of the Swayne's Hartebeest second to Senkelle Hartebeest Sanctuary. The area covers $202 km^2$.The park lies between 06° 03' to 06°30' N latitude and 37°25' to 37°40'E longitude. Its altitude ranges from 900 to 1200 masl. Bilbo Hot Spring, which is situated at the southern part of the park, is a natural beauty where hot water flows out of the ground forming a fountain; and used by local people and those who come from distant places as a source of cure. The annual rainfall ranges between 843 and 1321mm. The area experiences a long rainy season from March to October and the dry season is from November to February (Wondimagegnehu and Afework 2015). A variety of mammals, bird species, reptiles, amphibians as well as insects are reported in the Park. There are 146 vascular plant species. The park is covered mainly by Combretum-Terminalia woodland and savannah grassland composed of grass species that grow on average up to three meters (Wegene and Feleke 2015).

**Data collection**: Reconnaissance was made before the commencement of the actual data collection in order to acquire basic information on accessibility, vegetation type, topography and distribution of *Defassa* waterbucks. A research design was established based on these initial observations. The study area was divided into four major habitat types (i.e. open grassland, riverine forest, scattered tree and bush land). The number of transects in each habitat was varied depending upon the area and visibility (Norton-Griffiths 1978). A total of 10 transect lines, four for open grassland, two for riverine forest, two for scattered tree and the rest one for bush land were established. The length of transects were varied from 4 to 5 km at a distance of 0.5 -1.5 km between the two nearby transects. Transects were randomly originated and placed with respect to the types of habitat on the map of the study area. The end point of all transect was found to be reasonably far from their respective habitat edge to avoid the edge effect. Each transect lines were delineated by an artificial and natural boundaries. The wet season data were collected from October 2018 and March to April 2019, while the dry season data were collected from November to December 2018 and January 2019.

**Population census:** Data on population status of *Defassa* waterbuck were collected using sample count method (Norton-Griffiths 1978). Two trained observers were involved to collect data from the left and the right side of the line transect. When *Defassa* waterbuck were seen, total number/group size, sex/age group, date, habitat type, and GPS coordinates were recorded on a separate data sheet, as described by (Adane et al 2015). Each transect was visited two times per month and a total of 12 times within a study period. Data were collected two times a day in the early morning (06:30 to 10:30) and late afternoon (14:00 to 18:00) when the activities of animals are more active (Reta and Solomon 2013). To minimize disturbance during counting, silent movement followed by 3 to 5 minutes waiting period was allowed. Video recording and pictures were taken for further confirmation. Natural marking, group or individual size, age/sex ratio were taken in order to reduce double counting.

**Group size**: During each sample count, the group size of *Defassa* waterbuck was recorded before further subdividing into the respective sex and age categories. Animals were considered as members of the same group, if the separation distance is approximately less than 50 meters, following (Lewis and Wilson 1979). Sex ratios for the groups were obtained from direct count of the animals using the methods of (Altman 1974).

**Age and sex structure**: Sex composition of individual or herd *Defassa* waterbuck were recorded as adult male (AM), adult female (AF), sub-adult male (SAM), sub adult female (SAF) and young/unidentified sex (Y) (Kingdon 2015). Age and sex determination were carried out based on body size, presence or absence of horn, size of horn (Brashares and Arcese 2000).

**Habitat association**: Habitat association of *Defassa* waterbuck was indicated by the number of individuals observed in each habitat type during wet and dry seasons (Norton-Griffiths 1978).

**Data analyses:** Data were analyzed using SPSS version 20 computer software program and Microsoft excel. Total population in each habitat was estimated following Norton-Griffith formula Norton-Griffiths (1978). Number of counted

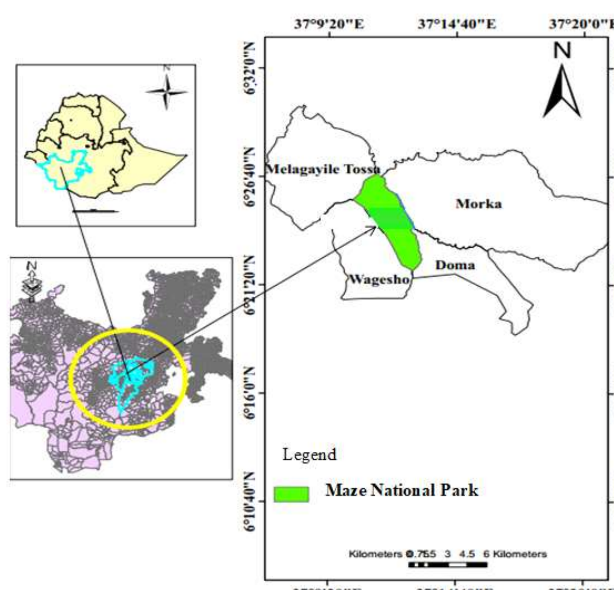


**Fig. 1**. Site location (6° 3' to 06°30' N latitude and 37°25' to 37°40'E longitude)

animals during different seasons in each habitat, age/sex category, herd size were compared using chi-square test. Other data were presented descriptively using tables and figures.

## RESULTS AND DISCUSSION

**Population estimate:** On average, 97 and 89 individuals of *Defassa* waterbuck were recorded during the wet and dry seasons, respectively. The mean numbers of individuals observed during both seasons of the study were 93.The estimated population of *Defassa* waterbuck in the area was 506 and 477 during the wet and dry seasons, respectively. The mean population estimate for the area was 491.5 individuals of *Defassa* waterbucks (Table 1). The average number of *Defassa* waterbuck was decreased during the dry season. This might be due to a lack of enough food during the dry season as compared to the wet season. Most of the study area is grassland habitat covered with a variety of grass species, frequently harvested by local communities for livestock and commonly burned by unprescribed fire during the dry season. As result, they live along the riverine forest and the nature of the topography is not suitable for their visibility and counting. Similar results were reported by Brnesh et al (2015) and Wubie and Mesele (2018) on other antelope species. In contrast to this Aramde et al (2011) described waterbucks were frequently encountered during the dry season than the wet season. On the other hand, the increment of population size in the wet season might be their peak breeding time. Similarly, the availability of food and water in the wet season is also the other positive factor to their addition. This result goes in line with Okello et al (2015) findings, which states that a relatively large number of young individuals were seen during the rainy season. On the opposing this, (Adane et al 2015) reported, a peak number of calves were observed during the dry season in CCNP. Here, the author explained that the Park has a better availability or conditions for counting during the dry season.

**Group size:** The group sizes were differed in both seasons during the study period with habitat type. The maximum size (ten) recorded was in the open grassland during wet season followed by nine in the riverine habitat during the dry season. This is likely that in MzNP the palatable grass for *Defassa* waterbuck were relatively abundant in such habitat types with respect to the season. Waterbuck forms small groups of 6 - 12 individuals, but larger groups reach up to 30 individuals (Skinner and Chimimba 2005). The minimum group size recorded was one during wet and dry seasons except in the bush land habitat, where no *Defassa* waterbuck recorded. There was a significant difference between the maximum and minimum group size during the wet and during the dry seasons. There was a small group size in the dry season. This might be due to the large group size were sparse in different habitats to increase their access for extra resources, which could not be enough within large groups. Tsindi et al (2016) strengthening this idea explained that due to the scarcity of the preferable food items in the summer waterbucks form a small herd size. Okello et al (2015) and Kasiringua et al (2019) showed that Waterbuck herds increase in the dry season, whereas the groups fragment in the wet months. Marino and Baldi (2014) reported that group sizes of large herbivores are mostly affected by habitat structure and population density. The maximum group size of *Defassa* waterbuck recorded during the wet season might be due to the animals were increasingly utilized in open grassland habitat, which has a better access for their visibility. The study shows in other ungulates that the group sizes of Buffalo and Kudu increased in the wet season in Mana Pools National Park Flood Plain in Zimbabwe (Tsindi et al 2016). Similarly, a research conducted on Gazella granti at Abijata- Shalla Lakes National Park by (Mesele and Afework 2012) confirmed this result.

**Age and sex structure**: Of the total mean numbers of individuals observed during both seasons, sub adults were the dominant followed by adults and young's. There was significant difference between the numbers of individuals in each age category (Table 2). The numbers of adult males were observed less frequently than other age/sex groups. According to Spinage (2013) and Adane et al (2011) male waterbucks are highly suffer an increased predation pressure compared with other groups.There were high proportions of females (55.1%) than males (43.8%) (Table 3). Similarly, the sex ratio of females was greater than males during both the wet (1:1.20) and dry (1:1.47) seasons (Table

**Table 1**. Population estimate of *Defassa* waterbuck in Maze National Park (Mean ± SE)

| Season | Individuals observed | Estimated |
|---|---|---|
| Wet | 97 ± 10.21 | 506 ±52.77 |
| Dry | 89 ± 12.23 | 477 ±149.94 |
| Mean | 93 ± 5.65 | 491.5 ± 20.50 |

**Table 2**. Number of observed individuals in each age categories during both seasons

| Age | Season | | | |
|---|---|---|---|---|
| | Wet | Dry | Mean ± S.D | Mean percentage |
| Adult | 45 | 34 | 39.5 ±7.78 | 42.47 |
| Sub adult | 50 | 55 | 52.5 ± 3.53 | 56.45 |
| Young | 2 | - | 1.0 ±1.41 | 1.08 |

4). A comparatively high ratio of females in the population indicated that *Defassa* waterbuck can tolerate their disturbance and have a potential to replace it. This indicates healthy and increasing population of the animal. This result is in line with (Adane et al 2011).

**Habitat association:** *Defassa* waterbuck were distributed into the three habitat types. However, their distribution and habitat preference were varied between seasons (Fig. 2). Seasonal variation of forage is mentioned as key factor determining the habitat use and movement of animals (De Vos et al 2017). Animal's distributions are mainly affected by suitable habitat types (Chabwela et al 2017). Out of 97 individuals of *Defassa* waterbuck observed in the wet season, 36 (37.12%) were in the open grassland, 37 (38.14%) were in the riverine forest and 24 (24.74%) were in the scattered tree (Table 5). Open grassland habitat and riverine forest were almost equally utilized by *Defassa* waterbuck in the wet season.This is probably due to the availability of palatable vegetation in open grassland habitat relatively in the wet season. In the dry season, riverine forest habitat was significantly utilised 60 (67.42%) than open grassland 11 (12.36%) and scattered tree 18 (20.22%). Unlike wet season, in dry season the distribution of *Defassa* waterbuck were significant differences among habitat types. This variation could be explained in terms of the availability of resources and human activity. Waterbuck is reported to be selective in habitats and moves from one habitat to another habitat based on the availability of food quality and their interactions with other species (Traill 2004). In the current study, the highest *Defassa* waterbuck population was observed in the riverine forest habitats in both seasons. They depend on permanent access to water (Kassa et al 2007, Hayward and Hayward 2012). It was not observed in bush land habitat in the current investigation. This could be owing

**Table 3**. Number of individuals observed in each age and sex categories during both seasons

| Age sex | Season | | |
|---|---|---|---|
| | Wet | Dry | Mean ± S.D |
| Adult male | 22 | 15 | 18.5±4.49 |
| Adult female | 23 | 19 | 21.0±2.82 |
| Sub adult male | 21 | 21 | 21.0±0.00 |
| Sub adult female | 29 | 34 | 31.5±3.53 |
| Young (Unidentified sex) | 2 | 0.0 | 1.0±1.41 |
| Total | 97 | 89 | 93.0±5.65 |

**Table 4**. Age and sex ratio of *Defassa* waterbuck during wet and dry seasons

| Season | Age and sex ratio | | | | |
|---|---|---|---|---|---|
| | M: F | SAM: SAF | AM: SAM | AF:SAF | AM: AF |
| Wet | 1:1.23 | 1:1.38 | 1:0.95 | 1:1.26 | 1:1.04 |
| Dry | 1:1.47 | 1:1.61 | 1:1.40 | 1:1.78 | 1:1.26 |
| Mean | 1:1.35 | 1:1.49 | 1:1.17 | 1:1.52 | 1:1.15 |

M: male, F: Female, AM: Adult male, AF: Adult female, SAM: Sub adult male, SAF: Sub adult female

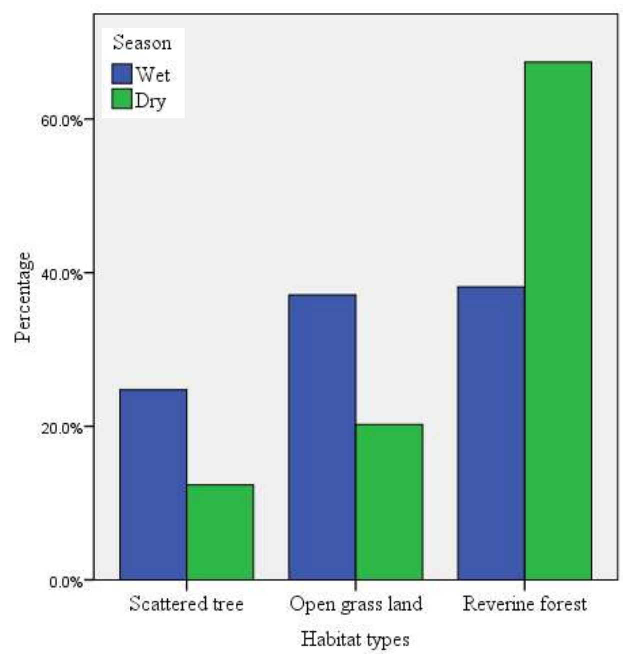


**Fig. 2**. Habitat association of *Defassa* waterbuck observed in Maze National Park across season

**Table 5**. Mean observed and the total estimated number of *Defassa* waterbuck in wet and dry seasons

| Season | Habitat type | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Open grassland | | Riverine forest | | Scattered tree | | Bush land | | Total EsDw ± S.D |
| | MoDw | EsDw | MoDw | EsDw | MoDw | EsDw | MoDw | EsDw | |
| Wet | 36.0 | 194.0 | 37.0 | 204.0 | 24.0 | 108.0 | - | - | 506 ±7.07 |
| Dry | 18.0 | 97.0 | 60.0 | 330.0 | 11.0 | 50.0 | - | - | 477 ± 149.94 |
| Mean | 27.0 | 145.5 | 48.5 | 267.0 | 17.5 | 79.0 | - | - | 491.5 ± 95.33 |

MoDw =Mean observed *Defassa* waterbuck population, EsDw = Estimated *Defassa* waterbuck population, DW = *Defassa* waterbuck (theses abbreviation's are not used elsewhere) to the area's distance from the river and lack of resources. Animal's distribution is affected by water body (Valeix et al 2009, Hayward and Hayward 2012). Aramde et al (2011) showed waterbuck was seen in the bush land habitat in the Nech Sar National Park. This might be due to the bush land habitats of the area may exist nearby the river or any other water body. There were no *Defassa* waterbucks sighted in areas where permanent water source is absent nearby (Patterson 2003).

## CONCLUSION

The present study provides relevant and base line information for concerned bodies about the current population and habitat association of the defessa waterbuck'. The result indicated that population of the defessa waterbuck healthy and increasing. *Defassa* waterbuck is tourist attracting animal, however, it listed as near threatened subspecies which needs prior conservation and management. For this reason, special attention should be given to conserve its habitat collaboratively with the community. As this is the poineer research further studies should be conducted on different aspects of *Defassa* waterbuck in the study area.

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# Breeding Behavior and Nesting Ecology of Pheasant-tailed Jacana

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***Abstract***: Present study was undertaken to observe the breeding behaviour, nesting ecology and role of males in raising of the young ones under polyandrous mating conditions in Pheasant-tailed Jacana at Kanjali Wetland (31.42°N - 75.37°E) a Ramsar site, in District Kapurthala, Punjab, India. The Pheasant-tailed Jacana, *Hydrophasianus chirurgus*is a bird that breeds in India, Indonesia and southeast part of Asia. The nest was found in floating vegetation formed of stems, branches and leaves of aquatic plants. Female lays 1 to 4 olive brown glossy eggs. Observations were made from 15$^{th}$ July, 2018 to 29$^{th}$ August, 2018. The incubation period last for 24 to 26 days.

***Keywords***: Breeding, Ecology, Nest, Pheasant-tailed Jacana, Polyandrous

A landmass with co-existence of water and soil that creates the favourable conditions for the growth of hydrophytes with relatively high productive nature, and harbours variety of flora and fauna referred as wetland (Hammer and Bastian 2020, Chatanga and Seleteng-Kose 2021, Balasubramanian 2021). These hydrophytes comprising the floating vegetation, in slow moving shallow water habitats are the preferred nesting sites of Pheasant-tailed Jacana (Khan and Mughal 2014) as they provide maximum foraging sites for females to steadily maintain maximum energy for the production of more clutches (Emlen and Oring 1977). Out of two species of Jacana, Bronze-winged Jacana and Pheasant-tailed Jacana, Pheasant-tailed Jacana is a common wader which belongs to family Jacanidae found in water bodies of Punjab, India (Grimmett et al 2012). These birds can swim in water but is usually found walking on the vegetation floating on water like lotus and water lily leaves with its well adapted feet and claws. In breeding plumage, bird develops a long pheasant like tail and hence called Pheasant-tailed Jacana. On the nape of neck, there is an attractive patch of golden feathers. In this phase of breeding, both male and female have slaty-blue bill and slight yellow tip (Ali and Ripley 1980). Breeding season lasts from June to September (Jenniand and Kirwan 2020). Pheasant-tailed Jacana is one of the polyandrous birds where, female can mate with multiple males during the breeding season. Mating partners vary from 8 to 10 in every breeding season (Thong-aree et al 1995). Major responsibilities such as nest building, incubation, raising of young ones, and their protection are carried out by the males. This study was carried out to understand the breeding behaviour under polyandrous conditions, nesting ecology and their reproduction. The breeding of this bird indicates that wetland is highly productive and provides healthy environment and suitable habitat.

## MATERIAL AND METHODS

**Studied site**: Present site is situated at Amritsar-Kapurthala Road with geographically located at 31.42°N 75.37°E having distance of four kilometres from Kapurthala, Punjab in village Kanjli with total area of 183 hectares and considered as internationally important water body and designated as a Ramsar site in 2002 (Kirti and Singh 2000, Singh et al 2017a, Singh et al 2017b). Shallow water with floating vegetation (*Eichhornia crassipes, Nelumbo nucifera, Trapa bispinosa*, *Typha angustata, Vallisneria spiralis, Pistia stratiotes, Panicum paludosum, Hydrilla verticillata, Lemna minor* and *Phragmites*) with abundance of food is the characteristic feature that support nesting and breeding of the Pheasant-tailed Jacana. The map showing the different sites which were occupied by the Pheasant-tailed Jacana for the nesting.

**Methodology**

Field visits from 15$^{th}$ July, 2018 to 29$^{th}$ August, 2018 were carried out to cover all important breeding events. Hourly visits were done in the gap of 2 to 3 days in morning, noon and evening in nesting cum foraging site of the breeding birds. Nests were found by walking along the edges and point count method was opted to observe nesting sites (Verner 1985). Hatching success and fledging success was calculated with traditional way (% of eggs that hatched out of total eggs and number of nestlings fledged out of hatched eggs). Field notes were made during every visit, photographic evidence of all important events was carried out during the survey with DSLR cameras Canon EOS 7D (2x extender) (100-400mm zoom lens), Nikon D7200 with 200/500mm Nikon lens and to avoid disturbance binocular (Olympus 8-16*40 zoom DPS-I) was used for observations.

## RESULTS AND DISCUSSION

On 15th July, 2018 (1230 hrs to 1700 hrs), birds were found and were locating the suitable site for building the nest. They had to choose the place covered with floating vegetation as it provides plenty of food and proper hide place from predators. *Eichhornia crassipes, Nelumbo nucifera, Trapa bispinosa*, *Typha angustata, Vallisneria spiralis, Pistia stratiotes, Panicum paludosum, Hydrilla verticillata, Lemna minor* and *Phragmites* are the major plant species found in their habitat. *Pistia stratiotes, Jussiaea repens, Vallisneria spiralis, Nelumbo nucifera* were the major component of the nest and also part of their diet explained by earlier workers (Subramanian et al 2000, Baek et al 2014, Khan and Mughal 2014, Khan and Mughal 2015). On 22nd July, 2018 (1230 hrs to 1630 hrs), birds have established themselves at several different locations and were busy in collecting nesting material, males were more active in making nest then females followed by mating within the nest. On 3rd August, 2018 (1200 hrs to 1400 hrs), male Jacana were in the nest with four eggs and incubation process was on its full swing. Males are found mostly near the nest during the whole duration of incubation and female visit occasionally as they have to visit multiple nests. On every minor disturbance, male jumped to the nest and stood just above the eggs. On 20th August, 2018 (1500 hrs to 1700 hrs), only three eggs were left in the nest as the eggs with doubtful paternity were removed from the nests by male because female mate with multiple males. Similar observations were reported at Taiwan (Chen et al 2008). On 21st August, 2018 (1600 hrs to 1700 hrs), the nest was observed with one egg and two chicks. Chicks were seemed to be of few hours old. Surprisingly, chicks were walking and swimming, and foraging around the nest as they are precocious. On an expeditious alarming call by adults under threat conditions like predation majorly by Marsh-harrier, all the chicks were hiding themself in water for a long time. The present field study shows that incubation, guarding of nest and raising of young ones was exclusively carried out by the male. The incubation period lasts for 26 days finding were supported by Khan and Mughal (2014).

In total 32 nests were located at eight different sites at Kanjli Wetland with 103 eggs. The fledging success at site II and VI was 100% and maximum hatchability was at V. (Table 1). The fledging success in Pheasant-tailed Jacana can be 100% but not hatchability as, it was also explained in earlier study (Chen et al 2008). Most of the wetlands are under severe threat of reclamation for agricultural purposes, encroachment and are infested with heavy load of toxicants discharge by industries (Tiwana et al 2008, Brraich and Jangu 2015). Natural wetlands like Rahon De Chhamb and Bhupinder Sagar are one of the examples of lost sites by these kinds of glitches (Ladhar 1995). Similarly, Kanjli wetland inhabiting very small area with significant

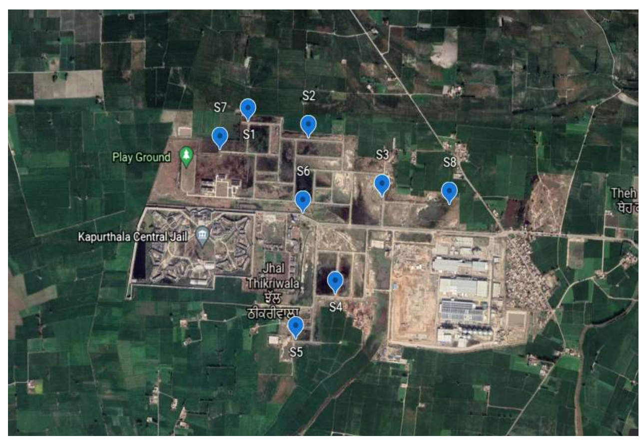


**Fig. 1.** Studied area

**Table 1.** Hatching and fledging success of Pheasant-tailed Jacana at different locations

| Site | Number of clutch | Number of eggs | Eggs hatched | Hatching success (%) | Number of young one fledged | Fledging success (%) |
|---|---|---|---|---|---|---|
| I | 6 | 21 | 14 | 66.67 | 13 | 92.85 |
| II | 3 | 8 | 5 | 62.5 | 5 | 100.00 |
| III | 5 | 17 | 11 | 64.7 | 10 | 90.90 |
| IV | 2 | 6 | 3 | 50.00 | 2 | 66.66 |
| V | 4 | 14 | 10 | 71.42 | 9 | 90.00 |
| VI | 5 | 16 | 10 | 62.5 | 10 | 100.00 |
| VII | 4 | 12 | 7 | 58.33 | 6 | 85.71 |
| VIII | 3 | 9 | 5 | 55.55 | 3 | 60.00 |


**Fig. 2.** (a) Showing mating in nest (b) Male guarding eggs within nest (c) First chick with unhitched egg (d) floating chick around nest (e & f) shows behaviour under threat conditions

biodiversity facing similar kind of stress form various quarters from last few years (Singh et al 2017a, 2017b. The present study indicates that this wetland sustains diverse habitat and higher productivity which makes it suitable site for breeding of various organisms. Although, wetland needs special attention for conservation from local people, researchers, conservators and stake holder as well as government agencies hence, combined efforts are highly required for the conservation of these invaluable ecosystems.

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# Computational Tools in Predicting Earthworm Distribution: A Pilot Study

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***Abstract*:** The study revealed that amongst all parameters, longitude, latitude, elevation and habitat revealed maximum correlation with distribution of earthworms. The methodology used is the first report of application of heatmap and correlation in ecological distribution of earthworms.

***Keywords***: Heatmap, Ecology, Distribution, Earthworms

Earthworms, belonging to phylum Annelida find importance as natural tillers of the soil. India being a country rich in its biodiversity and earthworms being of agricultural importance, their, ecology and distribution finds importance (Julka et al 2009). Since they are associated with soil and its quality control with a direct impact on agriculture, plant production, maintaining top soil quality, the study of the vast topic of ecological distribution of earthworm is complex but is of high importance. Earthworms mostly live in the soil, in different ecotypes of epi-endogeic, epigeic, endogeic, aneic forms, thriving on plant litter and soil (Ghosh 2019, Ghosh 2020-2021). Some aquatic forms of earthworms are also known residing in fresh water like lakes, ponds, soil adjoining fresh water areas etc. Like all life forms in the planet, earthworms are also being subjected to the impact of environmental stress factors like drought cold, soil salinity, famine, flood, exposed to pollutants from anthropogenic sources, pesticides, herbicides, pathogens from its habitat and food, subjected to harsh and harmful radiations and climate change. These agents have been reported to affect earthworm, health, distribution, reproduction and survival (Molnár et al 2012, Ghosh 2018, Singh et al 2019, Ghosh 2021). Ecological data about organisms is, heterogeneous, multidisciplinary of nature and voluminous and analysis by manual means is time and labour intensive process and is not only tedious but also challenging (Michener and Jones 2012, Arhami et al 2018). Therefore computational tools are gaining fast importance in data integration and analysis in the domain of ecology and recently computational tools algebra based applications has been used in ecological modelling (Jordán et al 2011) and attempts are being made to integrate the heterogeneous ecological data encompassing the genetic constitution of the organism and the biosphere (Jones et al 2006). A new domain of eco-informatics is developing that is helping researchers to collect, analyse, store, extract information, monitor and predicting trends from ecological data and aiding in solving various ecology related problems (Arhami et al 2018). In this study computational tools were used for generating a heat map and study of the correlation between datasets to understand and predict the correlation of an order of earthworms with its location, habitat, latitude, longitude.

## MATERIAL AND METHODS

**Data Collection**: The earthworms of Haplotaxida, Moniligastrida, and Lumbricida, (Table 1) were collected from two major locations Golghat, Assam, India with latitude 26.52°N, longitude 93.97°E at elevation 98.46 meters and Dehradun, Uttarakhand, India with latitude 30º 18´ N, longitude 78º 01E at elevation 197.206 metres in Sept-Nov 2019. The taxonomic keys were used to identify the species.

**Heatmaps:** The data was analysed using Python language by using the Jupiter notebook by generating heat map. A heatmap is a two-dimensional data representation in which colours indicate values or data, enabling a quick visualisation of data, thus helping to comprehend difficult data sets and large volumes of data. To find correlation of the data, heat maps were taken into consideration, to find out the correlation in data sets. A positive correlation value indicated that is close to 1 or above 0. Whereas correlation that is negative, is considered as inverse correlation.

## RESULTS AND DISCUSSION

*Eutyphoeus kempi* under Order Haplotaxida family Octochaetidae and *Metaphire posthuma* and *Lampito mauritii,* under Order Haplotaxida, family Megascolidae were common in distribution from NRC, Dehradun. From Golghat Assam. Order Haplotaxida including family Megascolecidae and species including *Amynthas diffringens, Perionyx excavatus , Perionyx pulvinatus* and Order Moniligastrida, family Moniligastridae, *Drawida nepalensis*, Order Lumbricida, family Lumbricidae, *Octolasion tyrtaeum* were exclusively collected while species under Order Haplitaxidae, family Megascolidae including *Amynthas hawayanus, Amynthas alexandri, Metaphire peguana,* were exclusively collected from NRC, Dehradun (Table 1). The strong positive correlations were observed between order and elevation (0.93), order and longitude (0.93),latitude (0.93), order and habitat (0.93) all four indicative of strong positive correlation (Fig. 2 A, B, C). The positive high correlation between genus and locality (0.7) and moderate positive correlation between genus and vegetation type (0.5) was observed (Fig. 2D-E). The results revealed positive correlation between latitude, longitude and genus and the rest scenarios like sex, earthworm family and state, revealed negative correlations. Availability of order of earthworms can be correlated strongly with elevation, longitude, latitude and habitat (Fig. 2A-C). Thus from the knowledge of the latitude longitude and habitat, one can predict the order of earthworm available in a locality. The positive high correlation between genus and locality description and moderate positive correlation between genus and vegetation type (indicated that the availability of a genus of earthworms can be predicted from its locality description and vegetation type Fig. 2D-E).

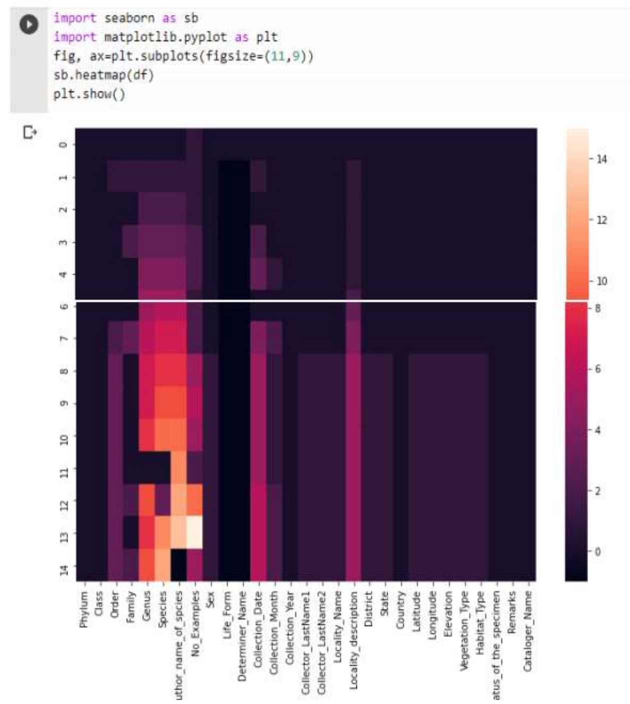


**Fig. 2.** Heatmaps


***Photo Courtesy:*** Director, Zoological Survey of India with permission.

**Fig. 1.** Earthworms in the study

**Table 1.** Earthworm collection data (Phylum – Annelida, Class- Clitellata)

| Order | Family | Scientific name | | Number | Month | Locality |
|---|---|---|---|---|---|---|
| Haplotaxida | Megascolecidae | *Lampito mauritii* | Kinberg 1866. 1ex. | 1 | November | Golaghat, Assam |
| Moniligastrida | Moniligastridae | *Drawida nepalensis* | Michaelsen 1907. 1ex. | 1 | | |
| Haplotaxida | Megascolecidae | *Amynthas diffringens* | Baird 1869 1ex. | 1 | | |
| Haplotaxida | Octochaetidae | *Eutyphoeus kempi* | Stephenson 1914. 2ex. | 2 | | |
| Haplotaxida | Megascolecidae | *Metaphire posthuma* | Vaillant 1868 2ex. | 2 | September | |
| Haplotaxida | Megascolecidae | *Perionyx excavatus* | Perrier 1872 1ex. | 1 | November | |
| Haplotaxida | Megascolecidae | *Perionyx pulvinatus* | Stephenson 1916. 2ex. | 2 | | |
| Lumbricida | Lumbricidae | *Octolasion tyrtaeum* | Savigny 1826. 2ex. | 2 | October | |
| Haplitaxida | Megascolecidae | *Amynthas hawayanus* | Rosa 1891 | 5 | September | ZSI, NRC Dehradun |
| Haplitaxida | Megascolecidae | *Amynthas alexandri* | Beddard 1900 | 6 | | |
| Haplitaxida | Megascolecidae | *Metaphire peguana* | Rosa 1891 | 5 | | |
| Haplitaxida | Megascolecidae | *Lampito mauritii* | Kinberg 1867 | 2 | | |
| Haplitaxida | Octochaetidae | *Eutyphoeus kempi* | Stephenson 1914 | 10 | October | |
| Haplitaxida | Megascolecidae | *Metaphire posthuma* | Sims and Easton 1972 | 15 | | |
| Haplitaxida | Octochaetidae | *Eutyphoeus* sp. | | 5 | | |

1. Year of collection and study: 2019, 2. Sex: Hermaphrodite, 3. Life form: mature for all specimens, 4. Latitude of sample collection zone of Golghat Assam and ZSI, NRC Dehradun: 26.52°N and 30º 18´ N respectively, 5. Longitude of sample collection zone of Golghat Assam and ZSI, NRC Dehradun: 93.97°E and 78º 01E respectively, 6. Elevation(m) of sample collection zone of Golghat Assam and ZSI, NRC Dehradun: 98.46 meters and 197.2 metres respectively, 7. Vegetation types, of sample collection zone of Golghat Assam and ZSI, NRC Dehradun: grasses and Bushes and grasses respectively, 8. Habitat types, of sample collection zone of Golghat Assam and ZSI, NRC Dehradun: terrestrial and garden respectively, 9. Status of the specimen collected from Golghat Assam and ZSI, NRC Dehradun are general : No variation

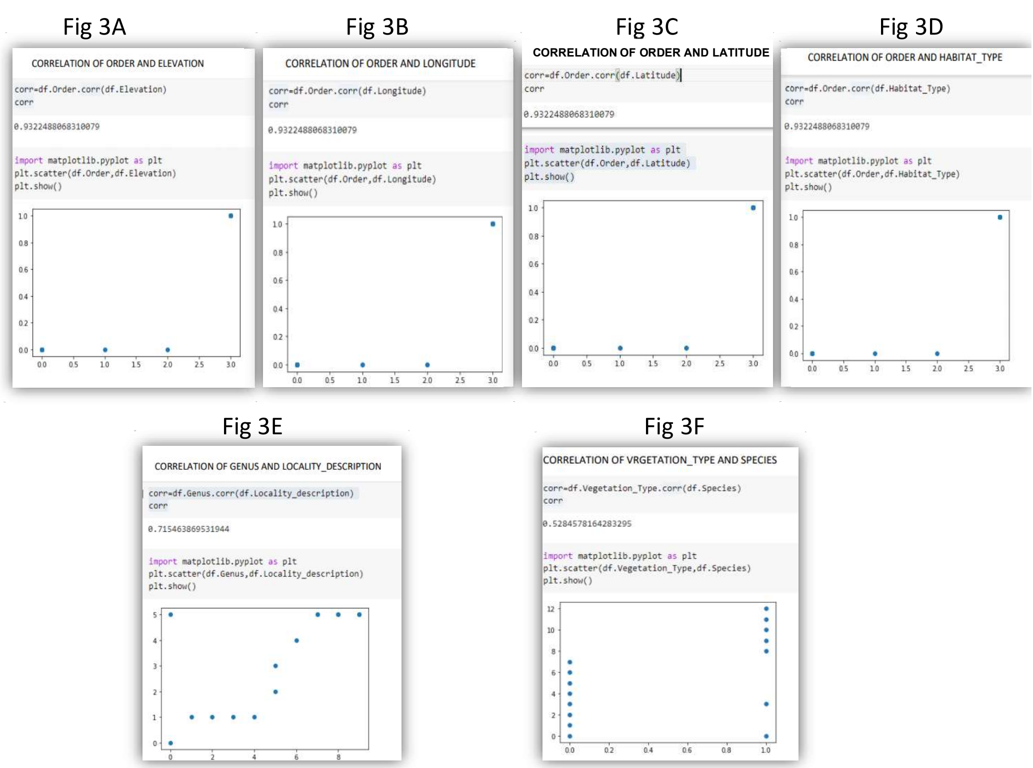


**Fig. 3.** Correlation

## CONCLUSION

The study revealed higher diversity of orders of earthworms including species. *E. kempi, M. posthuma, L. mauritii, A. diffringens, P. excavatus, P. pulvinatus,* under Order Haplotaxida, *D. nepalensis*, under Order Moniligastrida, *O. tyrtaeum* under Order Lumbricida in lower latitude, lower elevation and eastern longitudes in Assam as compared to that in Dehradun were observed revealing only collection of species *E. kempi, M. posthuma, A. hawayanas, A. alexandri, M. peguana,* under Order Haplotaxida in Sept-Nov 2019 while *E. kempi M. posthuma and L. mauritii* under Order Haplotaxida revealed common distribution in both locations. There were strong positive correlations between order and elevation, order and longitude, latitude and order and habitat with positive high correlation between genus and locality description and moderate positive correlation between genus and vegetation type. This is the first report of application of correlation and heatmaps by Python in understanding earthworm distribution and the study highlighted the importance of parameters including longitude, latitude, elevation and habitat in predicting earthworm distribution.

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