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Trends of Forest Phenology Studies in India-Challenges and Opportunity for Satellite Remote Sensing and Near Surface Sensors

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Abstract: Phenology, for being pulse of the ecosystem, elucidates the complex relationship between climate and vegetation, serving as a vital indicator of climate change. India, a biodiversity hotspot, has forests classified into 5 major groups, 16 subgroups, and 255 subtypes based on climatic, edaphic, and successional variations, displaying varying phenological traits. Recent advancements in technology have revolutionized our ability to collect valuable data across various spatial and ecological scales. Despite the abundant observational data capturing phenological changes at various scales, remote sensing remains a relatively less explored tool for operational forest phenology monitoring in Indian forest ecosystems. This comprehensive review explores the latent potential of long-term satellite remote sensing data supported with near surface sensor system networks to reveal complex patterns of phenological dynamics within a spectrum of diverse forest types in India. We found that, majority of the research has predominantly focused on field-based observations limited to moist and dry tropical forests, followed by montane temperate and subtropical forests driven by their ecological importance, higher accessibility, and their sensitivity to climate change impacts. Through the utilization of advanced satellite sensors (e.g., MODIS, Landsat, and Sentinel) thorough investigations have successfully examined the dynamics of vegetation in forest phenological studies. Looking ahead, integrated studies with diverse monitoring methods are crucial for upscaling phenological observations robustly. These advances are necessary to precisely quantify the impacts of a changing world on forest phenology.

Keywords: Phenology, Forest dynamics, Phenometrics, Remote Sensing, Vegetation patterns

Phenology, as a holistic environmental discipline that integrates biometeorology, ecology, and evolutionary biology (Morellato et al 2016), functions as the pulse of ecosystems, elucidating the intricate relationship between climate and vegetation, acting as a vital indicator of climate change (Rosenzweig et al 2008). Phenology has served as an important diagnostic proxy for a wide variety of areas, such as climate change (Jin et al 2017, Brown et al 2017), food security (Lobell et al 2008, Alemu and Henebry 2017, Gao and Zhang 2021), drought (de Beurs and Henebry 2008, Chang et al 2021), forest fire risk (Chéret and Denux 2011, Bison 2022), frost hazard (Ge et al 2013, Hänninen 2006), landscape dynamics (Jeganathan et al 2014, Dronova and Taddeo 2022), and biogeochemical cycling (Gray et al 2014, Piao et al 2019), as well as input to a number of prognostic models that are frequently used to make predictions in these fields (Ma et al 2022). It is possible to demonstrate the consequences of environmental change independent of ecological observations based on long-term phenological data (Walther et al 2002, Rosenzweig et al 2007, Jiang et al 2014).

Over the past two decades, there has been a notable growth in the development of multidisciplinary research frameworks for phenology, which incorporate technological advancements and aim to explore the intricate relationships between phenology, ecosystem function, and species across diverse locations and time periods (Cleland et al 2007, Morisette et al 2009, Pau et al 2011). The Intergovernmental Panel on Climate Change (IPCC) has prioritized the collection and analysis of phenological observations to enhance our comprehension of the biological effects of climate change in response to mounting evidence of early spring onsets (Ciais et al 2014). Moreover, phenology plays a role, as an aspect of Biodiversity Conservation particularly in achieving the goals outlined in objectives 13 (Climate action) and 15 (Life on land) of the Sustainable Development Goals (SDGs). It is essential to study patterns and their influencing factors to effectively develop strategies, for both adapting to and mitigating the impacts of climate change (Radeloff et al 2019).

The recent resurgence of phenology as an ecological specialization is driven by climate change implications, highlighting phenological variations as sensitive indicators of global warming's biological impact (Walther et al 2002).

Changes in vegetation attributes, coupled with the intricate connections to climate change, remain crucial, lacking a comprehensive mechanistic understanding (Richardson et al 2012). Technological advancements, particularly in remote sensing, have expanded phenological observation beyond manual methods, enabling efficient collection of substantial monitoring data from both ground-based and remote sensing technologies (Zhang et al 2003, Zhang et al 2016).

The study of vegetation phenology can provide an imperative knowledge about previous, present, and probable future ecosystem conditions (Wolkovich et al 2014). Alterations in the timing of phenological phenomena could desynchronize species interactions because different species respond to climate change differently (Thackeray et al 2016). The progression of vernal phenomena, the extension of the vegetative period, and the temporal displacement of the conclusion of the growing season (onset of senescence) are just a few of the important indicators of phenological response to the ongoing climate change which are responsible for change in carbon budget. This highlights the interest at the regional and global scales in understanding how climate influences forest ecosystems, with Indian forests serving as a notable case (Chaturvedi et al 2011, White et al 2014, Kumar et al 2019).

In the global context, Indian forests hold exceptional importance as mega-biodiversity hotspots and ecologically significant regions. Indian region and its environs is internationally recognized as one of the mega-diverse countries, harboring approximately 7-8% of the world's recorded species and encompassing four of the biodiversity hotspots identified globally: the Himalaya, Indo-Burma, Western Ghats and Sri Lanka, and Sunda land (Sivaperuman and Venkataraman 2018). These diverse ecosystems represent unique reservoirs of biodiversity and play a vital role in sustaining ecological processes and supporting numerous endemic species. Understanding the phenology of Indian forests becomes imperative in this broader global perspective of biodiversity conservation and sustainable ecosystem management.

Brief Historical Overview

In-situ observation

The commencement of efforts to observe the phenology of the tree species in India is believed to have taken place in the 1950s. Prior to that, India had undertaken several investigations pertaining to agricultural harvest, agro ecology of the flora (Misra 1946), classification of forests (Champion 1936), and silviculture (Chatterjee 1939). However, no explicit research has been documented on the phenology of forests. The eighth general conference of the United Nations Educational, Scientific, and Cultural Organization (UNESCO) convened in Montevideo in 1954. The conference aimed to promote global or regional initiatives on scientific matters, specifically those related to the humid tropical zone. The committee was established with the objective of examining issues related to research in the fundamental aspects of the natural sciences that are relevant to the humid tropical zones. The aim was to encourage and support the continuation of such research, and to take the necessary steps to initiate or promote research in those areas where significant problems were not adequately addressed. The symposium featured the participation of several Indian authors who presented their research on the humid tropics of India (Puri 1958).

The deep link between phenology and different aspects of our environment explains why, despite observing phenological events for thousands of years, it was officially acknowledged as a scientific discipline only in the 1900s (Fig. 1). Recognizing the vital role of phenology in various facets of our environment underscores its importance in understanding how our ecosystems work and managing resources, especially with changes in climate and habitats. The majority of phenology related studies in India are based on the field observations carried out during (1 to 3 years' timeframe), with a few longer-term studies (Datta and Rane 2013, Suresh and Sukumar 2018). Figure 1 depicts India's phenological study chronology. These community-level investigations provide a baseline understanding of plant behavior and how it responds to ecological conditions (Haq et al 2021). The limited period of temporal phenology variations hinders comprehending their causes and effects difficult. Few studies quantitatively relate these patterns to climate factors, whereas the majority describe the seasonal rhythms of leaf flushing, flowering, and fruiting. Earlier studies estimated phenophases time and extent by counting species in leaf, flower, or fruit (Kumar and Shahabuddin 2005).

Shukla and Ramakrishnan (1982) conducted the first formal phenological study in Meghalaya, in the northeastern region of India. The majority of phenological research have come from South (Prasad and Hegde 1986, Bhat 1992, Murali and Sukumar 1993, Sundarapandian et al 2005, Nanda et al 2011, Prabakaran et al 2013, Nanda et al 2015, Nanda 2017) and North-east India (Shukla and Ramakrishnan 1982, Boojh and Ramakrishnan 1983, Baruah and Ramakrishnan 1989a, Kikim and Yadava 2001, Paul et al 2018, Devi et al 2020) followed by Western (Jadeja and Nakar 2010), Northern (Ralhan et al 1985, Khare et al 2016), and North-Western India (Kushwaha and Singh 2005), with a few from Central India (Newton 1988) in later years. In India, the phenological research has mainly concentrated on dry deciduous (Prasad and Hegde 1986,

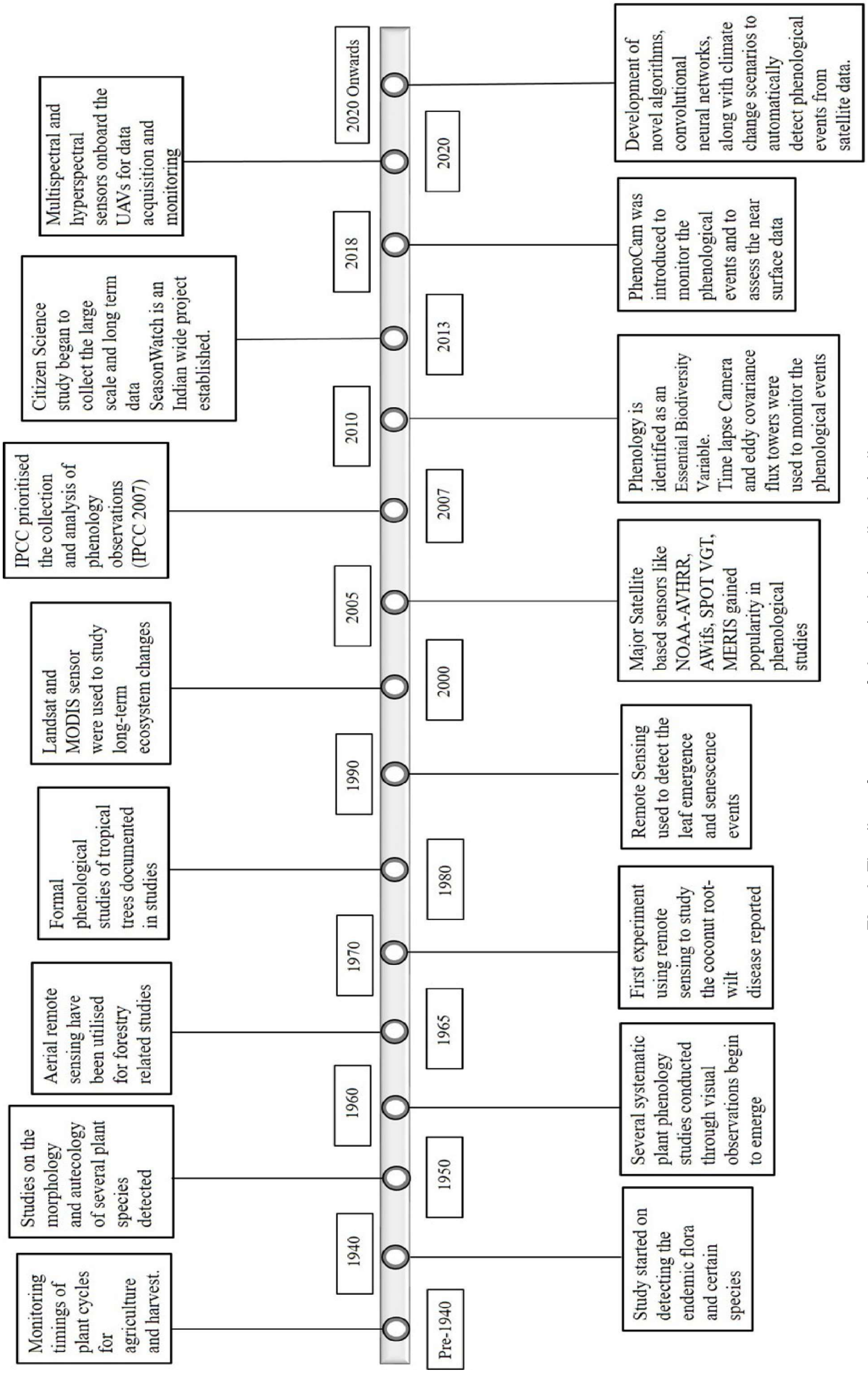

Fig. 1. Timeline of progress of phenological studies in India

Murali and Sukumar 1993, Murali and Sukumar 1994, Kushwaha and Singh 2005, Nanda et al 2011, Nanda et al 2014) and evergreen forests (Krishna et al 2007, Mohandass et al 2016, Nanda 2017) in the south, with less attention paid to tropical (Baruah and Ramakrishnan 1989b, Sundarapandian et al 2005) and subtropical moist forests (Baruah and Ramakrishnan 1989a, Bhat et al 2000, Bhat and Murali 2001) in the northeast (Table 1). This underscores the need for further research and in-depth investigations into the phenological patterns and processes of these tree species to enhance our understanding of their reproductive strategies, ecological interactions, and conservation requirements.

To enhance our understanding of phenology in Indian forests, comprehensive studies encompassing a wide range of tree species are crucial (Kushwaha and Singh 2008). Such investigations yield valuable insights into the temporal patterns of key phenological events, including flowering, fruiting, and leaf emergence. Moreover, they unravel the underlying ecological mechanisms governing these events, shedding light on aspects such as reproductive success, pollination dynamics, seed dispersal mechanisms, and the potential implications of climate change on patterns of phenology. Nevertheless, conducting *in-situ* observations for phenological studies in Indian woods encounters inherent limitations. The vast geographic expanse and diverse forest types pose challenges in achieving representative species and location coverage. Additionally, logistical complexities, time-intensive nature, and associated costs further impede the execution of *in-situ* observations. These constraints accentuate the necessity of complementing *in-situ* data collection with remote sensing techniques and automated phenocam towers, leveraging a more comprehensive phenological observation strategy (Chandra et al 2022). By integrating multiple methodologies and expanding the scope of phenological research in Indian forests, valuable insights into ecological dynamics and conservation imperatives can be gleaned.

Few qualitative studies have been conducted to examine evolutionary concerns associated with ecological determinants of tree phenology (Murali and Sukumar 1993, Murali and Sukumar 1994). With the few exceptions of studies (Krishnan 2002, Joshi and Janarthanam 2004), most of the research conducted focuses on trees. Nautiyal et al (2001) examined the phenology of 171 grass, herb, forb, and shrub species in an alpine pasture at an elevation greater than 3000 m a.m.s.l. Based on the findings, it has been discovered that flowering takes place between May and August after snowmelt, with fruiting occurring between June and August before senescence takes hold before the start of winter. The study conducted by Vashistha et al (2009) investigated the phenology of a total of 103 species of graminoids, forbs, and shrubs in an alpine pasture situated at an altitude of 3200 m a.m.s.l. in the North-West Himalaya region of India. In their research Joshi and Janarthanam (2004) examined the flowering phenology of a total of 113 endemic species in Goa, encompassing a diverse array of life-forms such as monocots, dicots, herbs, shrubs, trees, and climbers. Moreover, it has been stated that the plateaus located in the northern region of the Western Ghats are distinctive owing to their copiousness of herbaceous native species. The distribution of these endemics is closely linked to precipitation patterns, thus any alteration in the long-term moisture regime would have an impact on their habitat. In a study conducted by Krishnan (2002), the reproductive phenology of sixty understorey species, comprising of herbs such as terrestrial shrubs, orchids, and small trees, was examined in a moist evergreen forest located in the southern Western Ghats. Few studies have been carried out on the phenology of specific tree species that are either rare or have significant ecological roles (Ganesh and Davidar 1997, Shankar 2001, Bhat and Kaveriappa 2009, Datta and Rane 2013, Borah and Devi 2014, Nath et al 2016, Upadhaya et al 2018, Devi et al 2020, Chauhan and Chauhan 2020, Nandy et al 2021, Subin et al 2022).

Effective forest management and biodiversity conservation rely on comprehensive long-term datasets on ecosystem dynamics. Unfortunately, in India, there is a limited number of long-term observation sites, and access to such datasets is currently restricted. To comprehensively understand seasonal variations and climatic fluctuations and to detect alterations in the initiation, duration, extent, timing, and synchronization of vegetative and reproductive phases, extensive multi-year investigations are essential. Monitoring changes in species-level biological responses to local climate change can be achieved by utilizing prolonged phenological records derived from plant and animal observation networks. Extended studies in various regions such as Southeast Asia, Australia, Neotropics, Europe/North, America/South, Africa, and America commonly span over 10 - 30 years, occasionally even longer. In an era when the anticipated impacts of climate change are under intense scrutiny, it would be judicious to evaluate the ecological significance and potential advantages of establishing a network of phenological stations.

Satellite Remote Sensing in Phenological Studies

Remote sensing is recognized as an integral component in the advancement of phenological studies, as it offers substantial potential for comprehending widespread seasonal phenomena over extensive areas (Reed et al 2003). By analyzing long term phenological

Table 1. Phenological studies including location, forest types, methods employed, study duration and key findings:

Study region/State	Vegetation type	Reported (With date)		Field or satellite based	Study duration	Reference
		Leaf flushing	Leaf fall			
Meghalaya North-Eastern India	Sub-tropical humid forest	January-March	February-April	Field based	2 years	Shukla and Ramakrishnan (1982)
Meghalaya North-Eastern India	Deciduous Timber Tree	March- early April (From 1st of March at lower altitude and from 20th of March at higher altitude)	February-March	Field based	1 year	Boojh and Ramakrishnan (1983)
Kumaun Himalaya, Uttarakhand North India	Sub-tropical Evergreen	March-April	February-April	Field based	1 year	Ralhan et al (1985)
	Deciduous	March-April	October-January			
Bandipur, Karnataka South India	Tropical dry deciduous forest	April-May	December-January	Field based	4 years	Prasad and Hegde (1986)
Madhya Pradesh Central India	Moist Deciduous	April - July	February-April	Field based	14 months	Newton (1988)
Shillong, Meghalaya North-East India	Tropical trees	Early April - May	March-April	Field based	1 year	Baruah and Ramakrishnan 1989a)
Uttar Kannada, Karnataka South India	Tropical moist forest	February-March	November-January	Field based	2 years	Bhat (1992)
Mudumalai Sanctuary, Tamil Nadu South India	Tropical Dry Deciduous Forest	January-February	NA	Field based	2 years	Murali and Sukumar (1993)
Mudumalai, Tamil Nadu Southern India	Tropical Dry Forest	January-March	NA	Field based	2 years	Murali and Sukumar (1994)
Manipur North-east India	Subtropical deciduous and evergreen forest	March-April	November-February	Field based	1 year	Kikim and Yadava (2001)
Western Ghats Tamil Nadu, South India	Tropical moist deciduous forest	February-March	December-January	Field based	2 years	Sundarapandian et al (2005)
Vindhyan Plateau, Sonbhadra Uttar Pradesh North-west India	Tropical dry deciduous forest	March-June	January-March	Field based	2 years	Kushwaha and Singh (2005)
Similipal Biosphere Reserve, Orissa Eastern India	Tropical Moist Deciduous Forest	April	February-April	Field based	1 year	Mishra et al (2006)
Bala Fort Rajasthan Western India	Tropical dry-deciduous thorn forest	February-May	October-December	Field based	3 years	Yadav and Yadav (2008)
Girnar Reserve Forest, Junagadh Gujarat,Western India	Subtropical deciduous forest	February-March	January	Field based	1 year	Jadeja and Nakar (2010)
Bhadra wildlife sanctuary, Karnataka South India	Tropical dry deciduous forest	April-May	January-February	Field based	2 years	Nanda et al (2010)
Katerniaghat wildlife sanctuary, Uttar Pradesh North-west India	Tropical moist deciduous forest	End of March- April	November	Field based	11 months	Bajpai et al (2012)
Uttar Kannada Karnataka South India	Evergreen forest	August	May	Satellite + ground based available data	8 years	Prabakaran et al (2013)
	Semi-evergreen forest	June	February			
	Moist deciduous forest	May	January			

Cont...

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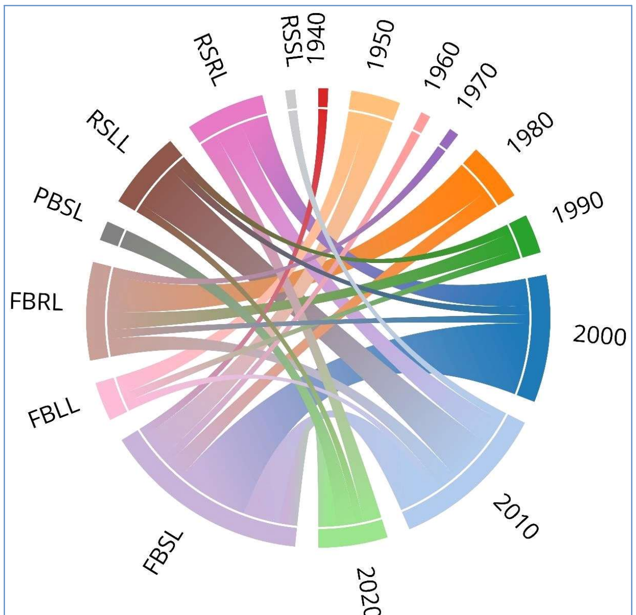
Study region/State	Vegetation type	Reported (With date)		Field or satellite based	Study duration	Reference
		Leaf flushing	Leaf fall			
Hollongapar Gibbon Wildlife Sanctuary, Assam North-east India	Moist Tropical Forest	December and in May (observed twice)	January- February	Field based	2 years	Borah and Devi (2014)
	Tropical dry deciduous forest	Beginning of May –end of May	Mid of January			
Bhadra wildlife sanctuary, Karnataka South India	Tropical evergreen forest	Early January- end of February	Mid of February	Field based	2 years	Nanda et al (2015)
Western Himalayan region of Doon valley, Uttarakhand North India	Moist Deciduous Forest	April	January-March	Satellite based	2 years	Khare et al (2017)
Kemmanugundi, Bhadra wildlife sanctuary Karnataka South India	Tropical evergreen forest	December-early January	August to October	Field based	2 years	Nanda (2017)
Arunachal Pradesh North-east India	Temperate mixed broad-leaved forests	May-June	October-November	Field based	1 year	Paul et al (2018)
Arunachal Pradesh North-east India	Dry mixed deciduous forests	July-October	January-April	Satellite based	33 years	Mohapatra et al (2019)
India	Dry and moist teak forests	July-August	November-end of December	Satellite based	13 years	Ghosh et al (2019)
Nimaichandpur-II, Hailakandi district Assam North-east India	Tropical Deciduous tree-Parkia timoriana	April- May	November-January	Field based	2 years	Devi et al (2020)
Narmada, Gujarat Western India	Tropical dry deciduous forest from 2003-2004	28 July	13 February	Satellite + ground based available data	2 years	Malhi et al (2021)
	Tropical dry deciduous forest from 2013-2014	11 August	22 March			
Rajmahal hills, Jharkhand Eastern India	Deciduous broadleaf forest	March (JD 81)-April (JD 97)	March (JD 65)-March (JD 81)	Satellite based	19 years	Ranjan and Gorai (2022)

data from forests, important issues with climate change modelling and monitoring can be addressed (Prabakaran et al 2013). Observations of phenological occurrences on the ground can give an accurate assessment and can provide a precise understanding of phenological patterns (Nandy et al 2021). However, these conventional field-based methods have several limitations like, huge investment of time and effort to cover a vast region, and it's difficult to make daily observations (required during transition period). Furthermore, these observations face challenges in terms of spatial specificity and are hard to modify. There is also a lack of a substitute to model them for different scenarios or specific conditions. It is at this point that remote sensing emerges with its advantages to address these shortcomings. By utilizing the benefits of stratification, remote sensing mapping and stratification could cover a vast area with even low intensity sampling. With greater accuracy and precision thanks to the satellites' temporal revisits and long historical records, it is possible to evaluate and analyze altered scenarios. Freely available passive optical satellite imageries with high temporal frequency were widely employed for vegetation phenology study in India (Dash et al 2010, Ghosh et al 2019, Jeganathan et al 2010, Pillai et al 2019, Ayushi et al 2022) and the rest of the world to get over these restrictions (Heumann et al 2007, White et al 2014, Zhang et al 2003, Zheng et al 2022) .

Role of Spatial and Spectral Resolutions

Accurate assessment of plant phenology's climate change sensitivity requires evaluating year-to-year spatial variations in leaf flush and fall timing over large areas and extended periods. Satellite imagery is optimal for discerning plant phenology across spatial scales (Czernecki et al 2018, Pastor-Guzman et al 2018, White et al 2009). Spatial and spectral resolutions of satellite sensors are crucial for phenology data quality. High spatial resolution provides detailed local views, while lower resolution offers broader perspectives. Higher spectral resolution enables precise vegetation characterization (Wingate et al 2015).

Commonly used sensors for plant phenology in India include AVHRR (Prasad et al 2008), MERIS MTCI (Jeganathan et al 2010), MODIS (Deka et al 2019), and Landsat (Mohapatra et al 2019). Synchronizing data between sensor families offers advantages like real-time monitoring, increased observation frequency, and more cloud-free observations in evergreen forests (Pastick et al 2018, Li et al 2019). Phenology detection depends on data availability and external factors like cloud cover (Younes et al 2021). The integration of various observation techniques (field, PhenoCam, satellite) at different levels (Species, landscape, regional) contributes to comprehensive phenological studies.



	1930	1940	1950	1960	1970	1980	1990	2000	2010	2020
FBSL		1	3	1		2		8	4	2
FBLL			2				1		1	
FBRL	1				1	4	2	1	2	
PBSL										2
PBLL										
PBRL										
RBSL									1	
RBLL							1	1	5	1
RBRL							3	3	2	

[**FBSL**: Field Based & Species Level, **FBLL**: Field Based & Landscape Level, **FBRL**: Field Based & Regional Level, **PBSL**: Phenocam Based & Species Level, **PBLL**: Phenocam Based & Landscape Level, **PBRL**: Phenocam Based & Regional Level, **RBSL**: Remote Sensing Based & Species Level, **RBLL**: Remote Sensing Based & Landscape Level, **RBRL**: Remote Sensing Based & Regional Level]

Fig. 2. Number of studies published using different techniques and level of observations

Long Term Remote Sensing-Based Phenological Studies Combining *In-Situ* and Remote Sensing Data

Efforts to observe the dynamics of the vegetated land surface from space commenced at the opening of Landsat era (Henebry and de Beurs 2013). Despite Landsat's continuous Earth surface data since 1970, its use for long-term ecosystem studies in India only started in the 2000s, initially limited by cost and processing constraints. The USGS's 2008 open access policy for Landsat data enabled broader time series research on ecology and biodiversity. Vegetation indices derived from remote sensing data contribute significantly to various aspects of forest monitoring, such as forest classification, analysis of vegetation phenology, change detection, and the retrieval of forest biophysical parameters (Glenn et al 2008, Lambert et al 2013).

The widely used normalized difference vegetation index (NDVI) is a key parameter for vegetation studies. A study on moist deciduous forests in the Western Himalaya, using Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) data, assessed phenological changes via NDVI and land surface temperature (LST) (Khare et al 2016). However, limitations in NDVI's ability to fully capture temporal vegetation development led to the introduction of the temporal normalized phenology index (TNPI), offering a valuable alternative to long-term monthly records for understanding forest phenology (Khare et al 2017, Khare and Rossi 2019).

Prasad et al (2008) used NOAA-AVHRR data (1990-2000) to study phenological variations in Indian forests, finding inverse correlations between NDVI and temperature, and positive correlations with precipitation. This aligns with the known influence of these variables on plant phenology, affecting energy, water, and CO2 fluxes (Vadrevu et al 2007). Few studies have used remote sensing to extract phenological variables in India's tropical and subtropical regions (Mohapatra et al 2019). Estimating phenological parameters for these vegetation types via remote sensing will enhance our understanding of their response to climate change.

A continental-scale vegetation map was created using NOAA AVHRR GAC data (1.1 km/4 km resolution), examining NDVI variations due to stress, leaf activity, vegetation amount, and seasonal changes. For finer regional-scale monitoring, the IRS Wide Field Sensor (WiFS) was developed to address NOAA AVHRR limitations (Roy and Joshi 2002). WiFS's temporal NDVI data effectively monitor vegetation cover and phenology (Singh et al 1999), suitable for tracking short-term vegetation changes regionally (Joshi et al 2006, Joshi et al 2001). With two radiometers, multiple spectral bands, and a wide sweep width, WiFS provides crucial vegetation information at 23.5 m (VNIR) and 70.5 m (SWIR) resolutions. It's valuable for vegetation discrimination, cover mapping, and environmental monitoring, offering sufficient temporal, spatial, and spectral resolutions for regional vegetation dynamics studies.

The low temporal resolution constitutes a significant hindrance to the in-depth examination of dynamic variations, emerging as a notable obstacle in the analysis. However, to overcome these challenges, since the early 2000s, MODIS (Terra and Aqua satellites) and VEGETATION (SPOT satellite) sensors have provided improved multispectral time-series, extending remote sensing applications to phenology and vegetation monitoring over large areas.

While NDVI has been traditionally used for vegetation phenology analysis, recent research focuses on the Enhanced Vegetation Index (EVI), which accounts for background and atmospheric effects and shows increased sensitivity in high biomass areas. Gupta et al (2014) employed MODIS EVI data from 2003 to 2012 to track changes in the phenological transition dates of tropical deciduous broadleaf forests (DBF) in Eastern India. The objective of the study was to examine seasonal and interannual changes in vegetation, with a particular focus on the districts of West Singhbhum and Sundargarh. The results demonstrated that there was an upsurge towards forest degradation: (i) the EVI varied from 0.41 in early April to 0.71 in mid-October; and (ii) the overall pattern declined with a slope of 0.0022. The findings indicate that the end of season (EOS) varied between 1stof February and 7th March, while the start of season (SOS) varied between 2nd of May and 20th June. The length of the season decreased overall, peaking in 2007 at 302 days and falling to 235 days in 2010.

Ghosh et al (2019) used MODIS-derived EVI to ascertain that the temporal extent of the growing season in moist teak (Tectona grandis) forests have a 48-day longer growing season than dry teak forests, with significant LAI differences (~2.8). The study established a significant correlation between changes in phenology and shifts in rainfall patterns. In their study, Chakraborty et al (2018) examined the spatial patterns of a significant downward trend of forest seasonal greenness over a wide range of forest types in India (2001-2014) using data from an 8-day composite MODIS NDVI time series. Deka et al (2019) utilized a threshold-based approach for phenological parameter extraction, finding stronger NDVI-temperature correlations than NDVI-precipitation. Singh et al (2020a) reported significant NDVI-rainfall associations, while Deka et al (2019) noted strong NDVI-temperature correlations in humid subtropical regions, suggesting that temperature could be a critical factor in the context of climate change.

Nandy et al (2021) examined the phenological changes of various Sal (*Shorea robusta*) forests in India and investigated the connection between phenology metrics and meteorological variables. Several phenological metrics such as start of season (SOS), length of the season (LOS), maximum of the season (MAX), and end of season (EOS) for teak growing in Narmada forests, Gujarat, India, were calculated using MODIS NDVI time series. Malhi et al (2021) used the derivative method to extract phenology metrics, identifying inflection points in NDVI time series. This method assumes the highest NDVI change rate indicates the start or end of the growing season, extracting key variables like SOS, peak of season (POS), and EOS.

Using a MODIS-EVI dataset, Ranjan and Gorai (2022); monitored phenological trends over the Indian Rajmahal Hills from 2001 to 2019. According to the study's findings, the SOS typically occurred between late, around 22nd March (Julian day (JD) 81) up till 7th April (JD 97), whereas EOS has primarily been recorded between early 6 March (JD 65) up till 22nd March (JD 81). Additionally, between 2001 and 2010, the SOS and EOS of many vegetation types showed a delayed tendency. On the other hand, from 2010 to 2019, the SOS and EOS of every type of plant exhibited an upward trend.

With the use of the SPOT-VGT NDVI time series data product and the TIMESAT tool, Prabhakaran et al (2013); obtained the forest phenological parameters and spatial calendar maps of the Uttar Kannada district, on the west coast of India. They found deciduous forests experience earlier greenness onset than evergreen forests, which have longer grown seasons. Meteorological factors, especially maximum temperature and rainfall, significantly influence forest tree phenology. The majority of satellite sensor-derived phenology studies have used the NDVI calculated from a variety of sensors, including the IRS WiFS (Joshi et al 2006), MODIS (Chakraborty et al 2018;), SPOT-VGT, and the NOAA-AVHRR (Prasad et al 2008). Nevertheless, NDVI has limitations such as saturation at high vegetation biomass and atmospheric influence. The MERIS Terrestrial Chlorophyll Index (MTCI) from the Medium Resolution Imaging Spectrometer (MERIS) sensor offers a potential solution (Dash and Curran 2007). MERIS, with 15 spectral bands and 300 m spatial resolution, making it a promising tool for extracting canopy chlorophyll content data.

The ENVISAT mission's programmable spectrometer MERIS, which operates in the solar reflective spectral band, was utilized to carry out India's first phenology study. The study captured foliage onset correlating with latitude, with minor inter-annual differences except for 2003 (Dash et al 2010). The study's limitations posed challenges in pinpointing the specific month, week, and date of leaf flushing and leaf fall based on qualitative descriptions (e.g., spring season, early dry period, post-monsoon period). Additionally, it was not possible to link flowering or bud burst data to the MERIS calculations (Atkinson et al 2012).

Jeganathan et al (2010) used the MTCI data, obtained from the Multitemporal MERIS, to investigate the phenology of four significant forest types in India, namely moist deciduous, dry deciduous, evergreen, and semi-evergreen. Their results indicated that the most frequent dates for the onset of greenness (OG) activity for tropical evergreen, semi-evergreen, wet deciduous, and dry deciduous vegetation types were February-April, January-April, March-May, and February-May, respectively. Additionally, the study found that the most frequent dates for end of senescence (ES) activity for tropical evergreen, semi-evergreen, wet deciduous, and dry deciduous vegetation types were February-April, January-April, February-April, and December-April, respectively (Jeganathan et al 2014).

Optical remote sensing faces challenges like atmospheric interference and cloud contamination. Trade-offs exist between spatial, temporal, and spectral resolutions. Various satellites offer different resolutions and revisit times, each with strengths and limitations for phenology studies (Helman 2018, Misra et al 2018). Recent advancements in satellite technology have improved sensing quality, making it crucial for phenology studies. However, challenges persist, including data acquisition costs, lack of ground-based validation, and processing expertise (Zhang et al 2016). There's a scarcity of ground-based observations and PhenoCams in forests, especially in the southern hemisphere (Singh et al 2020b). Efforts are underway in India to understand plant patterns and their connections to phenology and ecosystem models. Integrating PhenoCam data with Dynamic Global Vegetation Models (DGVMs) could improve local-level predictions and management strategies for climate change impacts on forest ecosystems (Jose et al 2023, Wang et al 2020).

Objective of Studying Vegetation Phenology

Three major categories-characterization, explanation, and application-can be used to group together the various research goals for studying vegetation phenology (Caparros Santiago et al 2021). Studies that emphasize spatial or spatiotemporal descriptions of vegetation phenology are included in the characterization process. Numerous researchers have systematically examined the spatial heterogeneity of phenological vegetation dynamics across diverse scales. This exploration often involves the utilization of mean or median phenometrics derived from satellite data, such as MODIS-NDVI, spanning the study duration (Deka et al 2019, Ayushi et al 2022). Notably, studies conducted in India have revealed that, compared to their evergreen counterparts, deciduous forests show an earlier onset of greenness (Singh et al 2020a). Furthermore, several studies conducted in India have analyzed the year, to year variations specifically focusing on the changes in timing for spring and autumn events (Singh and Sahoo 2019, Negi et al 2022). These investigations utilized sensing data with spatial resolution and have significantly contributed to a deeper understanding of the intricate relationship between vegetation phenology metrics and climatic effects across different types of forests in India. The findings from these studies shed light on the patterns observed in distinct forest ecosystems providing valuable insights into how climatic fluctuations impact vegetation dynamics in the region. This category of research on vegetation phenology also includes investigations into the potential effects of various methodological concerns (Atkinson et al 2012) on phenological estimation, the creation of phenological products (Ganguly et al 2010), or novel techniques that might make it possible to characterize the phenological behavior of vegetation.

The second category of studies includes those whose purpose was to analyze vegetation dynamics and how they relate to environmental conditions (Khare et al 2016, Reddy and Prasad 2018). Numerous investigations looked into the reactions of plant biological cycles to various climate variables. Temperature plays a crucial role in regulating phenological changes, especially in the Dry Deciduous and Temperate zone forests of India, influencing the timing of the growing season onset, duration, and foliage fall (Joshi and Janarthanam 2004). Conversely, water availability and precipitation patterns are key determinants of phenology in tropical forests. Experimental studies linking environmental temperature to plant phenology consistently show that higher temperatures lead to earlier spring and delayed autumn, while lower temperatures result in delayed spring and accelerated autumn. Photoperiod, in conjunction with low temperatures, contributes to deciduous tree leaf fall from November to February. Although some studies explore the relationship between vegetation phenology and variables like the carbon cycle, a significant portion of research in this domain focuses on phenological dynamics and its correlation with various factors (Kale and Roy 2012).

The third category encompasses research utilizing phenometrics as environmental data for diverse applications; the primary objective was not merely to comprehend the phenological behavior of vegetation, but also to explain it.

Most of this research primarily employed phenological data to categorize different types of land cover (Joshi et al 2006). Phenology-based investigations have significantly enhanced the classification of land covers, thereby advancing the comprehension of Earth's surface land cover maps (Qader et al 2016). These studies have proven instrumental in identifying potential changes in land cover, including agricultural expansion (Knauer et al 2017) and deforestation (Valderrama - Landeros et al 2016). This underscores the pivotal role of phenology in monitoring and detecting alterations in land cover, contributing valuable insights to our understanding of the Earth's surface dynamics.

Limitations of the Optical Datasets in Long Term Phenology Studies

The potential for Satellite Remote Sensing to enhance natural resource management is significant, despite certain constraints (Sharma et al 2021). Indian forests, with their rich biodiversity, provide an ideal context for remote sensing-based phenological studies. Recent research has demonstrated the utility of multi-temporal remote sensing data in tracking vegetation phenology relative to climate changes (Zhang et al 2006, Jeganathan et al 2014). Advances in technology have enabled more refined phenology retrieval at higher spatiotemporal resolutions (Ma et al 2022). While precise phenological event detection via satellite data is challenging, broader "land surface phenology (LSP)" descriptors are derived (De Beurs et al 2004, Richardson et al 2013). LSP overcomes limitations of ground-based observations, connecting traditional records with global models (Garonna et al 2018) and offering insights into Indian forest ecosystems (Jeganathan et al 2010). As of now, satellites are the sole practical means of maintaining a constant eye on Earth's dynamics at local to global scales. Specifically, when using optical datasets for long-term phenology studies we encounter some challenges (Berra et al 2019). Both species-specific phenology and vegetation phenology detection using satellite imagery still face a number of obstacles. The main obstacles arise from issues such as pixels, imprecise ground control points, atmospheric distortion and unclear definitions of ground objects (Sharma et al 2022). These factors ultimately affect the accuracy and clarity of the results obtained. These constraints persist across diverse image types, sensors, and platforms, including multi-spectral (hyper-spectral) images, high spatial resolution images, and LiDAR images (Prabakaran et al 2013). Researchers have employed techniques like maximum value compositing (MVC) and masking to address cloud impacts, though these methods have limitations (Dash et al 2010, Atkinson et al 2012, Chakraborty et al 2018).

Ground-based phenological studies in India typically observe nine plant development stages, which include leaves (Bud stage, mature, abscission), flowers (Bud stage, anthesis, abscission) and fruit (Bud stage, maturation, and abscission), but accurately monitoring all these stages via satellite data remains challenging. Moreover, there is a scarcity of ground-based observations in developing and underdeveloped countries that lack established networks for phenological monitoring. To address this gap, expanding the reach of PhenoCam networks to presently underrepresented regions hold the potential to enhance the comprehensive monitoring of vegetation phenology globally. Such an expansion could offer a more holistic perspective on the ramifications of climate change and contribute to a deeper understanding of ecological processes on a global scale (Jose et al 2023).

CONCLUSION

The review has highlighted several critical areas that warrant further attention to maximize the potential of satellite remote sensing in supporting forest phenological studies in India. The key observations are summarized as follows:

1. The immense potential of satellite remote sensing data to support forest phenological studies is evident, but significant challenges remain that must be addressed.
2. Expanding the spatial scale and improving the spatiotemporal resolution of phenological monitoring is critical for accurately assessing the impacts of environmental changes across diverse forest ecosystems.
3. The limited availability of long-term phenology datasets hinders the understanding of temporal patterns and trends, while the inherent complexity of these ecosystems poses analytical challenges.
4. Integrating in-situ data from local experts with remote sensing analysis is essential to maximize the value and application of satellite data for phenological research.
5. Combining SAR and optical satellite data can provide a more comprehensive dataset to enhance the understanding of woody vegetation dynamics.
6. Exploring alternative vegetation indices beyond the commonly used NDVI and EVI can offer valuable insights into phenological changes.
7. Strengthening interdisciplinary collaboration among remote sensing experts, conservationists, and environmental managers is crucial for shaping a unified research agenda and driving more effective outcomes.
8. Adopting emerging satellite technologies and innovative analytical methods, including machine learning, can advance the mechanistic understanding of phenological processes across multiple scales.

By strategically addressing these key focus areas, the research community can significantly enhance the accuracy, reliability, and comprehensive application of satellite remote sensing in support of forest phenological studies in India, ultimately driving more impactful and informed decision-making for the sustainable management of these critical ecosystems.

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AUTHOR'S CONTRIBUTIONS

Dhruvi Sedha: Writing-Original Draft preparation, Conceptualization, Methodology, Figure Preparation and Editing. Chandra Prakash Singh: Conceptualization, Formal Analysis, Supervision, Reviewing and Editing. Hitesh Solanki: Supervision. Jincy Rachel Mathew: Visualization and Editing. Mehul R Pandya: Supervision and reviewing. Bimal Bhattacharya: Resources and Supervision. C Jeganathan: Reviewing and Editing. Siddhartha Khare: Reviewing and Editing. All authors have read and agreed to the published version of the manuscript.

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Carbon Sequestration Potential of Woody Species in Thiagarajar College Campus, Madurai, India

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Abstract: Thiagarajar College Campus had 56 tree species and 5 shrub species with a total of 502 individuals during 2023. *Azadirachta indica* had a maximum number of 109 individuals. *Samanea saman* had the highest biomass (12923.72 kg/tree), Carbon storage (6461.80 kg/tree) and carbon sequestration (23456.56 kg/tree and 2148.70 kg/tree). The other potential tree species on the campus with high carbon sequestration were *Wrightia tinctoria, Parkia benghalensis, Ficus biglandulosa* and *Terminalia catappa*. The carbon level (497-538 ppm CO_2) in the surrounding environment was within the permissible limit due to the woody cover in the campus. The study recommends the potential tree species for disturbed and polluted urban space.

Keywords: *Azadirachta indica, Samanea saman,* Biomass, Carbon storage, CO_2 level

The heat-trapping gases released by human activities have become one of the great concerns of the world today as they cause global warming and its allied problems (https://www.epa.gov/climatechange-science/causes-climate-change). Carbon dioxide is the major greenhouse gas of global climate change (Dubal et al 2013). Around 87% of CO_2 is released from fossil fuel burning. The remaining is from forest clearing, industrial processes etc. Nearly 45% of CO_2 released during anthropogenic activities remains in the atmosphere. CO_2 trapping is essential for reducing our carbon footprint.

Plants act as a major sink of carbon as sequester carbon through photosynthesis. The forests, grasslands or rangelands play a significant role in carbon sequestration. They store 25% of carbon in their biomass. Aquatic systems store another 25% of CO_2. The bogs, peat and swamps can also store carbon as carbonate. Apart from that, carbon is sequestered in rocks through geological carbon sequestration (https://www.nationalgrid.com/stories/energy-explained/what-carbon-sequestration). The Kyoto Protocol and the United Nations Framework Convention on Climate Change gave directions to raise carbon sequestration. In the terrestrial landscape, trees play several important roles, especially carbon sequestration (Veeramani et al 2023). Trees offer several services for the sustenance of rural and urban ecosystems. They provide a significant contribution to climate change mitigation (Lahoti et al 2020). They trap heat and enable the purity of air, control the microclimate to regulate the urban heat island phenomenon (Jennings et al 2016). It is essential to maintain the urban green belt as it maintains air quality (Deshmukh et al 2020), ecosystem equilibrium (Anjali et al 2020) and to avoid climate change impact (Velasco and Chen 2019). Besides, they enhance socioeconomic and cultural values (Chaudhary and Tewari 2010).

The study by the Indian School of Mines, Dhanbad stated that the study of carbon sequestration in vegetation, litter and soil is important for ecorestoration of mining sites (https://bcclweb.in/files/2011/02/Eco_restoration2015.pdf). The short duration trees grown through agroforestry insist the significance of tree species in climate regulation (Singh and Gokhale 2024). Urban trees store carbon equal to that of tropical forest (https://www.fastcompany.com/ 40589994 /urban-trees-can-store-almost-as-much-carbon-as-tropical-rainforests). The amount of carbon stored by tree species is influenced by the edaphic features and land use changes (Moussa et al 2018, Agarwal et al 2021a, Vineeta et al 2023).

In India, except in a few cities, studies on urban green cover are limited. The study conducted at Amity University Campus highlighted the need of urban green space for climate change mitigation (Sharma et al 2021). The study conducted near adjacent areas of Kolkata city pointed out the relationship between biomass and carbon sequestration and the importance of species selection as trees provide health security to urban residents (Agarwal et al 2021b). The present study was designed to assess the tree cover and its carbon sequestration potential in educational institution namely Thiagarajar College situated in the disturbed and polluted urban space of Madurai in Tamil Nadu, India.

MATERIAL AND METHODS

Study area: The study area, Thiagarajar college campus is in Teppakulam, Madurai, Tamil Nadu, India located at 9.90108 latitude and 78.151 longitudes (Fig. 1). The average rainfall in Madurai is 849 mm with a minimum of 28ºC and a maximum of 42ºC. The campus is 13.1 acres in size with 6.16 acres of built-up area. The study area is the connecting link between National Highway NH87 and the main part of

Madurai city. It is amidst a residential area with a dense population and heavy vehicular movement. The study was conducted from January 2023 to April 2023.

Enumeration of woody plant species: The trees and shrubs in the campus were documented. The number of individuals of each species was listed. The scientific name of the trees and shrubs along with the author's citation were verified using Gamble Flora (1921-1935) and Mathew Flora (1991), International Plant Name Index (https://www.ipni.org/) and Plants of the World Online of Kew Botanical Garden (https://powo.science.kew.org/).

Estimation of morphometric parameters: The biomass of woody species was calculated using a non-destructive method. An allometric model with tree diameter, height and wood specific gravity was used (Saral et al 2017). Wood specific gravity was used to reduce the error of biomass estimate (Beets et al 2012). The tree height was measured using a GLM40 Distometer. The girth was measured at 1.3 m from the base of the tree using measuring tape. The diameter and radius were calculated from the girth. Wood Density of the tree species was obtained from http://db.worldagroforestry.org/wd.

Above ground biomass of the woody species (AGB): The above ground biomass of a tree includes the whole shoot, branches, leaves, flowers and fruits.

AGB (kg) = Volume of tree (m^3) X Wood Density kg/m^3.

$V = \pi r^2 H$, H = height of the tree in meters, R = radius of the tree in meters

Below ground Biomass (BGB): The below ground biomass (BGB) includes all biomass of live roots excluding fine roots. The BGB was calculated by using the following formula (Hangarge et al 2012)

BGB = AGB x 0.26

Total biomass (TBM): The total biomass is the sum of the above and below ground biomass.

Total biomass = AGB + BGB

Estimation of carbon storage: Generally, for any plant species, 50% of its biomass is considered as carbon content.

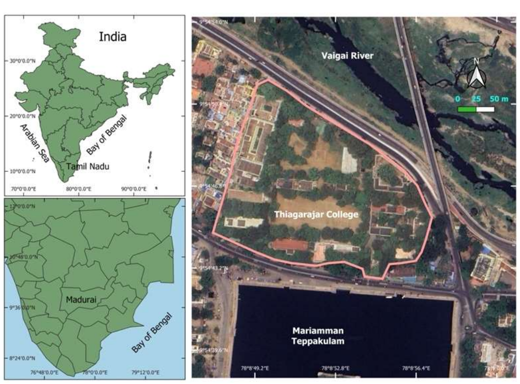

Fig. 1. Map showing the study area Thiagarajar College in Madurai, Tamil Nadu, India

Carbon = Total biomass x 50%

Estimation of carbon sequestration

Weight of CO_2 = carbon content x 3.6663

Weight of CO_2 is C + 2 X O = 43.99915.

Hence, the ratio of CO_2 to C is calculated as: 43.99915/12.001118 = 3.6663.

In order to determine the weight of carbon dioxide sequestered in the tree, the weight of carbon in the tree was multiplied by 3.6663.

Estimation of CO_2 level in the atmosphere: CO_2 levels (ppm) within the campus and outside the campus were measured using a CO_2 detector (Gas Analyzer Monitor Air Quality Meter for Home Indoor Outdoor/ B08FCK4GB7) during April 2023.

RESULTS AND DISCUSSION

The study area, Thiagarajar College Campus had total of 61 woody species (Table 1). Among them, 56 were trees and the rest of the 5 were shrubs. The total number of trees in the college campus was 503. *Azadirachta indica* had maximum number of individuals (109) followed by *Polyalthia longifolia*. Seventeen species were being represented by a single individual. Among the 61 species, 34 species (56%) were native species and 27 (44%) were exotic species. The tallest tree in the campus was *Polyalthia longifolia* (14.6 m). The smallest tree species was *Punica granatum* (2m).

Samanea saman had the largest trunk with 1.43 m diameter and the highest biomass (12923.72 kg/tree) and carbon storage 6461.80 kg/tree (Table 2). It sequestered 18616.13 kg/tree carbon in its aboveground components and 4840.24 kg/tree carbon in belowground components with a total of 23456.56 kg/tree (Table 3). It sequestered about 31% of the carbon in a tree among all the other species. It was followed by *Wrightia tinctoria*, *Parkia biglandulosa* and *Ficus benghalensis*. All these species had tall trunk, large diameter and wood density. Height, diameter and wood density influence the biomass, carbon storage and sequestration potential (Chave et al 2014, Mensha et al 2016, Saral et al 2017, Prasadan and Jithila 2018, Yumnam and Ronald 2022).

Besides the tree growth and morphometric parameters the relative abundance, tree cover and its diversity also influence the carbon storage in an area. Mouna et al (2019) observed correlation between carbon stock and number of individuals. High tree density could be one of the reasons for high carbon storage (Vineeta et al 2023). In the study site, *Azadirachta indica* had low biomass when compared to other species, due to its high density it sequestered 25.14 % of the total carbon. Channali et al (2022) observed that *Azadiracta indica* had high carbon sequestration capacity in Karnataka. *Azadirachta indica* and *Samanea saman* were the trees preferred to grow in urban environment due to their fast growth rate and wide range of adaptations to variety of soils (Rahman et al 2014). Besides

Table 1. Woody species with their morphometric parameters at Thiagarajar College Campus in Madurai, Tamil Nadu, India

Name of the woody species	Family	No. of individuals	Habit/ origin status	Height (m)	Diameter (m)	Wood density** (g/cm^3)
Adina cordifolia (Roxb.) Brandis	Rubiaceae	1	Tree Native	3.37	0.18	0.61
Aegle marmelos (L.) Corrêa	Rutaceae	1	Tree Native	5.52	0.12	0.78
Albizia lebbeck (L.) Benth.	Mimosaceae	7	Tree Native	11.18±2.17	0.19±0.02	0.59
A. procera(Roxb.) Benth.	Mimosaceae	17	Tree Native	10.39±2.06	0.36±0.1	0.68
Ailanthus excelsa Roxb.	Simaroubaceae	1	Tree Native	8.99	0.3	0.4
Artocarpus heterophyllus Lam.	Moraceae	1	Tree Native	5.02	0.16	0.59
Azadirachta indica A.Juss.	Meliaceae	109	Tree Native	8.87±2.88	0.36±0.23	0.72
Bauhinia purpurea L.	Caesalpiniaceae	2	Tree Native	5.66±0.90	0.21±0.13	0.72
B. tomentosa L.	Caesalpiniaceae	2	Tree Exotic	4.94±2.67	0.06±0.04	0.75
B. variegata L.	Caesalpiniaceae	1	Tree Native	5.56	0.07	0.75
B. rufescens Lam.	Caesalpiniaceae	1	Tree Exotic	3.75	0.05	0.75
Bombax ceiba L.	Bombacaceae	12	Tree Native	9.27±2.0	0.37±0.13	0.35
Caesalpinia coriaria (Jacq.) Willd.	Caesalpiniaceae	14	Tree Exotic	6.53±1.33	0.36±0.14	1.13
C. pulcherima (L.) Sw.*	Caesalpiniaceae	1	Shrub Exotic	4.16	0.05	0.84
Cassia siamea Lam.	Caesalpiniaceae	6	Tree Exotic	9.22±1.72	0.33±0.97	0.74
Casuarina equisetifolia L.	Casuarinaceae	1	Tree Native	10.66	0.31	0.91
Cocos nucifera L.	Arecaceae	1	Tree Exotic	13.20	0.36	0.61
Crateva religiosa G.Forst.	Capparaceae	4	Tree Native	8.58±2.05	0.29±0.14	0.33
Dalbergia latifolia Roxb.	Fabaceae	3	Tree Native	8.57±2.95	0.16±0.01	0.75
Delonix regia (Bojer ex Hook.) Raf.	Fabaceae	13	Tree Exotic	9.39±2.36	0.3±0.01	1.15
Duranta versicolor L.*	Verbenaceae	8	Shrub Exotic	2.12±.0.03	0.09±0.02	0.56
Elaeis guineensis Jacq.	Palmae	1	Tree Native	11.84	0.27	0.33
Ficus benghalensis L.	Moraceae	4	Tree Exotic	8.83±5.30	0.69±0.41	0.49
F. religiosa L.	Moraceae	7	Tree Native	8.12±2.70	0.35±0.19	0.44
Gliricidia sepium (Jacq.) Kunth	Fabaceae	2	Tree Exotic	9.35±1.09	0.29±0.01	0.68
Gmelina arborea Roxb. ex Sm.	Verbenaceae	2	Tree Native	2.9±0.82	0.75±0.03	0.43
Guazuma tomentosa Kunth	Sterculiaceae	4	Tree Exotic	6.98±1.10	0.16±0.06	0.05
Holoptelea integrifolia (Roxb.) Planch.	Ulmaceae	2	Tree Native	10.89±1.19	0.52±0.24	0.51
Hibiscus rosa-sinensis L.*	Malvaceae	1	Shrub Exotic	7.51	0.05	0.47
Hyophorbe verschaffeltii (W.Bull ex J.Dix) H.Wendl.	Arecaceae	20	Tree Exotic	6.57±1.06	0.38±0.08	0.64
Lannea coromandelica (Houtt.) Merr.	Anacardiaceae	3	Tree Native	6.92±0.98	0.16±0.05	0.58
Leucaena leucocephala (Lam.) de Wit	Fabaceae	2	Tree Native	12.03±1.33	0.15±0.02	0.72
Madhuca longifolia (L.) J.F.Macbr.	Sapotaceae	5	Tree Native	9.01±5.95	0.37±0.23	0.79
Mangifera indica L.	Anacardiaceae	1	Tree Native	5.79	0.10	0.55
Millingtonia hortensis L.f	Bignoniaceae	16	Tree Exotic	8.66±3.33	0.22±0.12	0.48
Mimusops elengi L.	Sapotaceae	13	Tree Native	6.38±2.62	0.22±0.16	0.88
Morinda tinctoria Roxb.	Rubiaceae	3	Tree Native	7.00±1.04	0.19±0.04	0.54
Manilkara zapota (L.) P.Royen	Sapotaceae	1	Tree Exotic	6.28	0.06	0.95
Muntingia calabura L.	Muntingiaceae	3	Tree Native	5.50±1.04	0.11±0.04	0.3
Parkia biglandulosa Wight & Arn.	Mimosaceae	5	Tree Exotic	12.01±1.06	0.61±0.14	0.47
Peltophorum pterocarpum (DC.) Backer ex K.Heyne	Caesalpiniaceae	9	Tree Exotic	10.54±1.48	0.39±0.04	0.63
Pithecellobium dulce (Roxb.) Benth.	Mimosaceae	2	Tree Exotic	9.97±2.16	0.41±0.22	0.66
Plumeria rubra L.	Apocynaceae	1	Tree Exotic	5.73	0.1	0.64
Polyalthia longifolia (Sonn.) Thwaites	Annonaceae	90	Tree Native	14.6±2.64	0.21±0.13	0.58
Pongamia pinnata (L.) Pierre	Fabaceae	17	Tree Native	7.18±2.45	0.2±0.12	0.61
Psidium guajava L.	Myrtaceae	2	Tree Exotic	6.22±2.32	0.12±0.02	0.85
Punica granatum L.	Lythraceae	1	Tree Exotic	2.00	0.006	0.7
Samanea saman(Jacq.) Merr.	Mimosaceae	3	Tree Exotic	12.82±2.16	1.43±0.05	0.52
Santalum album L.	Santalaceae	2	Tree Exotic	4.86±2.26	0.15±0.002	0.93
Sapindus emarginatus Vahl	Sapindaceae	5	Tree Native	8.14±1.55	0.18±0.11	0.71
Simarouba glauca DC.	Simaroubaceae	3	Tree Exotic	9.28±0.9	0.15±0.02	0.46
Sterculia foetida L.	Malvaceae	2	Tree Native	9.33±4.77	0.19±0.13	0.55
Syzygium cumini (L.) Skeels	Myrtaceae	7	Tree Native	5.88±1.83	0.19±0.07	0.7
Tamrindus indica L.	Caesalpiniaceae	42	Tree Exotic	8.99±3.26	0.36±0.25	0.99
Tabebuia rosea (Bertol.) DC.	Bignoniaceae	1	Tree Exotic	8.36	0.64	0.53
Tabernaemontana divaricata (L.) R.Br. ex Roem. & Schult.*	Apocynaceae	4	Shrub Native	2.78±0.90	0.1±.0.02	0.75
Tecoma stans (L.) Juss. ex Kunth*	Bigoniaceae	6	Shrub Exotic	3.79±0.73	0.08±0.05	0.46
Tectona grandis L.f.	Verbenaceae	2	Tree Native	8.56±1.71	0.18±0.02	0.61
Terminalia arjuna (Roxb. ex DC.) Wight & Arn.	Combretaceae	1	Tree Native	10.17	0.19	0.8
T. catappa L.	Combretaceae	1	Tree Native	12.45	0.54	0.54
Wrightia tinctoria (Roxb.) R.Br.	Apocynaceae	1	Tree Native	8.11	0.64	0.77

Values – Mean±SD, n= 1 to 10 depends on the species; *Shrub **Wood Density Source: http://db.worldagroforestry.org/wd

Table 2. Biomass and carbon storage potential of woody species (kg/tree) in Thiagarajar College Campus in Madurai, Tamil Nadu, India

Name of the woody species	Above-ground biomass (kg/tree)	Below-ground biomass (kg/tree)	Total biomass (kg/tree)	Above-ground carbon storage (kg/tree)	Below-ground storage (kg/tree)	Total carbon storage (kg/tree)
Adina cordifolia (Roxb.) Brandis	52.28	6.79	59.08	26.14	3.39	29.54
Aegle marmelos (L.) Corrêa	46.99	6.11	53.1	23.50	3.06	26.55
Albizia lebbeck (L.) Benth.	167.80	21.81	189.60	83.88	10.90	94.79
A. procera(Roxb.) Benth.	179.70	23.36	203.10	89.85	11.68	101.50
Ailanthus excelsa Roxb.	247.70	32.20	279.90	123.80	16.10	139.90
Artocarpus heterophyllus Lam.	45.57	5.924	51.49	22.79	2.96	25.75
Azadirachta indica A.Juss.	661.30	85.97	747.30	330.60	42.98	373.60
Bauhinia purpurea L.	128.00	16.63	144.6	63.98	8.32	72.30
B. tomentosa L.	10.47	1.36	11.83	5.24	0.68	5.91
B. variegata L.	11.78	1.53	13.32	5.89	0.77	6.66
B. rufescens Lam.	3.53	0.46	3.99	1.77	0.23	1.99
Bombax ceiba L.	353.80	46.00	399.80	176.90	23.00	199.90
Caesalpinia coriaria (Jacq.) Willd.	763.50	198.50	962.00	381.80	99.26	481.00
C. pulcherima (L.) Sw.	4.39	1.14	5.53	2.19	0.57	2.77
Cassia siamea Lam.	576.80	150.00	726.80	288.40	74.98	363.40
Casuarina equisetifolia L.	741.70	192.80	934.50	370.80	96.42	467.20
Cocos nucifera L.	818.60	212.80	1031.00	409.30	106.40	515.70
Crateva religiosa G.Forst.	191.00	49.66	240.70	95.50	24.83	120.30
Dalbergia latifolia Roxb.	128.00	33.29	161.30	64.01	16.64	80.66
Delonix regia (Bojer ex Hook.) Raf.	776.60	201.90	978.50	388.30	101.00	489.20
Duranta versicolor L.	5.96	1.55	7.52	2.98	0.78	3.76
Elaeis guineensis Jacq.	219.40	57.05	276.50	109.70	28.52	138.20
Ficus benghalensis L.	1623.00	421.90	2044.00	811.30	210.90	1022.00
F. religiosa L.	338.20	87.94	426.20	169.10	43.97	213.10
Gliricidia sepium (Jacq.) Kunth	410.00	106.60	516.60	205.00	53.30	258.30
Gmelina arborea Roxb. ex Sm.	536.00	139.40	675.40	268.00	69.69	337.70
Guazuma tomentosa Kunth	6.68	1.74	8.41	3.34	0.87	4.20
Holoptelea integrifolia (Roxb.) Planch.	1189.00	309.10	1498.00	594.50	154.60	749.10
*Hibiscus rosa-sinensis*L.	4.43	1.15	5.59	2.22	0.58	2.79
Hyophorbe verschaffeltii (W.Bull ex J.Dix) H.Wendl.	482.30	125.40	607.70	241.10	62.69	303.80
Lannea coromandelica (Houtt.) Merr.	76.81	19.97	96.79	38.41	9.99	48.39
Leucaena leucocephala (Lam.) de Wit	158.90	41.31	200.20	79.44	20.66	100.10
Madhuca longifolia (L.) J.F.Macbr.	775.80	201.70	977.50	387.90	100.90	488.80
Mangifera indica L.	22.84	5.9	28.78	11.42	2.97	14.39
Millingtonia hortensis L.f	153.00	39.79	192.80	76.52	19.89	96.41
Mimusops elengi L.	219.00	56.95	276.00	109.50	28.47	138.00
Morinda tinctoria Roxb.	112.00	29.12	141.10	56.00	14.56	70.56
Manilkara zapota (L.) P.Royen	19.00	4.94	23.94	9.50	2.47	11.97
Muntingia calabura L.	16.11	4.19	20.29	8.05	2.09	10.15
Parkia biglandulosa Wight & Arn.	1674.00	435.20	2109.00	836.80	217.60	1054.00
Peltophorum pterocarpum (DC.) Backer ex K.Heyne	813.10	211.40	1025.00	406.60	105.70	512.30
Pithecellobium dulce (Roxb.) Benth.	871.80	226.70	1098.00	435.90	113.30	549.20
Plumeria rubra L.	28.06	7.29	35.35	14.03	3.65	17.68
Polyalthia longifolia (Sonn.) Thwaites	302.70	78.69	381.30	151.30	39.34	190.70
Pongamia pinnata (L.) Pierre	134.20	34.89	169.10	67.10	17.45	84.54
Psidium guajava L.	60.79	15.80	76.59	30.39	7.90	38.29
Punica granatum L.	0.04	0.01	0.05	0.02	0.06	0.03
Samanea saman(Jacq.) Merr.	10256.92	2666.80	12923.72	5128.46	1333.40	6461.80
Santalum album L.	76.25	19.82	96.07	38.12	9.91	48.04
Sapindus emarginatus Vahl	149.50	38.88	188.40	74.77	19.44	94.21
Simarouba glauca DC.	78.35	20.37	98.72	39.17	10.18	49.36
Sterculia foetida L.	147.20	38.27	185.50	73.59	19.13	92.73
Syzygium cumini (L.) Skeels	114.10	29.68	143.80	57.07	14.84	71.91
Tamrindus indica L.	889.00	231.10	1120.00	444.50	115.60	560.10
Tabebuia rosea (Bertol.) DC.	1413.00	367.30	1780.00	706.30	183.60	890.00
Tabernaemontana divaricata (L.) R.Br. ex	16.37	4.26	20.62	8.18	2.13	10.31
Tecoma stans (L.) Juss. ex Kunth	8.01	2.08	10.09	4.00	1.04	5.04
Tectona grandis L.f.	135.20	35.14	170.30	67.59	17.57	85.16
Terminalia arjuna (Roxb. ex DC.) Wight & Arn.	233.20	60.64	293.90	116.60	30.32	146.90
T. catappa L.	1547.00	402.30	1949.00	773.60	201.10	974.70
Wrightia tinctoria (Roxb.) R.Br.	1884.00	489.90	2374.00	942.20	245.00	1187.00
Total	33110.81	8360.65	41469.55	16554.45	4179.93	20734.54

Table 3. Carbon sequestration potential of woody species in Thiagarajar College Campus in Madurai, Tamil Nadu, India

Name of the woody species	Above-ground carbon sequestration (kg/tree)	Below-ground carbon sequestration (kg/tree)	Total carbon sequestration (kg/tree)	Total carbon sequestration of all the individuals of the species (kg/ha)
Adina cordifolia (Roxb.) Brandis	94.89	12.34	107.23	3.27
Aegle marmelos (L.) Corrêa	85.29	11.088	96.38	2.94
Albizia lebbeck (L.) Benth.	304.49	39.58	344.08	73.54
A. procera(Roxb.) Benth.	326.14	42.39	368.55	191.31
Ailanthus excelsa Roxb.	449.56	58.44	508.00	93.07
Artocarpus heterophyllus Lam.	82.71	10.752	93.46	2.85
Azadirachta indica A.Juss.	1200.25	156.03	1356.29	4514.10
Bauhinia purpurea L.	232.25	30.19	262.44	16.02
B. tomentosa L.	19.00	2.47	21.47	1.31
B. variegata L.	21.39	2.78	24.16	0.74
B. rufescens Lam.	6.41	0.833	7.24	0.22
Bombax ceiba L.	642.20	83.48	725.68	265.90
Caesalpinia coriaria (Jacq.) Willd.	1385.76	360.29	1746.06	746.41
C. pulcherima (L.) Sw.	7.96	2.07	10.03	0.31
Cassia siamea Lam.	1046.88	272.19	1319.07	241.66
Casuarina equisetifolia L.	1346.12	349.99	1696.10	51.79
Cocos nucifera L.	1485.76	386.29	1872.05	57.16
Crateva religiosa G.Forst.	346.68	90.13	436.81	53.35
Dalbergia latifolia Roxb.	232.36	60.41	292.78	26.82
Delonix regia (Bojer ex Hook.) Raf.	1409.47	366.46	1775.97	704.95
Duranta versicolor L.	10.83	2.81	13.64	3.33
Elaeis guineensis Jacq.	398.22	103.54	501.77	15.32
Ficus benghalensis L.	2944.91	765.68	3710.59	453.20
F. religiosa L.	613.92	159.62	773.53	165.34
Gliricidia sepium (Jacq.) Kunth	744.19	193.49	937.68	57.26
Gmelina arborea Roxb. ex Sm.	972.92	252.96	1225.88	74.86
Guazuma tomentosa Kunth	12.12	3.15	15.27	1.87
Holoptelea integrifolia (Roxb.) Planch.	2158.05	561.09	2719.15	166.05
*Hibiscus rosa-sinensis*L.	8.05	2.09	10.14	0.31
Hyophorbe verschaffeltii (W.Bull ex J.Dix) H.Wendl.	875.31	227.58	1102.89	673.52
Lannea coromandelica (Houtt.) Merr.	139.42	36.25	175.67	16.09
Leucaena leucocephala (Lam.) de Wit	288.38	74.98	363.37	22.19
Madhuca longifolia (L.) J.F.Macbr.	1408.11	366.11	1774.21	270.87
Mangifera indica L.	41.46	10.78	52.24	1.59
Millingtonia hortensis L.f	277.76	72.22	349.97	170.98
Mimusops elengi L.	397.55	103.36	500.91	198.83
Morinda tinctoria Roxb.	203.28	52.85	256.14	23.46
Manilkara zapota (L.) P.Royen	34.48	8.97	43.45	1.33
Muntingia calabura L.	29.23	7.60	36.83	3.37
Parkia biglandulosa Wight & Arn.	3037.76	789.82	3827.58	584.36
Peltophorum pterocarpum (DC.) Backer ex K.Heyne	1475.85	383.72	1859.57	511.03
Pithecellobium dulce (Roxb.) Benth.	1582.37	411.41	1993.78	121.76
Plumeria rubra L.	50.93	13.24	64.17	1.96
Polyalthia longifolia (Sonn.) Thwaites	549.31	142.82	692.13	1902.00
Pongamia pinnata (L.) Pierre	243.57	63.33	306.89	159.30
Psidium guajava L.	110.33	28.68	139.01	8.49
Punica granatum L.	0.07	0.01	0.09	0.002
Samanea saman (Jacq.) Merr.	18616.32	4840.24	23456.56	2148.70
Santalum album L.	138.39	35.98	174.37	10.64
Sapindus emarginatus Vahl	271.42	70.57	341.99	52.21
Simarouba glauca DC.	142.19	36.97	179.16	16.41
Sterculia foetida L.	267.14	69.45	336.59	20.55
Syzygium cumini (L.) Skeels	207.17	53.86	261.03	55.794
Tamrindus indica L.	1613.57	419.53	2033.10	2607.3
Tabebuia rosea (Bertol.) DC.	2563.99	666.64	3230.63	98.64
Tabernaemontana divaricata (L.) R.Br. ex	29.71	7.72	37.43	4.57
Tecoma stans (L.) Juss. ex Kunth	14.53	3.78	18.31	3.35
Tectona grandis L.f.	245.33	63.79	309.12	18.88
Terminalia arjuna (Roxb. ex DC.) Wight & Arn.	423.29	110.06	533.35	16.29
T. catappa L.	2808.20	730.13	3538.33	108.04
Wrightia tinctoria (Roxb.) R.Br.	3420.12	889.23	4309.35	131.58
Total	60095.38	15174.4	75269.78	17949.45

these two tree species the other species such as *Delonix regia, Tamarindus indica, Ficus religiosa, Peltophorum pterocarpum, Albizia lebbeck, Terminalia catappa, Ficus benghalensis* and *Terminalia arjuna* growing in Thiagarajar College campus were observed as preferable species for road side plantation (Ragula and Chandra 2020). The outside environment of the college campus had an average of 537.87 ppm CO_2 and within the college campus 496.65 ppm CO_2 in the atmosphere. There was no large difference in the CO_2 level in and around the campus. From the study it was inferred that the CO_2 level was maintained within the permissible limit by the woody tree species, though the campus had high anthropogenic disturbances (https://www.health.state.mn.us/communities/environment/air/toxins/co2.html, Sharma et al 2021).

CONCLUSION

Samanea saman, Wrightia tinctoria, Parkia biglandulosa, Ficus benghalensis, and *Terminalia cattapa* have high sequestration potential. *Azadirachta indica* is able to thrive well in all kinds of soil. The study suggests that these species are suitable for urban spaces with high anthropogenic disturbances and heavy vehicular movement.

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Ethnobotanical Exploration of Polypetalous Riparian Flora along Beas River in Himachal Pradesh Utilized by Traditional Practitioners in the Management of Hypertension

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Abstract: Polypetalous plants of Riparian vegetation along the Beas River of Himachal Pradesh were utilized to treat various diseases. Extensive fieldwork was carried out to document the traditional use of ethnomedicinal plants, and a survey was conducted from March 2024 to June 2024 to assess the significance of these plants in healthcare practices. A total of 143 informants, including 65 men and 78 women, were randomly chosen for interviews via semi-structured questionnaires. The study computed several quantitative indices: frequency citation, Jaccard index, family importance value , and relative frequency of citation. Thirty polypetalous plant species distributed among 15 different families were identified for their use in treating hypertension in Himachal Pradesh. The predominant life form documented in the study was herbs (17 species). The most typical preparation mode was powder (11 species), and plant parts were root (8 species). Among the families, Fabaceae showed the highest family importance value of 20.97, and the relative frequency of citation varied between 0.10 and 0.41 across the reported plant species. This research bridges the conventional knowledge of polypetalous plants offering a promising avenue for developing novel therapeutics for hypertension.

Keywords: Ethnobotany, Hypertension, Traditional Medicine, Polypetalous, Jaccard index

Cardiovascular conditions are significantly high in human populations, making their avoidance and management a top priority in numerous countries (Aumeeruddy and Mahomoodally 2020). In current years, the practice of therapeutic herbs for treating diseases has seen a substantial increase. High blood pressure can harm the blood vessels that supply blood to the heart, eyes, brain, and kidneys (Malik et al 2018). It plays a significant role in the growth of cardiovascular incidents, heart disease, and stroke. The mortality rate from hypertension is double as high as that of the common populace. It raises the risk of rapid death in patients with cardiovascular disease. Hypertension, described by high BP levels, is a significant risk issue for circulatory diseases, stroke, and renal complications, contributing significantly to global morbidity and mortality (Baharvand-Ahmadi and Asadi-Samani 2017). The high BP affects around 1.27 billion adults aged 29-80 worldwide (Meresa et al 2017). This condition is most prevalent in low- and middle-income countries, where two-thirds of the affected populace resides. Approximately 10 million people die each year from hypertension-related causes, making it more lethal than all infectious diseases combined (Baharvand-Ahmadi et al 2015). Efforts to manage hypertension focus on lifestyle changes such as adopting a healthier diet, decreasing salt intake, boosting physical activity, giving up smoking, and limiting alcohol consumption. For many, medication is also essential to attain optimal blood pressure control (Diallo et al 2019). The alternative method to cure and manage hypertension is through the use of herbal remedies. These polypetalous plants are effective in treating high blood pressure and addressing various other health conditions (Ajayi et al 2019). Medicinal plants have been used for centuries in folk medicine to cure numerous ailments (Ozturk et al 2018). This ancient therapeutic medicine offers a practical and thorough approach to using herbal plants, and adhering to its principles can be advantageous in tackling public health challenges. Ethno-botanical surveys studies aimed at documenting therapeutic information and the usage of herbal plants. In modern times, pharmacology has made remarkable advances and herbal drugs are utilized alongside conventional pharmaceuticals to address a wide array of health conditions (Panmei et al 2019). Reports indicate that over 30% of modern medicines have their origins traced back to medicinal plants. Numerous herbal plants have been thoroughly researched for their medicinal properties thus far. Despite advances in conventional pharmacotherapy, many individuals worldwide rely on traditional medicinal practices, including the usage of plant-based medications, for the management of high BP (Hassaine et al 2019, Nunes et al 2015). The ethnobotanical knowledge embedded within traditional healing systems offers a rich repository of potential therapeutic agents that warrant systematic investigation and validation. Due to the widespread occurrence of hypertension globally, particularly in Himachal Pradesh, and the pressing demand for the exploration of potent herbal remedies, this research aimed to compile information on polypetalous plants endorsed by local people in the riparian region of Beas River of Himachal Pradesh for managing hypertension.

MATERIAL AND METHODS

Research area: The research was carried out in the riparian area of the Beas River in Himachal Pradesh, India. The Beas basin originates in the Shivalik Hills of Himachal Pradesh and extends over 460 km. This area covers 12,130 square kilometers, situated between latitudes 31°41' N to 32°46' N and longitudes 75°84' E to 77°88' E.

Methodology

Ethnobotanical survey: Direct interviews with traditional healers were carried out from March 2024 to June 2024 using a semi-structured questionnaire. The structured questionnaire was administered to traditional healers across diverse geographical regions known for their rich biodiversity. Information regarding the plants' identity, preparation methods, dosage, and perceived efficacy was documented.

Collection of plants and identification: Plant specimens cited by traditional healers were collected, identified, and authenticated by botanists and taxonomists from the Himalayan Forest Research Institute (HFRI), Shimla. Voucher specimens were deposited in the herbaria of Himachal Pradesh University, Shimla.

Quantitative Analysis

Relative frequency of citation (RFC): It is determined to assess the extent of indigenous information about the usage of therapeutic herbs in the studied regions (Nadaf et al 2019):

$$REF=\frac{Fc}{N}$$

Where "Fc" represents the number of participants who mentioned using the species, whereas "N" represents the overall number of participants.

Family importance value (FIV): These values indicate the respondents' information on the plant families used. The FIV values of the therapeutic herb were measured (Nadaf et al 2019):

$$FIV=\frac{\text{No. of families cited by authors}}{\text{Total no. of authors}} \times 100$$

A high value indicates that there is extensive information and several respondents are well-known, whereas a low value suggests limited awareness about the usage of that plant family (Nadaf et al 2019).

Jaccard similarity index (JI): It is computed by assessing previous research publications across national, international, and worldwide scopes. This calculation involves determining the proportions of the mentioned plant species and their therapeutic usage (Faruque et al 2018, Kayani et al 2015):

$$JI = \frac{c}{a+b+c}$$

In this formula, "a" symbolizes the count of plants in Area 1, "b" symbolizes the count of plants in Area 2, and "c" symbolizes the count of floras common to both Areas 1 and 2.

Statistical analysis: The Excel 2016 spreadsheet was utilized for basic calculations and to ascertain plant frequencies.

RESULTS AND DISCUSSION

Diversity of polypetalous plants: The riparian vegetation of the Beas River used 30 taxa from 15 families and 27 genera (Table 2, Fig. 3). The most participants were between the ages of 39 and 79 (Table 1). The majority of informants who are interested in traditional therapeutic information are from the older age group (Ahmed et al 2015; Kayani et al 2015; Malik et al 2018). The Fabaceae family, with 8 plants, followed by Ranunculaceae, was the most prevalent among medicinal plants (Fig. 4). Out of approximately 350,000 identified species of flowering plants, nearly 9% are part of the Fabaceae family, which can observed in almost every type of environment across various regions (Gbekley et al 2018). However, in the research site, more Ranunculaceae and Apiaceae species were employed, as previously reported. Informants identify a variety of herbal species within the same family, each with unique medical capabilities. Another possible explanation for the high citation of Fabaceae and Ranunculaceae is their higher occurrence in high-altitude regions, as observed in previous research.

The herbs were the preferred choice among therapeutic herb species due to their high natural richness in these regions and easy accessibility to local communities. Herbs are readily available and possess potent healing capabilities, producing secondary metabolites with therapeutic properties effective

Table 1. Demographic characteristics of the respondents

Characteristics	Groups	Informants	Percentages
Gender	Male	65	45.45
	Female	78	54.54
Age	30-50	31	21.67
	51-65	46	32.16
	66-79	57	39.86
Ethnic group	Gaddi	72	50.34
	Gujjar	69	48.25
Education	Illiterate	41	28.67
	Matric	59	41.25
	Secondary school	52	36.36

Table 2. Ethnomedicinal uses of polypetalous plants

Botanical name	Local name	Family name	Habit	Parts used	Mode of preparation	Ethnobotanical uses	FC	RFC	Jaccard Index (JI)	FIV
Acacia nilotica (L.)	Kikar	Fabaceae/ Leguminosae	Tree	Root	Infusion	One glass of root infusion is drunk after a meal to reduce high blood pressure.	26	0.18	0.53	20.97
Argemone mexicana L.	Kanduri, Bharbhand	Papaveraceae	Herb	Seed and Root	Powder, Infusion	1-2 grams of the dried seed powder is given with mildly heated water to reduce hypertension. The root infusion is drunk during the night to reduce high blood pressure.	18	0.12	0.60	6.99
Bauhinia variegata L.	Karali	Fabaceae	Tree	Flower and Bud	Powder	One teaspoon of powder of dried flowers and buds is taken with water to reduce hypertension.	33	0.23	0.57	20.97
Berberis lycium Royle	Kashmal	Berberidaceae	Shrub	Root	Infusion	4-5 ml of root infusion is drunk early in the morning to decrease high blood pressure.	39	0.27	0.58	6.99
Berberis aristata DC.	Kashmal	Berberidaceae	Shrub	Leaf and fruit	Cooked	Leaves and fruits are cooked to make an infusion and 2-3 ml is drunk two times a day to reduce high blood pressure.	22	0.15	0.55	6.99
Capsella bursa pastoris (L.) Medik.	Jangli sarson	Brassicaceae	Herb	Shoot	Extract	1-2 ml extract of the shoot is drunk once a day to decrease hypertension.	15	0.10	0.69	6.99
Cassia fistula L.	Amaltas/ Aliah	Fabaceae/ Leguminosae	Tree	Bark	Powder	1-2 grams of the dried bark powder is given with water to treat hypertension.	28	0.19	0.76	20.97
Cassia occidentalis Linn.	Bara elwan	Caesalpiniacae/Leguminosae	Shrub	Seed	Infusion	2ml of the seed infusion seed is drunk after a meal to reduce hypertension.	31	0.21	0.77	6.99
Cassia tora L.	Reli	Caesalpiniaceae/Leguminosae	Shrub	Seed	Powder	1-2 grams of dried seed powder is drunk with warm water to reduce high Bp.	29	0.20	0.70	6.99
Centella asiatica (L.) Urban	Brahmi	Apiaceae/ Umbelliferae	Herb	Whole plant	Decoction	The decoction of the entire plant is drunk early in the morning to reduce high blood pressure.	24	0.16	0.63	6.99
Clematis grata Wall.	Dhand	Ranunculaceae	Climber	Flower	Powder	1 gram powder of the dried flower is given with mildly heated water to treat hypertension.	17	0.11	0.57	10.48
Fragaria nubicola Lindl.	Kida-bhumla/ Lal aakhe	Rosaceae	Herb	Fruit	Fresh	Fresh fruits are consumed to lower hypertension.	32	0.22	0.50	6.99
Fumaria indica (Haussk) Pugsley.	Pitpapra	Papaveraceae	Herb	Whole plant	Decoction	The decoction of the entire plant is drunk after a meal to cure high blood pressure.	21	0.14	0.64	6.99
Geranium wallichianum Oliv.	Laljari	Geraniaceae	Herb	Root	Decoction	3-4 ml of root decoction is utilized for the treatment of hypertension.	27	0.18	0.52	3.49
Impatiens balsamina L.	Tiur	Balsaminaceae	Herb	Leaf and Root	Decoction and Powder	The leaf decoction is given after a meal to cure High Blood pressure. The dried root powder is given with mildly heated water to treat hypertension.	29	0.20	0.60	3.49

Cont...

Table 2. Ethnomedicinal uses of polypetalous plants

Botanical name	Local name	Family name	Habit	Parts used	Mode of preparation	Ethnobotanical uses	FC	RFC	Jaccard Index (JI)	FIV
Indigofera hamiltonii Graham	Kathi	Fabaceae	Shrub	Root	Decoction	5 ml of the decoction of the root is drunk two times a week to reduce hypertension.	39	0.27	0.58	20.97
Mangifera indica L.	Aam	Anacardiaceae	Tree	Stem, Bark	Decoction	25–30 mL of decoctions of stem and bark are drunk twice daily to cure high blood pressure.	51	0.35	0.67	3.49
Melilotus alba Medik.	Kutaik	Fabaceae	Herb	Leaf	Infusion	The infusion of the leaves is given daily to reduce high blood pressure.	30	0.20	0.57	20.97
Medicago polymorpha L.	Khokhani	Fabaceae	Herb	Whole plant	Powder	The powder of the entire plant is given with warm water to lower hypertension.	42	0.29	0.54	20.97
Murraya koenigii (L.) Spreng.	Kadipata	Rutaceae	Shrub	Leaf	Powder	Dried leaf powder is taken with lukewarm water to cure hypertension	20	0.13	0.50	3.49
Nasturtium officinale W.T.Aiton	Chuch, Nadd	Brassicaceae	Herb	Shoot	Decoction	Shoots are cooked to make a decoction and taken early in the morning to decrease hypertension.	44	0.30	0.61	6.99
Nigella sativa L.	Kala jeera, kalonji	Ranunculaceae	Herb	Seed	Extract	3-4 ml extract of seed is utilized to reduce high blood pressure.	22	0.15	0.48	10.48
Oxalis corniculata L.	Malori	Oxalidaceae	Herb	Aerial part	Extract	The extract of the aerial part is utilized to reduce hypertension.	54	0.37	0.72	3.49
Pimpinella acuminata (Edgew.) C.B. Clarke	Tarpakhi	Apiaceae	Herb	Root	Powder	2-3 g powder of the dried root is drunk with mildly heated water to reduce hypertension.	17	0.11	0.41	6.99
Ranunculus muricatus L.	Jaldhar/ bimbi	Ranunculaceae	Herb	Stem and Leaf	Infusion	The infusion of stem and leaves is drunk daily to decrease high blood pressure.	48	0.33	0.48	10.48
Rosa brunonii Lindl.	Kuje	Rosaceae	Shrub	Root	Decoction	5-6 ml decoction of the root is drunk early in the morning to reduce hypertension.	45	0.31	0.54	6.99
Sida cordifolia L.	Dragain	Malvaceae	Shrub	Seed	Powder	The powder of the seed is taken with lukewarm water to decrease hypertension.	32	0.22	0.55	3.49
Thalictrum foliolosum DC.	Barmot	Ranunculaceae	Herb	Leaf	Fresh	Fresh juice is used to treat pimples and boils.	56	0.39	0.74	10.48
Trigonella emodi Benth.	Kuchona	Fabaceae	Herb	Leaf	Fresh	Fresh leaves are eaten to decrease hypertension.	23	0.16	0.36	20.97
Viola canescens Wall.	Banfshah	Violaceae	Herb	Flower	Powder	One teaspoonful powder of dried flower is given with mildly heated water to decrease high blood pressure.	59	0.41	0.68	3.49

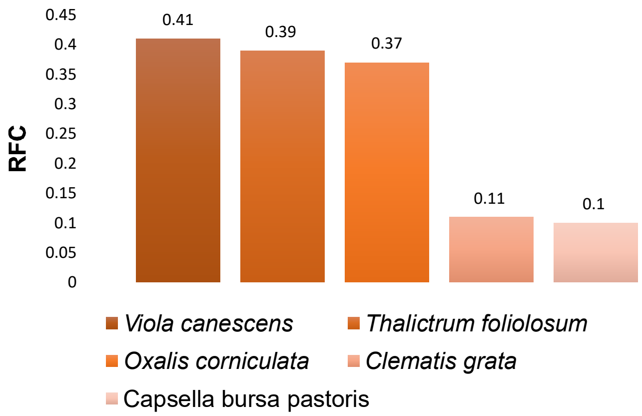

Fig. 1. RFC of polypetalous plants

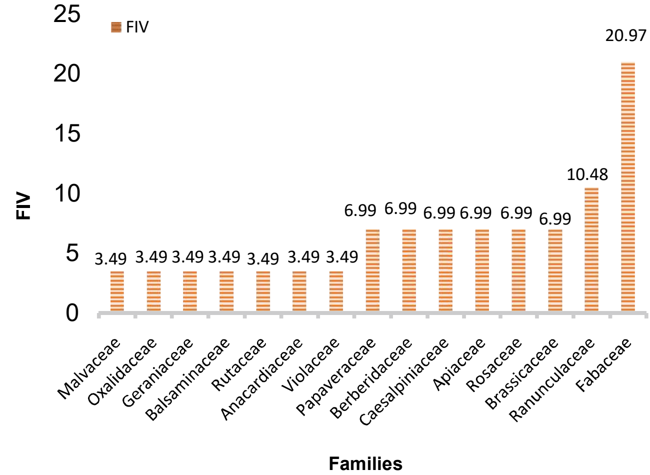

Fig. 2. FIV of polypetalous plants

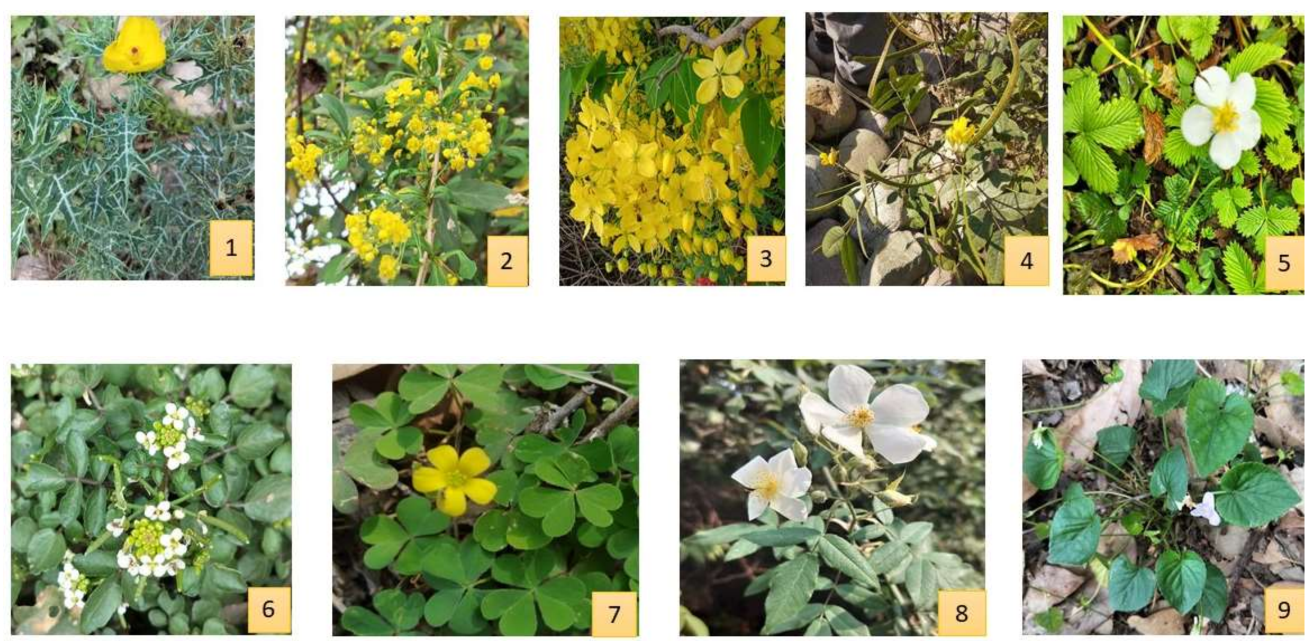

Fig. 3. Some polypetalous plants 1. *Argemone mexicana* 2. *Berberis lycium* 3. *Cassia fistula* 4. *Cassia occidentalis* 5. *Fragaria nubicola* 6. *Nasturtium officinale* 7. *Oxalis corniculata* 8. *Rosa brunonii* 9. *Viola canescens*

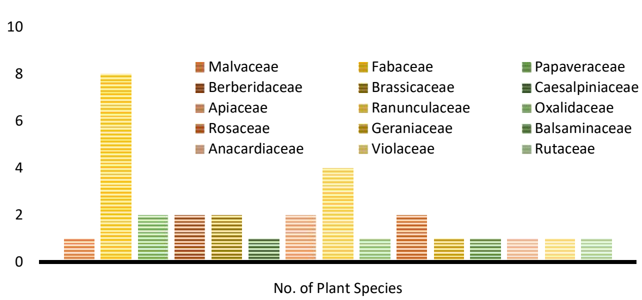

Fig. 4. Families of polypetalous plants

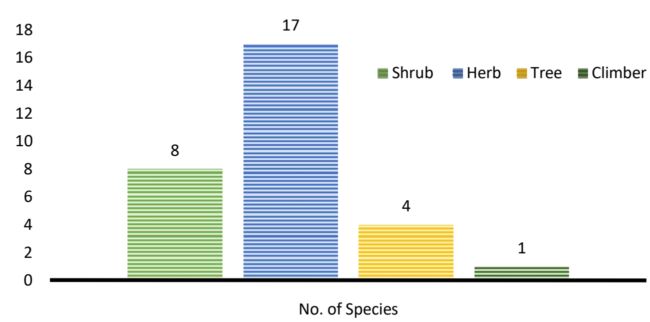

Fig. 5. Habit of polypetalous plants

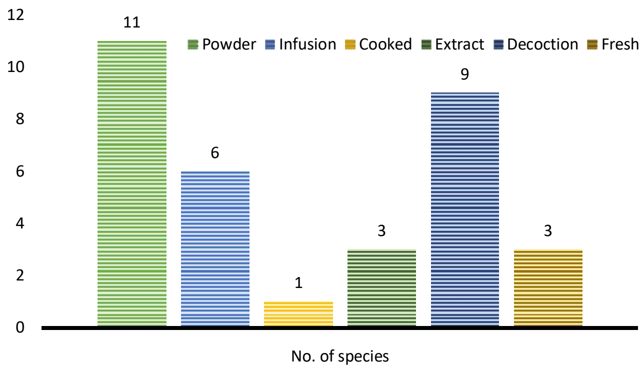

Fig. 6. Mode of preparations

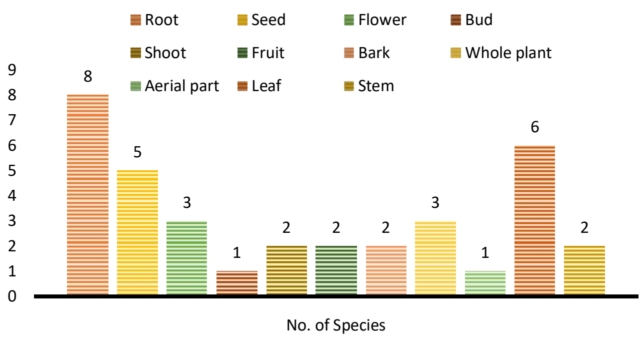

Fig. 7. Plant parts of polypetalous plants

against numerous ailments (Yaseen et al 2015). This research focused mainly on the use of roots as the main parts of the plant for medicinal purposes. When comparing our results with previous studies, significant variations were observed in terms of the Jaccard Index (JI). The JI ranged from 0.41 to 0.77. In RFC, *Viola canescens*, *Thalictrum foliolosum*, and *Oxalis corniculata* were identified as the most significant plants. This study highlights numerous medicinal plant species that exhibit pharmacological activity but remain largely unexplored, emphasizing the need for further research.

Plant parts used: Different plant parts used in preparing herbal remedies include roots, stems, leaves, flowers, seeds, fruits, bark, aerial parts, and whole plants, especially when dealing with small herbal plants. Root was the most commonly used part (8), followed by leaf (6 each), flower, and whole plant (3 each), shoot, fruit, bark, and stem (2 species each), and bud, and aerial parts (only 1 species) (Fig. 7). Herbs constituted the main source of native medicines (17), followed by shrubs (8), trees (4), and climbers (1) (Fig. 5).

Mode of preparation: Herbal preparations were created using various methods such as infusion, powder, decoction, extract, and cooking. The most common usage method was powder (11), followed by decoction, infusion, extract, fresh, and cooked (Fig. 6). Local communities used varied quantities of herbal concoctions to cure a variety of illnesses.

Quantitative Analysis

Relative frequency of citation (RFC): *Viola canescens* had the maximum RFC value (0.41), followed by *Thalictrum foliolosum*, *Oxalis corniculata*, and *Clematis grata* (0.11) had the lowest RFC (Fig. 1).

Family importance value (FIV): Fabaceae was the most prevalent medicinal plant family in terms of both species and FIV index, with 8 species and an FVI of 20.97%. This was followed by Ranunculaceae (10.48%), and Apiaceae, Papaveraceae, Caesalpiniaceae, Berberidaceae, Brassicaceae, and Rosaceae (6.99%). The remaining families have fewer species such as Anacardiaceae, Geraniaceae, Balsaminaceae, Rutaceae, Malvaceae, Oxalidaceae, and Violaceae each containing one species with an FIV of 3.49% (Fig. 2).

CONCLUSION

The ethnobotanical survey presented herein provides a valuable understanding of the use of polypetalous herbs by tribal people to treat hypertension. The total of 143 informants, including 65 men and 78 women, were randomly chosen for interviews via semi-structured questionnaires. A total of 30 polypetalous plant species distributed among 15 different families were identified for their use in treating hypertension in Himachal Pradesh. The predominant was herbs. The most typical preparation mode was powder and plant parts were root. Among the families, Fabaceae showed the highest family importance value. RFC. These findings offer a foundation for further research aimed at connecting the healing potential of therapeutic herbs in the growth of harmless and effective treatment for hypertension.

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Carbon Stock Quantities of *Shorea robusta* Gaertn. along Altitudinal Gradient in Shivalik Hills of Western Himalaya

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Abstract: The study explains altitude wise carbon stock quantities of *Shorea robusta* Gaertn. in the Bhabhar transition zone of Western Himalaya, an important zone from biodiversity conservation and climate change point of view in Uttarakhand. The area was divided into three zones viz. zone I (400-700 m), II (701-1000 m) and III (1001-1300 m). 10 sample plots (total 30 plots) were laid randomly for tree investigation and soil sampling. Based on the generated data through non-harvesting method, a gradual reduction was observed in studied parametric values from 96 trees. Tree volume and carbon stock (105.12-457.38 t ha^{-1}) were recorded highest at lower elevation. Contrary to this, soil carbon content increased from 33.33 t ha^{-1} to 40.96 t ha^{-1} as the elevation went-up from 700 to 1300 m., indicating a positive correlation with altitude. MC and BD showed weak positive correlation at mid-elevation. The findings suggested altitude as a detrimental factor for carbon stocking in trees and soil. It also provide a preliminary idea on influence of other factors such as slope, grazing pressure, choice of management practices and certain climatic factors like humidity and temperature on altitude wise reduction in carbon stocking of tree species in transitional zones.

Keywords: Altitude, Bhabhar zone, Biomass, Carbon stock, *Shorea robusta*

Carbon sequestration is often considered as a leading process reducing carbon dioxide (CO_2) emissions under changing climatic scenario. Trees are known to store the atmospheric carbon by sequestrating it in the growth of woody biomass through the process of photosynthesis. Since trees store and exchange carbon through vital physiological processes, they can be effectively managed to sequester significant quantities of carbon from the atmosphere. *Management of Shorea robusta* Gaertn., commonly known as sal, can contribute to global sustainability as the species holds immense potential in context to forest productivity and climate change. In India, the species is extended from foothills of south of Himalaya to far regions of Satpura and Eastern Ghats. In Uttarakhand, mostly found in Terai and Bhabhar regions, especially in the Shivalik hills. As a tree species in natural forests, *S. robusta* not only holds higher economic value but also serves as an important ecological benefit in the form of slackening global warming and climate change through sequestering atmospheric carbon dioxide (Shrestha et al 2023). It contributes to approximately 10.87% of total growing stock in country's forests (ISFR, 2021). However, its capacity to store carbon can vary along the elevation gradient which may, furthermore influence the amount of greenhouse gases from the atmosphere, an important phenomenon to slowdown the process of global warming.

Forests store approximately half of total carbon of earth and therefore, their role in climate change mitigation is widely recognized (Ekholm 2016, Gren and Zeleke 2016). Generally considered that as a complex terrestrial ecosystem, forests play a profound role in reducing ambient CO_2 levels as they contribute from 20 to 100 times more carbon sequestration per unit area than agrarian lands. In addition to this, mechanism to regulate regional and global carbon (C) cycle through carbon sequestration requires information on tree carbon stock for different species in different regions with varied local environmental conditions. Due to different climatic conditions, forests are markedly different in their individual types. In India, the diversity level of subtropical forests of Northern Himalayan region in Uttarakhand is different from the subtropical forests of Arunachal Pradesh with varied rate of ecological functioning (Himshikha et al 2022). Forest biomass consists of above ground and below ground biomass (Nonini and Fiala 2019, Bhandari and Chhetri 2020). On average, 50% of the biomass is estimated as the carbon content for all species of trees. Empirical measurements of below ground biomass are time consuming, costly and difficult. Therefore, BGB is often estimated using a constant proportion of AGB. In milieu of assessing sequestration potential of any tree species, AGB and BGB need to be measured to enable better calculations of total forest carbon particularly in different geographic conditions. There have been relatively few studies on below ground biomass and carbon stock, particularly in mountainous region. There is an information gap on the altitude wise differential amount of carbon stocking especially in *S. robusta* forests in Bhabhar area, a transitional zone of Shivalik Himalaya in Uttarakhand, India.

Among locality factors, altitude is the major factor affecting the properties of the soils in different forest ecosystems. In forests, soil is also an important pool for storing a huge amount of atmospheric carbon and twice soil organic carbon (SOC) as vegetation and two-thirds as much as the atmosphere (Shreshtha et al 2023). Soil carbon plays a critical role in the global carbon cycle and is an important tool for mitigating the effects of climate change (Fageria 2012). Sakin (2012) suggested that about 55–58% of the soil organic matter (SOM) contains SOC. Soil C stocks and forests in general, act as a carbon sink, removing CO_2 from the atmosphere and therefore mitigate climate change (Mauki et al 2023). The quantification from natural forests in vegetation transition zone becomes more important to estimate their potential in mitigating impacts of climate change as such sensitive zones are important for policy prescription and management planning and harboring ecological services from the species in the region. Species in transitional areas often display adaptive response and therefore, such areas may be crucial for long-term biodiversity conservation and mitigation of climate change. To assess the impact of deforestation and re-growth or regeneration rates on the global carbon cycle, it is necessary to know the stocks of carbon as biomass per unit area for forest types from different perspectives on locality factors under singular agro-climatic zone. The effective monitoring of forests in vegetation transition zone is essential to understand the carbon cycle and its' responses to climate change and anthropogenic activities. Additionally, can provide useful details on the structural and functional characteristics of forest ecosystems along the altitudinal gradient. The hypothesis is that tree and soil carbon stock in sal forest generally changes along with the change in altitude in Bhabhar zone of Uttarakhand.

MATERIAL AND METHODS

Study area: The experiment was conducted in three locations in sal (*S. robusta*) dominated forest along vertical elevation gradient (400-1300 m) in Duggada forest range from Pauri Garhwal Forest division, Uttarakhand. The area comes under tropical to sub-tropical forest zone of Shivalik Hills situated in Western Himalaya. All selected forest stands are managed by State Forest Department. The area lies between latitudes 78° 34' and 78° 37' E and longitudes 29° 46' and 29° 50' N. The elevation gradients were established through three elevation grids, the higher, mid and lower elevation as zone I (400-700 m), II (701-1000 m) and III (1001-1300 m).

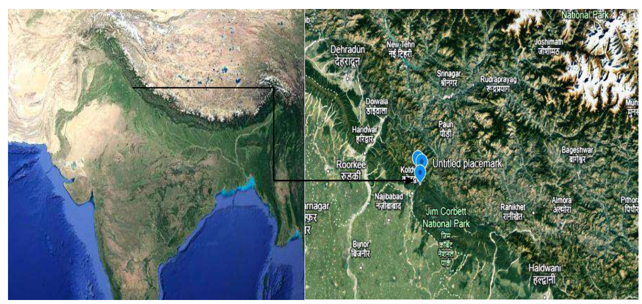
Sample plot design and tree measurements: The study employed a systematic random sampling method to collect data at each altitudinal zone. Total 30 sample plots sizes of 10 m×10 m, 10 sample plots at each altitudinal range were randomly selected for field measurement and sampling purpose of trees (Fig. 1).

For sampling of soil, 1 m x 1 m quadrates were dug to 30 cm depth to collect soil samples from each plot. Data were collected from the field survey that includes measurement of tree parameters (height and girth). Trees with ≥ 30 cm girth at breast height (≥10 cm DBH) at 1.37 m within sample plots were selected for measurement (Joshi et al 2021). For estimation of tree biomass, the quantitative data were obtained from 96 trees. Trees on the border were included if > 50% of their basal area falls within the plot and, excluded if < 50% of their basal area falls outside the plot. Determination of tree basal area and tree volume was carried out using tree form factor method.

Estimation of Biomass and Carbon Content

Above ground biomass (AGB): AGB is described by IPCC (2006).

AGB (t ha^{-1}) = Stem Volume × wood density × biomass expansion factor



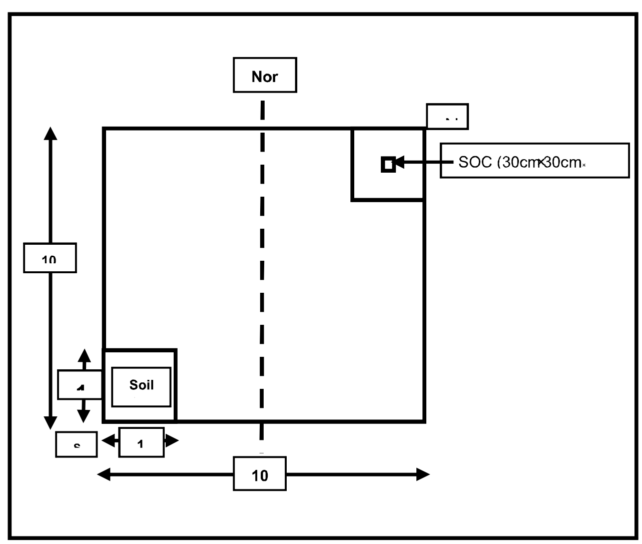


Fig. 1. Sample plot design for enumeration of trees and soil sampling

For the estimation of AGB, wood density scale was used as 0.72 and biomass expansion factor as 3.4 (IPCC, 2003).

Below ground biomass (BGB): It is recommended to estimate BGB as 26% of AGB (IPCC, 2003). IPCC (2006) has suggested carbon fraction as 0.50.

BGB (t ha^{-1}) = AGB × conversion Factor (0.26)

Total biomass: After acquiring the biomass per ha, it was multiplied by a default carbon fraction of 0.5 to calculate the net carbon content (carbon stock density per ha).

Total biomass (t ha^{-1}) = $AGB + BGB$

Carbon stock density (t ha^{-1}) =Total biomass × carbon fraction

Tree/stand biomass, volume of tree stem or bole: This was calculated as:

Stem/ bole volume ($m^3 ha^{-1}$) = Form factor × Tree height × Tree basal area

Form factor: This was calculated as:

Form factor (F) = 2 H1 / 3H

Whereas, H1 = Tree height at which diameter is half of diameter at breast height;

H = Total height of tree

Soil analysis

Soil moisture: The soil moisture content (MC %) was calculated as follow:

$$MC\ (\%) = \frac{\text{Fresh weight} - \text{Oven dry weight}}{\text{Fresh weight of soil}} \times 100$$

Soil organic carbon (SOC): Walkley and Black Wet Digestion Method was used to determine SOC % (Abraham 2013).

Actual soil organic carbon: There is incomplete oxidation of organic matter in this procedure. Therefore, the organic carbon was multiplied by 1.32 on the assumption that there was 77% recovery.

Actual soil organic carbon (%) = Soil organic carbon × 1.32

Soil carbon stock = SOC (%) × bulk density × soil depth

Statistical analysis: Data were analyzed using descriptive and inferential statistical tools on MS Excel 2010 and SPSS software.

RESULTS AND DISCUSSION

Tree Carbon Stock

Basal area and volume: The lowest average tree basal area and volume (7.37 $m^2 ha^{-1}$ and 44.23$m^2 ha^{-1}$) was in the lower altitude (400-700m) followed by 11.47 $m^2 ha^{-1}$and 108.58 $m^2 ha^{-1}$at middle (701-1000 m) and highest (20.27 $m^2 ha^{-1}$ and 186.84 $m^2 ha^{-1}$) in the uppermost side (1001-1300m) in the forest.

AGB and BGB: AGB and BGB was highest (288.15 t ha^{-1} and 118.92t ha^{-1}) in the lower side, followed by mid (167.47 t ha^{-1} and 69.11 t ha-1) and lowest values (66.77 t ha^{-1} and 28.14 t ha^{-1}) at higher elevations. Similarly, total tree carbon stock were as 457.38 t ha^{-1} (highest) in lower 265.82 t ha^{-1} in mid zone and, 105.59 t ha^{-1}in the uppermost elevation (Table 1).

The studied parameters decreased significantly with increasing altitude (Except tree basal area). Tree carbon stock showed strong inverse correlation with altitude, indicating a strong negative correlation with elevation gradient. It could be due to less anthropogenic disturbance and differences in temperature regime between lower (Tropical zone) and upper elevations (Subtropical zone) limiting to tree growth along the altitudinal gradient. The contribution of above-ground and below-ground biomass of trees to the total biomass in the present study was 70.79 and 29.21 % from zone I and II, while was slightly varied as 70.35 and 29.65%, respectively at zone III (Table 2). Nandal et al (2019) mentioned contribution of AGB and BGB as 81.4 to 85.9 and 14.1 to 18.6 percent in total tree biomass. The findings favor to the fact that carbon quantification varies at regional to local scale depending on microclimatic and other environmental factors followed by various silvicultural and forest management practices adopted by concerned authorities.

Table 2. Percentage of AGB and BGB for TB in study area

Zone	AGB (%)	BGB (%)
I (400-700 m)	70.79	29.21
II (701-1000 m)	70.79	29.21
III (1001-1300 m)	70.35	29.65

Table 1. Average basal area, volume and total carbon stock in *Shorea robusta*

Elevation zone	Basal area ($m^2 ha^{-1}$)	Volume ($m^3 ha^{-1}$)	AGB (t ha^{-1})	BGB (t ha^{-1})	TB (t ha^{-1})	Total carbon stock (t ha^{-1})
I (400-700 m)	20.27 ± 2.26	186.84 ± 27.73	288.15 ± 42.77	118.92± 17.65	407.07	457.38 ± 67.88
II (701-1000 m)	11.47 ± 2.10	108.58 ± 23.57	167.47 ± 36.63	69.11 ± 15.12	236.58	265.82 ± 58.15
III (1001-1300 m)	7.37 ± 0.00	44.23± 6.51	66.77 ± 9.77	28.14 ± 4.15	94.91	105.59 ± 17.17
r value	0.99	0.99	0.99	0.99	0.99	0.99
p value (≤ 0.05)	0.13	0.04*	0.03*	0.04*	0.04*	0.03*

r = Correlation coefficient, p-value = Significance level*

Table 3. Correlation of soil properties (Moisture, BD, SOC% and SOC stock) with altitude

Elevation zone	Soil moisture (%)	BD (g cm)$^{-3}$	SOC (%)	SOC Stock (t ha^{-1})
I (400-700 m)	1.94 ± 0.34	0.87 ± 0.5	1.24± 0.18	33.33 ± 6.23
II (701-1000 m)	1.43 ± 0.26	0.97 ± 0.03	1.22 ± 0.23	35.38± 5.99
III (1001-1300 m)	2.19 ± 0.23	0.86 ± 0.03	1.55 ± 0.23	40.96 ± 6.66
r Value	0.32	0.08	0.84	0.97
p Value (≤ 0.05)	0.79	0.95	0.37	0.17

r = Correlation coefficient, p-value = Significance level*

Soil Properties

Soil moisture, SOC% and BD: The highest value of soil moisture (2.19%), soil carbon stock (40.96) and SOC% (1.55%) was at higher elevation (1001-1300m). The lowest value of soil moisture and SOC (1.43 % and 1.22%) was in the middle altitude respectively. Opposite to SOC%, the highest value of BD was in middle altitude as 0.97g cm^{-3} whereas lowest BD (0.86g cm^{-3}) was in higher elevation (Table 3).

SOC stock (t ha^{-1}): Maximum amount of SOC stock (40.96 t ha^{-1}) was estimated from upper elevation while minimum (33.33 t ha^{-1}) at lower elevation. Soil samples from all three altitudinal gradients showed weak positive correlation between moisture, bulk density, SOC % and SOC with altitude. By depicting weak positive correlation, the statistical analysis confirmed that soil carbon stock increases as the elevation goes up. It might be possible due to change in temperature and at higher elevations, the soils generally exhibit low nutrient absorption due to increased slope. This may also happen because of the soil texture, constant input of carbon with less loss, decrease in the microbial and enzymatic activity due to the decreasing temperature (Imtimogla et al 2021). Jeyakumar et al. (2020) mentioned general trend of decreasing SOC and biomass carbon as altitude increases at higher side. Therefore, additional research efforts are required to explore effects of other locality factors on SOC content. The overall effect of elevated atmospheric CO_2 on soil structure is not very well understood yet and enhanced atmospheric CO_2 may result in the increase in photosynthesis and ensuing increase in photosynthate, roots and microbial communities and hence increased amount of SOC in certain species dominated forests such as *S. robusta*.

Other factors such as slope, grazing pressure, certain climatic factors such as humidity, precipitation aspect and temperature may accelerate the influence of altitude on carbon stocking in the species. One of the limiting factors might be that the upper altitude range selected for this study falls under the fire prone area of the Duggada forest range under state forest dept. The estimates acquired in the study suggest that natural population of Sal at lower elevations has the potential to store a large amount of CO_2 than the population found at upper elevations in the region. Overall, though altitude as alone, impacts negatively on carbon stocking potential of this species, the study suggest that other parameters such as stand structure, choice of management practices, slopes, vegetation dynamics, succession stages of the forest community, biological factors such as anthropogenic disturbance, management regime, grazing pressure, environmental factors such as temperature, precipitation and seasonal Indices etc. should also be considered while estimating the carbon stocking potential of tree species.

CONCLUSION

The findings confirmed that the elevation gradient factor significantly influences the rate of carbon sequestration in the natural population of *S. robusta* present at transition zone. The population from lower elevation showed potential to store a large amount of CO_2. Low carbon stocking in trees present at higher side was probably due to certain limiting factors such as successional stages, stand structure, fire, and anthropogenic influence at higher side. Increased SOC content with altitude might be an outcome of decreasing temperature and less microbial activity in the forest soil present in the higher elevation. Overall, the variations in carbon stocking is attributed to altitudinal characteristics in transitional zones. Hence, periodic inclusive research with multidimensional evaluation of local factors is recommended considering each critical factor while determining carbon stock quantities of tree species in transition zones such as Bhabhar in Shivalik Himalaya.

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Variation in Fruit and Seed Morphology of *Pyrus pashia* (Buch-Ham ex D. Don) in Alaknanda Valley of Garhwal Himalaya, India

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Abstract: The study was conducted on fruit and seed morphology of *Pyrus pashia* populations. Seven characters (fruit length, width, thickness, seed length, width, thickness and seed number) were measured from 450 trees in 15 different locations at altitude ranging from 650 to 2190 metres. The altitudes were grouped as follows: the first group (650 m, 1790 m), third group (1260 m, 1460 m, 2100 m), and the second cluster containing the remaining altitude locations. The coefficient of variation confirmed significant difference of morphological characters. The correlation between morphological characteristics of fruits and seeds and geographic features showed a negative and weak correlation with altitude and latitude. Furthermore, altitude negatively correlates with fruit length, seed number and seed length morphological traits but positively with others, emphasizing the need to consider specific parameters when selecting germplasm collection sites. Among different locations, altitude of 1220 meter showed that the seed and fruit characteristics confirm it as the best germplasm collection site.

Keywords: *Pyrus pashia,* Himalaya, Fruits, Seeds, Morphology, Populations

Understanding the morphology of fruits and seeds is fundamental in identifying the Indian wild pear *P. pashia* (Buch-Ham ex D. Don), a highly valued deciduous tree species (Arya et al 2011). This significant intermediate species between the oriental and occidental groups of pears has played a crucial role in forming the *Pyrus* genus. The round, brown fruits are edible and have high nutritional and ethnomedicinal value. Depending on the topographic and climatic conditions, the fruit's colour changes from willow green to brown with light spots in the middle stage and eventually turns black when ripe (Prakash et al 2021a). Each fruit contains around five seeds, which are black in colour, tiny, light, and pyriform in shape. A mature tree may produce up to 45 kg of fruit per year, with a taste ranging from rigorous to sweet and gritty. Approximately 50 seeds are available per gram (Prakash et al 2021b). The oval, hairless and shiny leaves are accompanied by clusters of white flowers, adding to its aesthetic appeal. *Pyrus* species face threats worldwide that have caused the loss of 85% of numerous pear varieties in 19th century or even today (Sindelar 2002). Considering the variations in fruit and seed traits is difficult for determining the best geographic source of seeds (Mkwezalamba et al 2015). This study aimed to evaluate altitudinal variation in fruit and seed morphology of *Pyrus pashia* in Alaknanda valley of Garhwal Himalaya, India.

MATERIAL AND METHODS

Sampling location: The study was conducted during October to December 2020 and 2021 in the Alaknanda Valley, covering an area of approximately 1400 km^2 in the Garhwal Himalayan region, India. Based on the altitudinal gradient, fifteen different locations (L1 to L15) ranged from 650 to 2190 m were randomly selected, all of which had wild populations (Table 1). Samples were collected from 30 randomly selected trees in each location, making a total of 450 trees.

The 5 kg of fully ripened fruits was collected from October to December 2020-21. Two to three branches per tree were harvested at mid-height to reduce individual variation and after the initial fruit screening, 100 ripened and undamaged fresh fruits were measured. After de-pulping, the seeds were extracted from the fruits and sun-dried for further tests. The comprehensive data on seven parameters, fruit length, width, and thickness, seed length, width, thickness, and number of seeds/fruits, were recorded.

Statistical analysis: The statistical was done using R.4.1.1 (Cluster analysis) and SPSS 4.9 (Correlation matrix). The Minitab-18 statistical software was used for one way analysis.

RESULTS AND DISCUSSION

Morphological characteristics of fruits of *P. pashia*: There was high degree of variation in its phenotypic characteristics. The fruit length varied among locations, ranged from 16.29 mm for L6 to 24.93 mm for L2 (1220 m). Similarly, the mean fruit width varied from 25.97 mm for L2 to 17.86 mm for L6 (1420 m). However, the fruit thickness ranged from 26.01 mm for L8 (1465 m) to 17.94 mm for L6.

The length and width of the fruit were lower at both higher elevations (2190 m) and the lowest elevation (650 m). The L2 (1220 m) has shown superior fruit size of 24.93 mm and maintained its superiority over other locations. L3 (1260 m) consistently underperformed in all traits of *P. pashia* fruit. Kishore et al (2017) also observed the smallest fruit size of *P. pashia* at 1350 m. The shape of the fruit (Round, oblong and pyriform) varied, with the maximum fruit length (24.93 mm) and fruit width (25.97 mm) at an elevation of 1220 m. These findings suggest that the population from this area can be utilized for genetic and tree breeding programs (Table 2). Lone et al (2000) observed significant variation in fruit traits in temperate fruits. These findings suggest that the quantity of *P. pashia* fruit seeds tend to decrease with altitude. Shankar et al (2012) also observed considerable variation in the morphological traits of fruits and seeds of *P. nepaulensis* among different locations. The lowest diameter in the fruit at the middle altitude of 1420 m might be due to the fruit's

Table 1. Geographical coordinates of study sites in Alaknanda valley, Garhwal Himalaya

Location code	Name	Altitude (m)	Latitude	Longitude
L1	Luneta	650	30°12'32.39" N	78°40' 35.04" E
L2	Kund	1220	30°30'20.11" N	79°05' 29.87" E
L3	Silyara	1260	30°27'14.01" N	78°38' 56.62" E
L4	Kuhed	1300	30°22'35.51" N	79°19' 37.98" E
L5	Gadora	1400	30°24'56.35" N	79°25' 50.34" E
L6	Kauliyadhar	1420	30°17'37.18" N	78°50' 22.17" E
L7	Kandikhal	1460	30°20'41.71" N	78°37' 50.67" E
L8	Barsori	1465	30°09'26.68" N	78°48' 31.57" E
L9	Chunikhal	1630	30°18'10.75" N	78°48' 43.70" E
L10	Agroda	1700	30°07'08.46" N	78°47' 49.84" E
L11	Chandrabadni	1780	30°18'20.90" N	78°37' 38.93" E
L12	Gopeshwar	1790	30°25'12.53" N	79°19' 16.41" E
L13	Tapowan	1970	30°30'02.40" N	79°37' 31.34" E
L14	Nauti	2100	30°12'43.59" N	79°12' 26.96" E
L15	Tala	2190	30°30'32.69" N	79°10' 14.24" E

Table 2. Variation in morphological characteristics (Length, width and thickness) of fruits of *Pyrus pashia* (Mean ± SD)

Location code	Altitude (m)	Fruit length (mm)	Fruit width (mm)	Fruit thickness (mm)
L1	650	17.94±0.48	18.75±0.53	18.70±0.59
L2	1220	24.93±0.79	25.97±0.78	25.76±0.69
L3	1260	17.81±0.50	19.01±0.49	19.19±0.50
L4	1300	20.89±0.05	23.86±0.39	23.83±0.34
L5	1400	22.62±0.37	19.82±0.34	19.53±0.43
L6	1420	16.29±0.78	17.86±0.70	17.94±0.72
L7	1460	19.39±0.21	20.07±0.29	21.95±0.00
L8	1465	20.70±0.02	24.12±0.44	26.01±0.74
L9	1630	20.89±0.05	23.41±0.31	23.42±0.27
L10	1700	20.19±0.07	21.94±0.04	21.95±0.00
L11	1780	20.07±0.09	21.46±0.04	21.42±0.09
L12	1790	22.06±0.26	20.83±0.15	20.64±0.23
L13	1970	22.10±0.27	22.07±0.06	22.10±0.03
L14	2100	21.90±0.24	23.87±0.39	23.68±0.31
L15	2190	21.07±0.08	22.43±0.13	22.84±0.16
F		56.43**	63.45**	62.78**

Statistically significant difference, **=P<0.05

maturity. Altitude and other local factors cause a net decline in the variation between day and night temperatures, thus modifying the characteristics of inland growing areas. However, it is suggested that altitude alone is not the only factor affecting these variations.

Morphological characteristics of seeds of *P. pashia*: The variation in the seed size and number can affect a species reproductive ability. In wild fruits, the mean seed length ranged from 1260 m to 1630 m. The maximum seed width was in L11 (1780 m- 3.83 mm), while the minimum seed width was in L9 (1630 m- 2.92 mm), followed by L1 and L14.The average number of seeds/fruits differed from 5.97 for L2 (1220 m) to 4.76 for L3 (1260 m). This confirmed a significant change in altitude-wise seed morphology in terms of mean seed width and thickness (Table 3). The increasing trend in the morphological values of seeds up to the middle elevation (1420 m) was observed except for 1220 m. This variation in seed morphology may also be due resources, which change from season to season. The observed variations in seed characteristics of wild pear accessions could also be due to hybridization, sexual reproduction, bud mutation, and diverse agroecological conditions. Similar observations were observed wild, primitive varieties and landraces of other temperate fruits (Zafar et al 2004).

Correlation between the morphological features of *P. Pashia* to geographical distribution: The size of the fruit and seed mass of *P. pashia* increased as longitude increased which differed from Baker's rule. The sample locations show a strong correlation between altitude and longitude, which suggesting that the fruit of *P. pashia* has evolved to adapt to different latitudes and longitudes. Fruit length showed positive linear regression coefficient associated with fruit width, thickness and number of seeds/fruits. Fruit length displayed a weak correlation with the length, width and thickness of seeds. The width of the fruits was highly significant with fruit thickness and seed width the correlation between morphological characteristics of fruits and seeds and geographic characteristics showed a negative and weak correlation with altitude and latitude. Fruit thickness, however, significantly positively correlated with altitude and longitude and was negatively correlated with latitude. Number of seeds/fruits did not relate to seed length, width, and thickness but showed a significant correlation with longitude and latitude. There is no linear relationship, either increasing or decreasing, of selected morphological characters of fruits and seeds of *P. pashia* to its distribution along all gradients (Table 4). The differences in the physical characteristics of seeds and fruits may be due to natural limitations in their location. Environmental factors resulting from variations in latitude and altitude, including soil type, human activity, and wind patterns, along with different communities of dispersers separately and together might be responsible for the differences in fruit size in *P. Pashia* across or between species.

Table 3. Variation in morphological characteristics (Length, width, thickness and number of seeds/fruits) of seeds of *Pyrus pashia* (Mean ± SD)

Location code	Altitude (m)	Seed length (mm)	Seed width (mm)	Seed thickness (mm)	Number of seeds/fruits
L1	650	6.03±0.03	3.05±0.06	2.11±0.02	5.20±2.19
L2	1220	6.53±0.05	3.74±0.06	2.39±0.08	5.97±2.12
L3	1260	6.88±0.1	3.78±0.06	2.02±0.01	4.76±2.27
L4	1300	5.96±0.05	3.52±0.02	2.01±0.01	5.57±2.51
L5	1400	5.98±0.04	3.56±0.03	2.19±0.04	5.32±2.56
L6	1420	6.20±0.00	3.64±0.04	1.78±0.03	5.48±2.21
L7	1460	6.25±0.00	3.29±0.02	1.83±0.02	5.69±2.27
L8	1465	6.24±0.00	3.27±0.02	1.99±0.00	5.46±2.32
L9	1630	5.38±0.15	2.92±0.08	1.54±0.07	5.62±1.57
L10	1700	6.30±0.01	3.55±0.02	1.90±0.00	5.71±1.77
L11	1780	6.46±0.03	3.83±0.08	1.97±0.00	5.50±2.50
L12	1790	5.68±0.10	3.25±0.02	2.12±0.03	5.69±2.07
L13	1970	6.45±0.03	3.18±0.03	2.09±0.02	5.76±2.97
L14	2100	6.75±0.09	3.06±0.06	1.68±0.04	5.59±2.25
L15	2190	6.61±0.06	3.27±0.0	1.61±0.06	5.55±2.36
F		43.95*	30.32**	246.47**	219.99**

Statistically significant difference, *=P<0.01, **=P<0.05

Principal component analysis (PCA) and hierarchical cluster analysis between morphological traits and locations: The populations were classified into three main groups, with group 3 being the largest, consisting of 10 populations. The first three principal components (PC1, PC2, and PC3) explained 73.6% of the location changes. PC1's first component accounted for 37.91% of the total variation, followed by the second component which accounted for 19.52%. Through hierarchical cluster analysis, three primary groups of locations were identified based on their similarity. The first group consisted of L1 and L12 (650 m, 1790 m) and the third cluster comprised L3, L7, and L14 (1260 m, 1460 m, 2100 m) and the remaining 10 location formed the second cluster.

The lowest fruit length, weight, and thickness values were recorded at middle elevations around 1440-1600 meters. However, these findings partially contradict earlier observations that fruit size increases with elevation (Dinis et

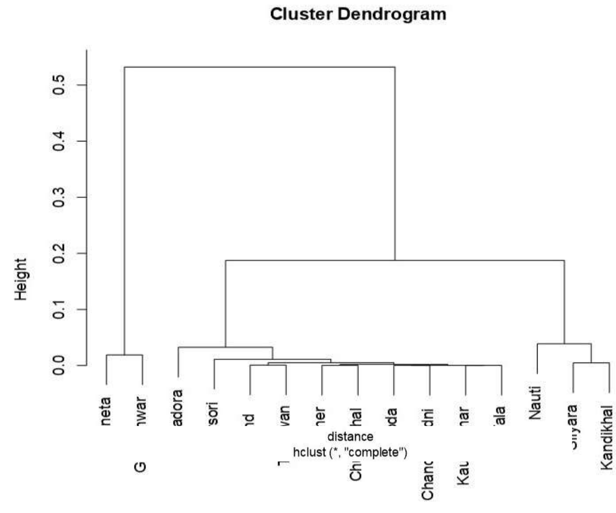

Fig. 2. Dendrogram (Hierarchical clustering) of 15 locations of *Pyrus pashia* based on fruits and seeds morphological characters

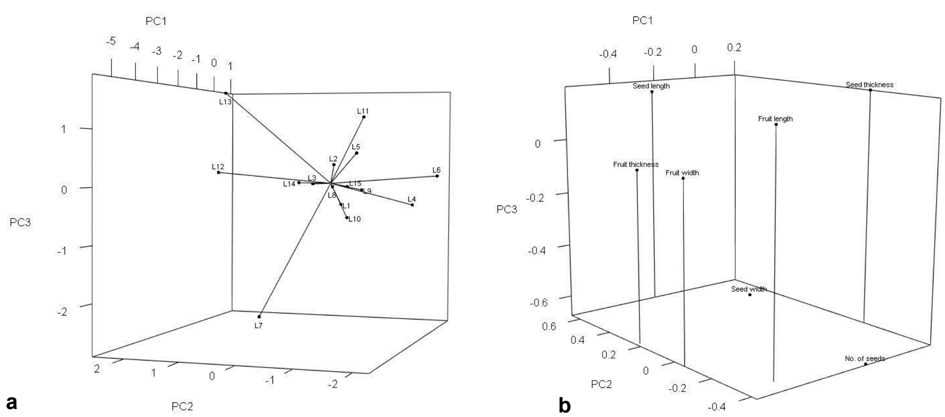

Fig. 1. Principal component analysis (PCA) of fruits and seed characteristics at different locations **(a)** and projection of morphological characters **(b)** on the space formed by the first three axes

Table 4. Pearson's correlation coefficient relationship between locations parameters concerning fruit and seed morphological traits of *Pyrus pashia*

Characters	1	2	3	4	5	6	7	8	9
Fruit length 1	1								
Fruit width 2	0.621**	1							
Fruit thickness 3	0.444*	0.521**	1						
Number of seeds/fruits 4	0.837**	0.317	0.151	1					
Seed length 5	0.134	0.207	0.315	0.205	1				
Seed width 6	0.165	0.403*	0.426*	0.232	0.028	1			
Seed thickness 7	0.041	0.079	0.683	0.304	0.149	-0.538	1		
Altitude 8	-0.328	0.373	0.725*	-0.726*	-0.261	0.628*	0.564	1	
Latitude 9	0.514	0.417	0.801**	0.768*	0.703*	-0.508	0.650	0.416	1
Longitude 10	-0.458	0.137	-0.780**	0.805*	0.695	0.255	-0.634	-0.380	-0.840*

Statistically significant difference, *=P<0.01, **=P<0.05

al 2011, Trad et al 2013, Silvanini et al 2014, Maro et al 2014). This can be ascribed to the different climatic and soil conditions at the three monitored altitudes. Contrasting results in previous studies could be due to differences in the altitude of the studied areas. The results demonstrate considerable morphological diversity in fruit and seed characteristics. This was evident from the PCA and hierarchical clustering trends. However, despite being geographically distant, populations belonging to the same group were morphologically similar (PCA and Cluster dendrogram). This highlights the importance of considering location and geographical origins when analysing such data. These findings indicate that location is crucial in determining the physical features of fruits and seeds. Brenes-Gamoba (2017) observed the need to consider the specific characteristics of each site, such as soil slope, acidity, organic matter content, and the impact of climatic factors, when comparing different altitudes. Furthermore, optimal environmental conditions are necessary to achieve the highest possible yields and qualities from fruit plantations, conditions that are linked to the genetic potential of the species (Perez and Melgarejo 2015).

CONCLUSIONS

The altitude of 1220 m exhibited the most considerable fruit length, width, and seed thickness, making the ideal location for collecting germplasm for propagation and germination to achieve the best fruit quality. Correlation coefficient, PCA, and hierarchical clustering analyses confirmed that fruit width, thickness, altitude, and number of seeds/fruits are crucial factors in determining the optimal altitude for germplasm collection, especially when fruit quality is the primary consideration. The study found a negative and weak correlation between the morphological characteristics of fruits and seeds and geographic features (latitude and longitude). Despite the altitude, seed morphology varied widely and irregularly, indicating that specific morphological parameters should be considered when selecting suitable germplasm of *P. pashia* from different location.

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Wood-rotting Macrofungi of Kikruma Community Forest, Phek, Nagaland

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Abstract: Survey and documentation of wood-rotting macrofungi of Kikruma community forest, Phek, Nagaland was carried out for period of three years from January 2015 to December 2017. The identified wood-rotting macrofungi are classified under two phyla, sixteen families, thirty one genera and forty three species. Thirty six wood-rotting macrofungi belonged to phylum Basidiomycota and the remaining seven to phylum Ascomycota. Polyporaceae was the most dominating Family with fourteen wood-rotting macrofungi, followed by Stereaceae and Xylariaceae with five wood-rotting macrofungi each. For seasonal variation, Pre monsoon (March to April), Monsoon (may to august), Retreating Monsoon (September to November) and Dry Season (December to January) were considered. Majority of the species were sampled during retreating monsoon season followed by monsoon and pre monsoon seasons respectively. Three species, *Auricularia polytricha*, *Lopharia cinerascens* and *Schizophyllum commune* were found growing in all the four seasons. The species dominance index, species evenness and Shannon's diversity index were calculated to be 0.064, 0.517 and 3.077 respectively.

Keywords: Basidiomycota, Diversity, Edible wood-rotting macrofungi, Polyporaceae, Seasonal variation

Wood-rotting fungi comprised of a largely unexplored group of magnanimous macrofungi. Their role and mechanisms involved in wood biodegradation is studied in detail however, the full potential of majority of the species still remain unexplored. They are the only known group of living organism actively involved in wood biodegradation. Singh et al (2016) reported the ability of bacteria to degrade wood however their ability to degrade wood is much slower as compared to basidiomycete wood biodegradation. Wood-rotting fungi degrade the complex components of the plant cell wall employing various complex enzymatic degradation and reactive oxygen species (Riley et al 2014, Castano et al 2018, Goodell 2020). White rot fungi have the ability degrade a number of persistent environmental pollutants such as chlorinated aromatic compounds, hetero-cyclic aromatic hydrocarbons, dyes and synthetic polymers (Bennett 1994). In addition to biodegradation of wood, this group of macrofungi play important roles in balancing ecological services, improving soil fertility, in bioremediation and also many species are known for their medicinal and nutritive properties. It has been reported that lignicellulose hydrolytic enzyme machinery of Basidiomycota members makes low cost bioremediation projects more attractive (Sanchez 2008). Wood-rotting macrofungi are reported to be the only group of organism able to decompose all woody components and thus, they play an important role in both carbon and nitrogen cycles by degrading non-living organic substrates (Pinar and Rodriguez-Conto 2024). The use of polypore fungi such as *Ganoderma lucidum*, *Phellinus linteus* and *Trametes versicolor* in the treatment a number of diseases including hypertension, prostate cancer, as cancer chemotherapy agents and their antibacterial, antifungal and antiviral effects have been studied by many researchers and reported positive results (Hsieh and Wu 2001, Silva 2003, Liang et al 2010).

Kikruma village is well-known for its rich cultural and patriotic history. It is located under Phek administrative district of Nagaland, Northeast India. Studies on wood-rotting macrofungi in northeast India is still at its dormant phase and majority of the region is still unexplored. The forest canopy of Kikruma community forest is neither open nor dense but it is of moderate type. The present study provides a preliminary documentation of wood-rotting macrofungi from Kikruma village, Phek, Nagaland.

MATERIAL AND METHODS

Survey and documentation of wood-rotting macrofungi of Kikruma Community forest, Phek district, Nagaland was carried out for period of three years from January 2015 to December 2017 on seasonal basis. The village is located at an altitudinal range of 1,581 to 1,650 meters above sea level (masl) with the geographical coordinates 2537.38' N and 094º 13.71'E. The village is surrounded by broad-leave deciduous forest with a vegetation hugely dominated by

Quercus serrata distributed all along the altitudinal gradient interfered with few patches of *Pinus wallichiana* and *Prunus cerasoides.* Based on the prevailing seasons, samplings were conducted during Pre monsoon (March to April), Monsoon (May to August), Retreating Monsoon (September to November) and Dry Seasons (December to January). Depending on the slope of the areas, both transect (50x5m) and quadrat methods (50x50m) were used for sampling wood-rotting fungi following the protocol recommended by Mueller et al (2004). The transects and quadrats were laid randomly. The collected basidiocarps were bought to the laboratory and dried under light to moderate sunlight condition. The dried basidiocarps were then kept in clean and labelled polythene bags with naphthalene balls wrapped in cotton. For microscopic studies, 4% KOH, lactophenol cotton blue and Melzer's reagent were used for staining, observation and identification. Identification was done through comparative consultations from the available monograph and literatures (Bakshi 1971, Ryvarden and Johansen 1980, Gilbertson and Ryvarden 1987, Nunez and Ryvarden 2000, 2001, fungifromindia.com, mycobank.org and indexfungorum.org). Diversity indices such as Dominance index (D), Evenness (eˆH/S) and Shannon's diversity index (H') were used for calculating the diversity of wood-rotting fungi using PAST 1.93 software. All the identified wood-rotting fungi were deposited in Department of Botany, North-Eastern Hill University (NEHU), Shillong Campus, Meghalaya.

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RESULTS AND DISCUSSION

Forty three wood-rotting macrofungi were collected and identified. The identified wood-rotting macrofungi are classified under two phyla (Basidiomycota and Ascomycota) with a total of sixteen families, thirty one genera and forty three species. The phylum Basidiomycota comprised of fourteen families, twenty eight genera and thirty six wood-rotting macrofungi whereas, the phylum Ascomycota comprised of two families, three genera and seven species (Table 1). Polyporaceae was the most dominating Family with fourteen wood-rotting macrofungi, followed by Stereaceae and Xylariaceae with five wood-rotting macrofungi each (Fig. 1). Majority of the species were sampled during retreating monsoon season followed by monsoon and pre monsoon seasons respectively. Thirty six wood-rotting fungi were found growing during retreating monsoon, thirty two during monsoon, seventeen during pre-monsoon and only three during dry season.

Three species, *Auricularia polytricha*, *Lopharia cinerascens* and *Schizophyllum commune* were found growing in all the four seasons studied. Five species, *Auricularia auricula-judae*, *A. polytricha*, *Lentinussajor-caju*, *Pleurotus ostreatus, Schizophyllum commune* and one species belonging to the genus *Ramaria* are reportedly consumed by the localities of the village as edible macrofungi. The remaining wood-rotting fungal species are identified as non-edible. The species dominance index, species evenness and Shannon's diversity index were calculated to be 0.0638, 0.5165 and 3.077 respectively. Few selected photographs of wood-rotting macrofungi sampled from Kikruma community forest (reproduced from Chuzho 2021), are shown in Figure 2.

Study of wood-rotting macrofungi was for the first time documented from Kikruma village, Phek, Nagaland through the present study however, studies on wood-rotting macrofungi, particularly, members of Basidiomycota is well documented in India by many workers (Leelavathy and Ganesh 2000, Forutan and Jafary 2007, Swapna et al 2008, Ranadive et al 2011, Ranadive 2013, Lyngdoh 2014, Adarsh et al 2018, Vabeikhokhie et al 2019a,b, Ao and Deb 2019, Chuzho 2021, Chungreiliu 2023). The family Polyporaceae is the most dominant taxon at level as compared to the other families recorded in the present study. The dominance Polyporaceae members have also been reported by many researchers (Sharma 2007, Prasher and Ashok 2013, Tapwal et al 2013, Lyngdoh 2014, Chuzho 2021, Chungreiliu 2023). Most of the polyporaceae members are characterized by having rigid and corky basidiocarps and the rigidity of the basidiocarps have attributed to their persistence thereby increasing their chances of being frequently encountered unlike other ephemeral wood-rotting macrofungi with soft basidiocarps which persist only for one to few days. Lyngdoh and Dkhar (2018) study on the decay potential of four wood-rotting fungi on *Batula alnoides* and *Quercus dealbata* wood-blocks showed that polypore species have higher degradation ability as compared to non-polypore species. The ability of polypores to degrade lignin more effectively might have helped them to be better opportunist on wood degradation and thereby increasing their chance to colonize woody debris more effectively.

Occurrence of wood-rotting fungi varied with different seasons. Majority of wood-rotting fungi were recorded during retreating monsoon season followed by monsoon season, pre monsoon and dry season. Baptista et al (2010) also showed a bimodal pattern in fruiting phenology. They observed that basidiocarp formation occurred in two distinct seasons (retreating monsoon and pre-monsoon) with the higher number of species collected during retreating monsoon than during pre-monsoon. The present result showed that maximum wood-rotting fungi occurred during retreating monsoon followed by monsoon which slightly

Table 1. Wood-rotting fungi, their families and distribution at different seasons

Family	Specimen name	Season*			
		1	2	3	4
Phylum Ascomycota					
Hypoxylaceae	*Daldinia concentrica* (Bolton) Ces. & De Not.	+	+	+	-
	U1 01 Pul - Hypoxylaceae	+	-	-	-
Xylariaceae	*Kretzschmaria deusta* (Hoffm.) P. M. D. Martin	-	+	+	-
	Xylaria grammica (Mont.) Mont.	-	+	+	-
	X. hypoxylon (L.) Grev.	+	+	+	-
	X. longipes Nitschke	+	+	+	-
	X. polymorpha (Pers.) Grev.	+	+	+	-
Phylum Basidiomycota					
Agaricaceae	*Cyathus striatus* (Huds.) Willd.	+	+	-	-
Auriculariaceae	*Auricularia auricula-judae* (Bull.) J. Schrot.	-	+	+	-
	A. delicata (Mont.) Henn.	+	+	+	-
	A. polytricha (Mont.) Sacc.	+	+	+	+
Dacrymycetaceae	*Dacryopinax spathularia* (Schwein.) G.W. Martin	-	+	+	-
Fomitopsidaceae	*Daedalea quercina* (L.) Pers.	-	-	+	-
	Fomitopsis pinicola (Sw.) P. Karst.	+	+	+	-
Ganodermataceae	*Ganoderma lucidum* (Curtis) P. Karst.	-	+	+	-
Gloeophyllaceae	*Gloeophyllum sepiarium* (Wulfen) P. Karst.	-	+	-	-
Gomphaceae	*Ramaria* sp.	-	+	-	-
Hymenochaetaceae	*Hymenochaete tabacina* (Sowerby) S.H. He & Jiao Yang	-	-	+	-
	Phellinus gilvus (Schwein.) Pat.	-	+	+	-
	Phellinus sp.	-	-	+	-
Phanerocahetaceae	*Bjerkandera adusta* (Willd.) P. Karst	+	+	+	-
Pleurotaceae	*Pleurotus ostreatus* (Jacq.) P. Kumm.	-	+	+	-
Polyporaceae	*Coriolopsis polyzona* (Pers.) Ryv.	-	-	+	-
	Heterobasidion insulare (Murrill) Ryv.	-	+	-	-
	Hexagonia tenuis (Hook.) Fr.	-	+	+	-
	Lentinus sajor-caju (Fr.) Fr.	-	-	+	-
	Lopharia cinerascens (Schwein.) G. Cunn.	+	+	+	+
	Microporus xanthopus (Fr.) Kuntze	+	+	+	-
	Nigrofomes melanoporus (Mont.) Murrill	-	+	-	-
	N.vinosus (Berk.) Murrill	+	+	+	-
	Pycnoporus cinnabarinus (Jacq.) P. Karst.	-	-	+	-
	P. sanguineus (L.) Murrill	-	-	+	-
	Rigidoporus microporus (Sw.) Overeem	-	-	+	-
	Trametes hirsuta (Wulfen) Pil.	+	+	+	-
	T. versicolor (L.) Lloyd	+	+	+	-
	Trichaptum abietinum (Pers. ex. J.F. Gmel.) Ryv.	-	+	+	-
Psathyrellaceae	*Coprinellus micaseus* (Bull.) Fr.	+	+	+	-
Schizophyllaceae	*Schizophyllum commune* Fr.	+	+	+	+
Stereaceae	*Aleurodiscus ahmadii* (Biodin) Biodin	+	+	-	-
	Stereum complicatum (Fr.) Fr.	-	+	+	-
	S. gausapatum (Fr.) Fr.	-	-	+	-
	S. hirsutum (Willd.) Pers.	-	+	+	-
	S. ostrea (Blume& T. Nees)	-	-	+	-

*1 – Pre monsoon (March to April); 2 – Monsoon (May to August); 3 – Retreating Monsoon (September to November); 4 – Dry Season (December to January) differs from the observation made by Baptista et al (2010), however, in both cases, maximum number of wood-rotting macrofungi occurred during retreating monsoon. Ho et al (2002), Pouska et al. (2010) and Adarsh et al. (2015) also reported the maximum occurrence of basidiocarps of agarics and polypores during August to October which supports the present finding. Basidiocarp formation of wood-rotting fungi required high level of water supply and seasonal drought can limit fruiting of wood-rotting fungi to a great extent (Olou et al 2019). Three wood-rotting fungi viz., *A. polytricha*, *L. cinerascens* and *S. commune* were sampled from all the four seasons studied. This finding indicated that these species have wide range of seasonal adaptation. Nagadesi and Arya (2014a) and Lyngdoh (2014) also reported the wide range of seasonal adaptation of certain wood-rotting fungal species including *S. commune*. Apart from seasonal variations and precipitation, occurrence of wood-rotting macrofungi depends on other environmental factors such as altitude, type of forest vegetation, presence of host tree species and other micro- and macro-environmental factors (Chuzho and Dkhar 2019a,b). The lower number of wood-rotting macrofungi sampled in three years survey may be because Kikruma village is dominated by *Q. serrata* and thus it mostly harbours those species that grow on *Q. serrata*. Northeast India is a major storehouse for biodiversity. The exploring into wood-rotting macrofungal communities from Nagaland and other North-eastern states of India, the actual figure macrofungal bioresources of Northeast India is expected to increase drastically.

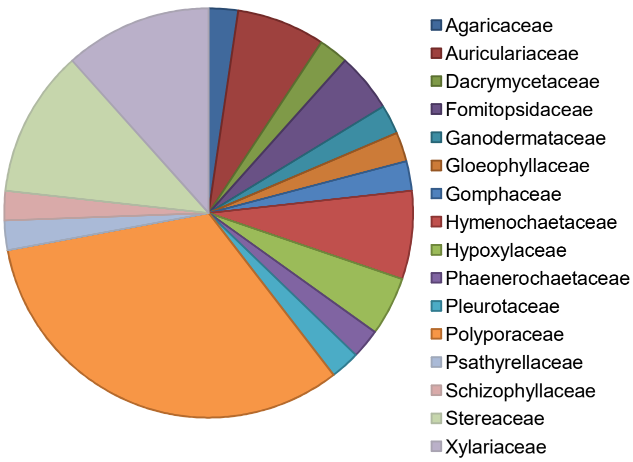

Fig. 1. Wood-rotting fungi belonging to different families

Fig. 2. Selected photographs of wood-rotting macrofungi sampled from Kikruma community forest (Photographs reproduced from Chuzho 2021)

CONCLUSION

The present study provided a preliminary documentation of wood-rotting macrofungi from Kikruma village, Phek, Nagaland. Forty three wood-rotting macrofungi, classified under two phyla, sixteen families, thirty one genera were collected and identified from the present study. Majority of the species were sampled during retreating monsoon season followed by monsoon and pre monsoon seasons respectively. The Shannon's diversity index with a value of 3.077 showed that Kikruma community forest harboured high wood-rotting macrofungal diversity.

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Genetic Analysis of Morpho-Physiological Traits in Relation to Heat Tolerance in Barley (*Hordeum vulgare* L.)

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***Abstract*:** The subject of the current study was to assess heat susceptibility index with the aim to identify the heat tolerant genotypes, in addition to recognize the selection criterion for heat tolerance. Forty four barley genotypes were tested in two environments as created by different sowing dates *i.e.* timely sown (non-stress) and late sown (heat stress) during 2021-22 at CCS Haryana Agricultural University, Hisar. The genotypes namely BH 1018, IBON-HI-2021-52, BH 1036, DWRUB 64, 7th GSBON-2020-101, IBON-HI-2021-102, IBON-HI-2021-85 and DWRB 123 were identified heat tolerant based on heat susceptibility index of grain yield. Further, results based on average of ranks of HSI of all traits illustrated the genotypes, BH1018,IBON-HI-2021-102, IBON-HI-2021-52, DWRB 209 and IBON-HI-2020-55 with high heat tolerance under stress condition. Correlation among HSI of different traits indicated significant positive association of grain yield per plant with days to heading and maturity, spike length, number of grains per spike, biological yield per plant, harvest index and NDVI 2, exhibiting the relevance of these traits for deciding the selection criterion for stress condition. The genotypes of cluster III portrayed better performance under stress condition for grain yield and other traits studied. The genotypes from this group could be utilized as promising breeding material intended to develop new heat tolerant barley varieties.

Keywords: Barley, Heat stress, HSI, Tolerance

Barley (*Hordeum vulgare* L.) is a true diploid (2n=14) species that belongs to the genus *Hordeum* of family *Poaceae* and tribe *Triticeae*. Since ancient times, barley has been used in diverse ways as human food, livestock feed and in malt production (Kumar et al 2020) and is a hardy and versatile crop that allows its cultivated in a variety of agro-climatic zones. It is one of the globally accepted cereal crops due to its low input requirements and cost effective cultivation. Abiotic stresses remain one of the major yield reducing factors of various crop plants. Among them, high temperature, drought and salinity *etc*. are some of the factors causing undesirable effects on commercial cultivation of crops (Kumar et al 2022). Heat stress is emerging as a great threat influencing growth and development of most crop plants due to climatic disturbances as a result of global warming. The influence of high temperature on crops depends on the intensity and duration of heat, rate of temperature rise, and developmental stage of plants (Wahid et al2007). Increase in temperature particularly at post anthesis stages shorten the grain filling period and also reduces individual grain weight (Dias and Lidon 2009, Kaur and Behl 2010). Furthermore, crop yield can be affected by high temperatures by inducing pollen sterility as well as causes seed abortion during the reproductive growth stage (Barnabas et al 2008). There is challenge for crop researchers and need of hours to develop heat tolerant high yielding barley cultivars with good malt content for heat stress conditions. The most favorable temperature in barley for grain filling is 20°C in sub-tropical regions (Dwivedi et al 2017). It was,however, also reported that during grain filling even an increase of 1° C temperature from the optimum range causes adverse effects on grain yield (Narayanan 2018).

Under heat stress among the physiological processes, photosynthesis is the most sensitive mechanism (Wang et al 2015). The decline in the performance of genotypes under stress for various attributes could be due to inhibition of photosynthesis, as reflected by the loss of leaf chlorophyll content. The physiological responses of tolerance to abiotic stresses need to be studied in details at the genetic level before they can be exploited in the introgressive breeding. Reduction in crop productivity as a consequence of heat stress during the reproductive stage has also been reported in barley (Klink et al 2014). Vaezi et al (2010) observed grain yield loss by 39.59 and 31.39%, respectively in two-and six-row barley genotypes owing to reduction in number of spikes per square meter, grain number per spike and 1000-grain weight due to delayed sowing. In addition, average grain yield reduction in barley genotypes by 17% was also stated by Modhej et al (2015), when the crop was exposed to heat stress after anthesis. The development of stable barley genotypes with higher economic yield under different environments is a need of breeding program intended to stress tolerance. The investigationof new sources of genetic variability and their utilization is an essential task that breeders would like to achieve for incorporation of heat tolerance in the varietal development process (Verma et al 2021).The crop production will be seriously challenged as a result of rise in temperature by 2.0-4.5 °C till the end of the century (Liu et al 2017), as reported by the Intergovernmental Panel on Climate Change (IPCC). Hence, effective exploitation of heat tolerant genetic resources in breeding programmes is imperative in context to genetic erosion and climate change scenarios (Bahrami et al 2019).Therefore, to cope up with the alarming threat of high temperature stress, detailed understanding of physiological responses and mechanisms of plants to heat tolerance and their further possible strategies for improving crop thermo tolerance is vital (Devi et al 2021). The heat susceptibility index may be used as a measure of heat tolerance in order to display yield stability under heat stress (Kavita et al 2016). Consequently, fourty four genotypes of barley including six and two-row types were evaluated for heat tolerance using HSI based on grain yield of stress and non-stress environments.

MATERIAL AND METHODS

The field trial was conducted during 2021-22 crop season at CCS Haryana Agricultural University, Hisar which is situated in subtropical region of North Western Plain Zone of India at latitude of 29°10′N, longitude of 75°46′E and altitude of 215.2 m above sea level. The experimental material consisted of 44 barley genotypes representing both 2-row (23) and 6-row (21) types including four check varieties, DWRB 123 and BH 946 (Timely sown); and DWRB 91 and DWRUB 64 (Late sown genotypes) in randomized block design replicated thrice. Each genotype was planted in paired rows of 2.5 m length spaced at 23 cm apart. The experimental material was grown under timely (non-stress) and late sown (heat stress) conditions on 20th November and 20th December, 2021, respectively. The package of practices recommended for both environments in terms of inputs were accordingly applied to raise the crop.

Twelve morphological traits *viz*., days to heading, days to maturity, grain filling duration, number of effective tillers per plant, plant height (cm), peduncle length (cm), spike length (cm), number of grains per spike, 1000-grain weight (g), biological yield per plant (g), grain yield per plant (g), and harvest index (%) alongwith physiological parameters namely canopy temperature depression at anthesis (CTD 1) and 15 days after anthesis (CTD 2), normalized difference vegetation index at anthesis (NDVI 1) and 15 days after anthesis (NDVI 2), and SPAD chlorophyll content at anthesis (SPAD 1) and 15 days after anthesis (SPAD 2) were studied under both stress and non-stressed environments.

Heat susceptibility index (HSI) based on grain yield and all other traits were calculated using the formula as suggested by Fischer and Maurer (1978). HSI = [1-YD/YP]/D Where, YP = Mean of genotypes under timely sown, YD = Mean of genotypes under stress and D = 1-[Mean YD of all genotypes/Mean YP of all genotypes].The recorded data was subjected to statistical analysis using Microsoft Excel for calculation of HSI. R studio version 2023.12.1.402 was used for correlation coefficients and cluster analysis.

The weather parameters for 2021-22 crop season were obtained from the Agricultural Meteorology Department, CCS HAU, Hisar and are presented in Figure 1. During crop season, highest values for maximum (41.1°C) and minimum temperature (21.2°C) were recorded in standard week 15th and 16th (2022), respectively. The data disclosed that the average minimum and maximum temperature for post heading phase of the crop under timely sown condition was 11.37 and 28.50°C, whereas, under late sown condition, it was 14.64 and 34.32°C, respectively (Fig. 2). An average increase of 3.26°C and 5.82°C were observed for minimum and maximum temperature under stress as compared to non stress conditionduring post heading, denoting the appearanceof significant heat stress under the late sown condition.

RESULTS AND DISCUSSION

The estimates of HSI for grain yield revealed that the genotypes, BH 1018 followed by IBON-HI-2021-52, BH 1036 and DWRUB 64 exhibited minimum values of HSI, revealing the genotypes with low heat susceptibility and high yield stability under heat stress condition (Table 1). In contrast, IBON-HI-2020-155 followed by 7th GSBYT-2020-20 and BH 1029 recorded maximum HSI for grain yield and were identified as highly heat susceptible genotypes. HSI of various traits in barley were also used by Ram and Shekhawat (2017) for selection and utilization of heat tolerant genotypes in future breeding programme. For biological yield per plant, minimum HSI was shown by 7th GSBON-2020-101 followed by IBON-HI-2021-85, BH 1027 and BH 1026. Similarly, minimum HSI for harvest index was recorded for genotype BH 1018 followed by IBON-HI-2020-6, IBYT-HI-2021-17, IBON-HI-2021-81 and BH 1036. All of these genotypes showed their superiority for tolerance to high temperature than other genotypes for concerned traits.The genotypes confirmed with negative values of HSI for trait under study signifies the better performing genotype under heat stress as compared to non-stress condition, is suitable for climate resilience (Thakur et al 2020).

Three genotypes namely IBON-HI-2021-52, BH 1034 and BH 946 showed their superiority for days to heading and maturity by exhibiting low estimates of HSI for these traits. Four genotypes were promising for grain filling duration *viz*., IBON-HI-2021-27, IBYT-HI-2021-3, DWRB 209 and 7th GSBON-2020-101. The HSI estimates for number of effective tillers per plant were minimum for BH 1038 followed by BH 946, DWRUB 64 and BH 1018. The heat tolerant genotypes with respect to plant height were IBON-HI-2021-81 followed by IBYT-HI-2020-6, BH 1038, IBYT-HI-2021-3 whereas, for peduncle length, IBYT-HI-2021-3 followed by BH 1018, IBYT-HI-2021-15 and BH 1027 showed tolerance to heat under stress condition. Spike length and number of grain per spike, important yield attributes for which DWRB 209, IBON-HI-2021-38 and IBON-HI-2020-55 showed low estimates of HSI. The genotype *i.e.* BH 1035 followed by BH 1026, IBYT-HI-2021-15 and IBON-HI-2021-33 exhibited minimum reduction in 1000-grain weight under heat stress among all evaluated genotypes. Bahrami et al (2020) selected heat tolerant genotypes employing selection indices based on grain yield in cultivated (*Hordeum vulgare ssp. vulgare* L.) and wild (*H. vulgaressp*. *spontaneum* L.) barley genotypes. All the physiological traits considered together and it was found that five genotypes *i.e.* BH 1025, IBON-HI-2021-102, DWRB 209, IBON-HI-2020-155 and DWRB 91 had low estimates of HSI simultaneously for four physiological characters, implies physiologically efficient entries under stress condition in context to heat tolerance.Various morpho-physiological traits were also used for heat tolerance screening by Sallam et al (2018) in barley.

All the genotypes including check varieties were first ranked on the basis of HSI of concerned studied trait and then based on average of ranks of HSI of all traits, the genotypes were further ranked, indicated as overall rank (Table 1). The genotypes *viz*., BH 1018, IBON-HI-2021-102, IBON-HI-2021-52, DWRB 209 and IBON-HI-2020-55 were the most tolerant to terminal heat stress among the experimental material evaluated. Due to detrimental effect of high temperature during reproductive phase, the genotypes performed differently under stress. Few genotypes could combat with the stress, while some of them were adversely affected (Fig. 3). The promising genotypes showing minimum reduction in grain yield were BH 1018 (2%) followed by IBON-HI-2021-52, BH 1036 and DWRUB 64. The reduction in grain yield, spike length, grains per spike and 1000-grain weight in

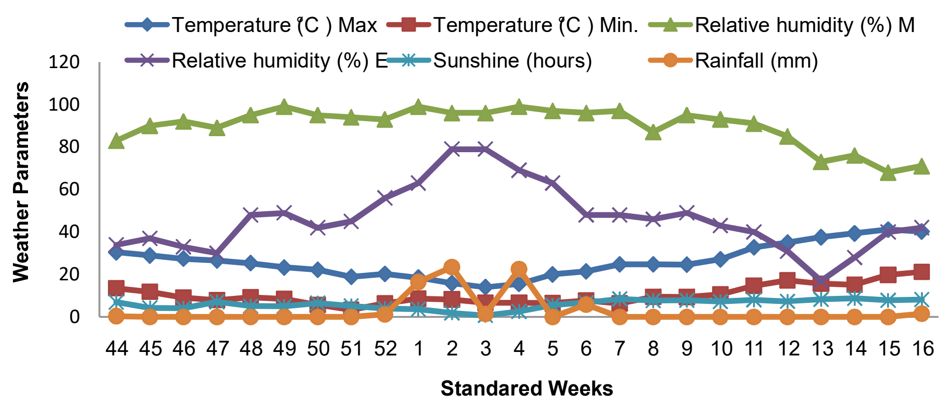


Fig. 1. Mean meteorological data during crop season 2021-2022

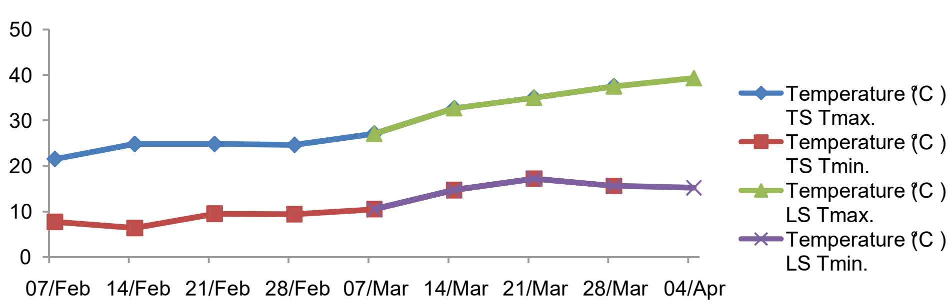


Fig. 2. Post heading maximum and minimum temperature under normal and late sown condition during 2021-22

Table 1. Heat susceptibility index (HSI) of barley genotypes for different traits

Genotypes	DH	DM	GFD	ETP	PH	PL	SL	GPS	TGW	BY	HI	GYP	SPAD1	SPAD2	NDVI1	NDVI2	CTD1	CTD2	R	OR
BH 1029	0.88	0.82	0.96	0.99	0.73	1.47	1.41	0.81	0.26	1.79	-0.15	1.71	0.22	0.64	0.36	0.44	3.74	3.49	42	44
BH 1034	0.53	0.69	1.22	0.66	0.80	1.67	0.90	0.24	0.10	0.84	-0.17	0.71	0.32	0.53	0.40	0.24	3.60	3.14	14	15
BH 1035	0.70	0.79	1.38	0.43	0.80	1.50	0.70	0.12	-0.18	1.17	-0.49	0.82	-0.34	0.35	0.05	0.48	3.72	3.44	20	20
BH 1036	0.63	0.72	1.12	0.40	1.02	2.17	0.67	0.58	0.14	1.15	-1.01	0.42	-0.32	0.07	0.27	0.25	3.72	3.48	3	10
BH 1038	0.68	0.73	1.14	-0.62	0.28	1.92	0.25	0.96	0.30	1.23	0.28	1.42	-0.11	0.41	0.16	0.34	3.64	3.29	34	13
BH 1039	0.74	0.76	1.05	0.54	0.63	1.93	-0.04	0.76	0.11	1.42	-0.66	0.98	-0.20	0.28	0.41	0.78	3.68	3.33	25	27
BH 1018	0.67	0.69	0.93	0.18	0.52	0.71	0.46	0.61	0.75	1.20	-1.57	0.09	-0.12	0.29	0.31	0.12	3.67	3.38	1	1
BH 1025	0.74	0.77	1.01	0.64	0.86	0.98	0.61	0.21	0.04	1.49	-0.87	0.94	0.21	0.06	0.31	0.19	3.48	2.63	23	6
BH 1026	0.74	0.74	0.94	1.01	0.63	1.46	0.95	0.39	-0.04	0.70	0.88	1.43	-0.50	0.59	0.20	0.61	3.56	2.89	35	16
BH 1027	0.77	0.77	1.06	0.78	0.36	0.83	0.80	0.50	0.05	0.65	0.08	0.72	0.62	0.16	0.21	0.44	3.65	3.22	16	14
IBYT -HI-2021-3	0.83	0.72	0.61	0.78	0.32	0.22	0.34	0.53	0.22	1.05	0.05	1.09	0.33	0.38	0.15	0.38	3.58	2.99	29	7
IBYT -HI-2021-9	0.62	0.78	1.55	0.66	0.95	1.59	0.43	0.17	0.50	1.70	-0.73	1.27	0.07	1.05	0.41	0.13	3.72	3.48	32	36
IBYT -HI-2021-15	0.82	0.84	1.03	0.34	0.83	0.78	0.46	0.84	0.00	1.67	-0.70	1.25	0.22	0.27	0.05	0.67	3.60	3.05	30	18
IBYT -HI-2021-17	0.85	0.87	1.21	0.90	0.95	1.38	0.97	0.86	0.96	2.08	-1.06	1.54	-0.02	0.19	0.05	0.58	3.68	3.34	38	40
IBYT -HI-2021-18	0.87	0.84	1.06	0.49	0.76	1.27	0.18	0.84	0.27	1.48	-0.72	1.02	0.09	0.34	0.27	0.50	3.73	3.52	27	35
IBON-HI-2021-27	0.87	0.75	0.53	0.23	0.55	1.47	0.79	0.30	0.54	1.94	-0.65	1.59	0.08	0.75	0.37	0.21	3.77	3.52	39	34
IBON-HI-2021-31	0.82	0.81	1.01	0.70	0.55	2.19	0.93	0.52	0.21	1.22	0.56	1.62	0.18	0.18	0.31	0.95	3.74	3.41	40	42
IBON-HI-2021-33	0.81	0.80	0.94	0.41	0.62	1.59	0.84	0.38	0.04	1.20	-0.69	0.71	0.11	0.04	0.27	0.57	3.73	3.48	14	21
IBON-HI-2021-38	0.70	0.78	1.22	0.43	0.69	1.19	0.17	0.24	1.19	1.17	-0.21	1.02	0.17	0.14	0.26	0.55	3.79	3.60	27	30
IBON-HI-2021-52	0.53	0.66	1.18	0.35	0.63	1.18	0.48	0.34	0.06	0.85	-0.79	0.23	0.06	0.17	0.26	0.47	3.75	3.51	2	3
IBON-HI-2021-56	0.74	0.81	1.31	0.68	0.64	1.09	0.94	0.48	1.19	1.36	-0.15	1.25	0.32	0.23	0.31	0.49	3.79	3.62	30	43
IBON-HI-2021-81	0.75	0.85	1.30	0.89	0.14	1.33	0.03	0.58	0.82	1.32	-1.02	0.63	0.33	0.53	0.37	0.14	3.63	3.16	12	25
IBON-HI-2021-85	0.51	0.71	1.40	0.86	0.77	1.72	0.59	0.18	1.20	0.38	0.17	0.53	0.32	0.85	0.26	0.36	3.57	3.07	7	24
IBON-HI-2021-99	0.62	0.73	1.28	0.41	1.07	1.58	1.61	0.47	0.80	1.25	-0.36	1.00	0.49	0.04	0.38	0.06	3.69	3.41	26	33
IBON-HI-2021-102	0.75	0.78	0.99	0.64	0.08	0.94	0.38	0.90	0.47	0.76	-0.31	0.51	-0.20	0.19	0.16	0.23	3.59	3.16	6	2
RD 3002	0.68	0.78	1.27	0.67	0.53	1.91	0.76	0.27	0.67	1.12	-0.69	0.61	-0.19	0.28	0.36	0.32	3.68	3.33	11	19
DWRB 197	0.63	0.75	1.41	0.38	0.51	1.12	1.01	1.03	1.12	1.16	-0.49	0.81	0.31	0.62	0.05	0.66	3.69	3.37	19	31
DWRB 209	0.70	0.64	0.63	0.52	0.87	1.72	0.11	0.03	0.62	0.73	0.05	0.77	0.08	0.16	0.26	0.12	3.65	3.32	18	4
BCLA 11-6	0.69	0.78	1.34	0.39	0.64	1.64	0.45	1.50	0.36	1.47	0.00	1.47	0.11	0.22	0.20	0.13	3.70	3.40	37	32
IBON-HI-2020-71	0.72	0.82	1.32	0.52	1.08	1.89	1.25	0.19	0.34	1.38	-0.78	0.86	0.59	0.15	0.32	0.68	3.76	3.53	21	41
7th GSBON-2020-90	0.66	0.75	1.22	0.21	1.03	1.47	0.84	1.18	1.23	1.46	-0.23	1.30	0.39	0.73	0.37	0.26	3.66	3.31	33	39
IBON-HI-2020-6	0.59	0.72	1.34	0.59	0.63	1.97	0.54	0.29	1.34	1.35	-1.13	0.58	0.51	0.62	0.27	0.39	3.69	3.33	9	28
IBON-HI-2020-51	0.67	0.65	0.83	0.59	0.59	2.09	0.62	0.30	0.43	1.05	-0.61	0.60	0.58	0.67	0.21	0.18	3.65	3.30	10	11
7th GSBON-2020-140	0.68	0.65	0.74	0.81	0.39	1.59	0.31	1.23	0.23	1.60	0.03	1.62	0.20	0.65	0.00	0.57	3.64	3.24	40	21
IBON-HI-2020-55	0.67	0.65	0.74	0.61	0.67	1.61	0.37	0.16	0.29	1.12	-0.61	0.67	0.07	0.67	0.21	0.06	3.70	3.40	13	5
7th GSBON-2020-101	0.72	0.67	0.68	0.33	0.41	2.19	0.57	0.65	0.80	-0.02	0.48	0.47	0.23	0.36	0.21	0.06	3.66	3.38	5	12
IBYT-HI-2020-6	0.73	0.72	0.92	0.24	0.28	0.86	0.36	0.91	0.33	0.89	0.05	0.93	0.21	0.17	0.36	0.42	3.67	3.32	22	9
7th GSBYT-2020-20	0.65	0.78	1.33	1.02	0.57	1.53	0.45	0.56	1.32	1.69	0.05	1.72	-0.07	0.39	0.05	0.70	3.69	3.33	43	37
IBYT-HI-2020-11	0.61	0.76	1.37	0.40	0.77	2.22	0.14	0.73	0.66	0.97	-0.27	0.76	0.17	0.26	-0.05	0.55	3.61	3.21	17	17
IBON-HI-2020-155	0.70	0.80	1.19	0.89	0.57	2.01	1.56	0.09	0.70	1.80	0.11	1.86	-0.08	0.59	0.10	0.64	3.64	3.20	44	38
DWRB 123 (c)	0.61	0.76	1.42	0.34	0.99	2.10	1.25	0.45	0.18	1.05	-0.64	0.56	0.19	0.23	-0.27	0.54	3.69	3.41	8	23
BH 946 (c)	0.56	0.67	1.27	-0.08	0.78	2.02	0.71	0.68	0.58	1.40	-0.63	0.97	0.00	0.65	0.16	0.22	3.71	3.48	24	26
DWRB 91 (c)	0.72	0.76	1.05	0.45	0.62	1.66	1.36	0.67	0.70	1.83	-0.72	1.43	-0.12	0.20	0.10	0.12	3.71	3.44	35	29
DWRUB 64 (c)	0.52	0.74	1.35	0.04	0.39	1.07	0.68	0.23	0.50	0.85	-0.52	0.43	0.06	0.34	0.26	0.30	3.76	3.57	4	8

DH: Days to heading, **DM**: Days to maturity, **GFD**: Grain filling duration, **ETP**: Number of effective tillers per plant, **PH**: Plant height, **PL**: Peduncle length, **SL**: Spike length, **GPS**: Number of grains per spike, **TGW**: 1000-grain weight, **BY**: Biological yield per plant, **HI**: Harvest index, **GYP**: Grain yield per plant, **SPAD 1**: Chlorophyll content (SPAD) at anthesis, **SPAD 2**: Chlorophyll content (SPAD) at 15days after anthesis, **NDVI 1**: Normalized difference vegetation index at anthesis, **NDVI 2**: Normalized difference vegetation index at 15 days after anthesis, **CTD 1**: Canopy temperature depression at anthesis, **CTD 2**:Canopytemperaturedepressionat15days after anthesis, **R**: Rank based on grain yield; **OR**: Overall rank based on average ranks of HSI of all traits barley also cited by Pathak et al (2017) under stress condition.

Grain yield per plant exhibited significant positive association with days to heading and maturity, spike length, number of grains per spike, biological yield per plant, harvest index and NDVI 2, exhibiting the relevance of these traits for deciding the selection criterion for stress conditions (Table 2). HSI based association study for heat tolerance was also conducted by Shehrawat et al (2020). Significant positive correlations were also observed for days to heading with days to heading, number of effective tillers per plant, and biological yield; days to maturity with grain filling duration, number of effective tillers per plant, biological yield and NDVI 2; grain filling duration with plant height and 1000-grain weight; plant height with peduncle length, spike length and biological yield; biological yield with CTD 2; CTD 1 with CTD 2.The positive association enhances the progress under selection and vice-versa. Similarly, significant negative correlation was existed for days to heading with grain filling duration and peduncle length; number of effective tillers per plant with CTD 2; plant height with harvest index; biological yield with harvest index; and NDVI 1 with NDVI 2. These results corroborates for one or more traits with the findings of Devi et al (2021).

The clustering pattern recognized cluster I as largest one with 13 genotypes, followed by cluster V (9) and cluster III (8), while the cluster II and IV being smallest contained seven genotypes each (Table 3). The estimates of various stress indices were also used by Lamba et al (2023) for clustering of genotypes evaluated under stress condition. Several other genetic studies for classification of genotypes into different tolerance categories have also been conducted in barley based on HSI (Parashar et al 2019, Yadav et al 2023). The maximum intra-cluster distance for cluster I followed by cluster II and cluster III, implies the genotypes with relatively more diversity compared to genotypes belonging to other clusters. Similarly, the genotypes of cluster V showed more similarity as deciphered by minimum intra-cluster distance. The results in addition also revealed that cluster II placed most distantly from cluster III as exhibited by maximum inter-cluster distance among all cluster combinations, followed by clusters I and III. However, cluster III is most closely placed to cluster V as observed based on minimum distance among inter cluster distances.

The low estimates of HSI indicates the tolerance of genotypes to terminal heat. Cluster II exhibited superiority for days to maturity, grain filling duration, number of grains

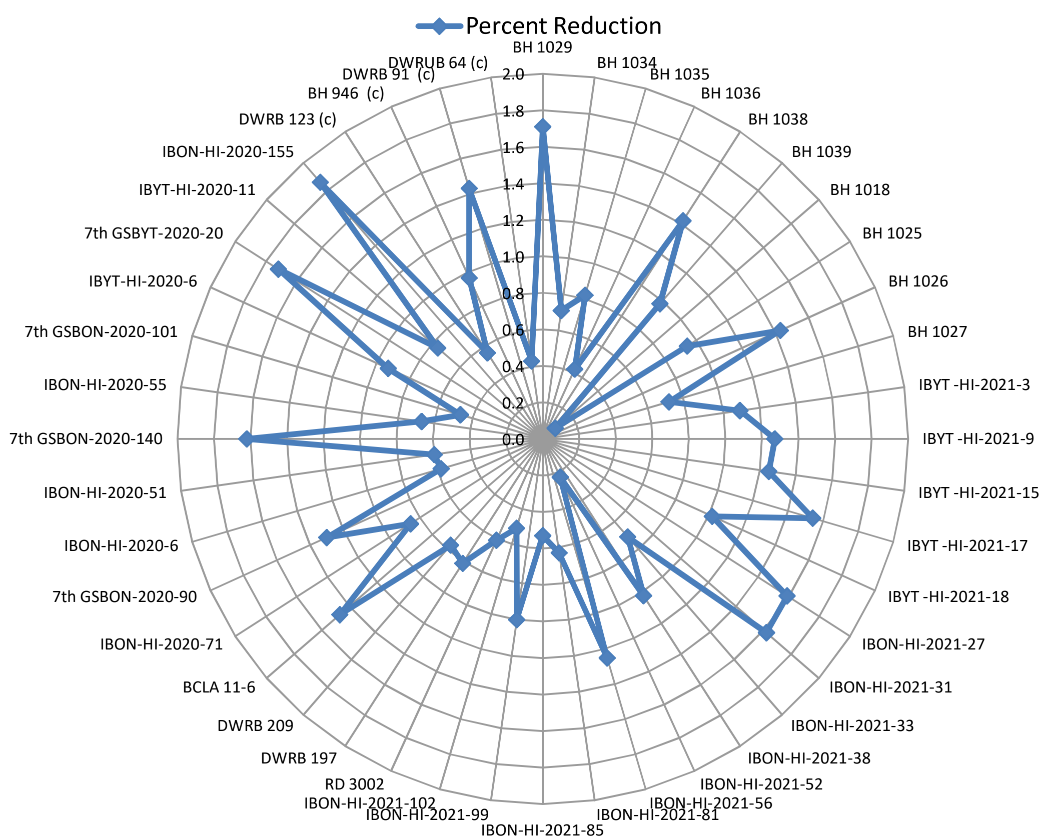
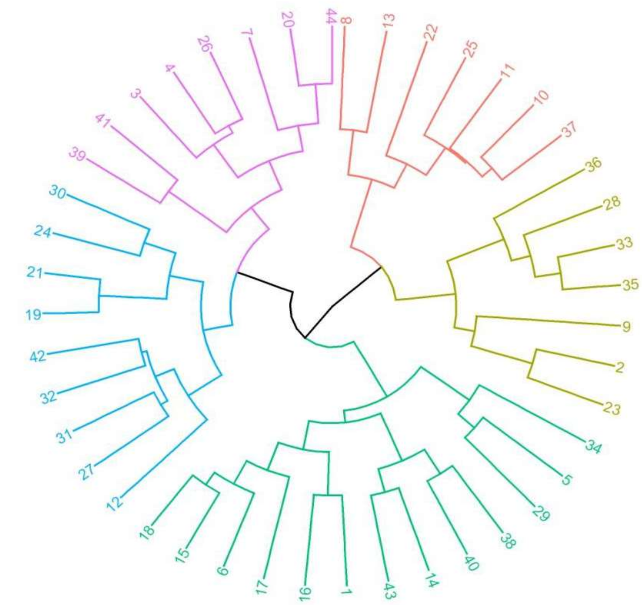


Fig. 3. Per cent reduction in grain yield in barley genotypes

Table 2. Correlation among HSI of different traits in barley genotypes

Traits	DH	DM	GFD	ETP	PH	PL	SL	GPS	TGW	BY	HI	GYP	SPAD 1	SPAD 2	NDVI 1	NDVI 2	CTD 1	CTD 2
DH	1.000	0.564**	-0.550**	0.297*	-0.228	-0.358*	0.003	0.236	-0.278	0.305*	0.057	0.436**	0.003	-0.229	0.074	0.230	0.008	-0.038
DM		1.000	0.307**	0.310*	0.109	-0.199	0.213	0.104	-0.020	0.497**	-0.174	0.407**	-0.033	-0.248	0.043	0.466**	0.242	0.173
GFD			1.000	-0.032	0.340*	0.163	0.183	-0.119	0.325*	0.069	-0.165	-0.094	0.067	0.058	-0.071	0.187	0.206	0.195
ETP				1.000	-0.058	-0.039	0.097	-0.226	0.009	0.106	0.200	0.317	0.080	0.126	0.002	0.268	-0.258	-0.340*
PH					1.000	0.252*	0.272*	-0.262	-0.054	0.223*	-0.299*	0.063	0.078	-0.144	0.129	0.000	0.186	0.227
PL						1.000	0.100	-0.158	0.086	-0.028	0.106	-0.042	-0.086	0.139	-0.055	-0.023	0.053	0.069
SL							1.000	-0.149	0.010	0.162	0.011	0.173*	0.125	-0.052	0.019	0.131	0.241	0.227
GPS								1.000	0.058	0.225	0.070	0.256*	0.000	-0.002	-0.213	0.136	-0.137	-0.116
TGW									1.000	0.159	-0.007	0.028	0.180	0.242	0.048	-0.199	0.085	0.109
BY										1.000	-0.352**	0.702**	-0.099	0.147	0.066	0.162	0.289*	0.237
HI											1.000	0.338**	0.106	0.145	-0.223	0.147	-0.272	-0.296
GYP												1.000	-0.065	0.167	-0.099	0.348*	0.080	-0.005
SPAD 1													1.000	0.053	0.214	-0.042	-0.109	-0.137
SPAD 2														1.000	-0.031	-0.120	-0.167	-0.179
NDVI 1															1.000	-0.283*	0.239	0.222
NDVI 2																1.000	0.097	-0.007
CTD 1																	1.000	0.973**
CTD 2																		1.000

See Table 1 for details



(For detail of genotypes with Sr. No., refer to Table 1)

Fig. 4. Dendrogram portraying clustering pattern of 44 barley genotypes

per spike, biological yield as well as for NDVI 2 (Table 4). The genotypes of cluster III were promising for days to heading, number of effective tillers per plant, harvest index, grain yield per plant, SPAD1 and 2, and NDVI 1. Similarly, cluster IV was positively associated with the traits *viz*., plant height, peduncle length, spike length, 1000-grain weight, and CTD.Accordingly, the promising genotypes may be sorted from different clusters for their utilization in breeding program intended to develop heat tolerant cultivars. Suresh et al (2018) observations substantiated results for deciding criterion of selection and /or identification of genotypes based on HSI. The relationship among the studied genotypes is presented in Figure 4 in the form of circular dendrogram displaying the serial number of genotypes that may be decoded by conferring Table 1.

CONCLUSION

HSI used was recognized as vital for identifying cultivars with high tolerance to heat stress. The genotypes, BH 1018, IBON-HI-2021-52, BH 1036, DWRUB 64, 7th GSBON-2020-101, IBON-HI-2021-102, IBON-HI-2021-85 and DWRB 123 were promising based on HSI of grain yield. However, results based on average of ranks of HSI of all traits illustrated the genotypes, BH 1018, IBON-HI-2021-102, IBON-HI-2021-52, DWRB 209 and IBON-HI-2020-55 with high heat tolerance under stress condition.Further, association study signifies the importance of days to heading and maturity, spike length,

Table 3. Clustering of barley genotypes based on HSI of different traits and their genetic distances

Cluster members	Number of genotypes	Clusters	Cluster distances				
			Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V
BH 1029, BH 1038, BH 1039, IBYT-HI-2021-17, IBYT-HI-2021-18, IBON-HI-2021-27, IBON-HI-2021-31, IBON-HI-2021-33, BCLA 11-6, 7th GSBON-2020-140, 7th GSBYT-2020-20, IBON-HI-2020-155, DWRB 91	13	Cluster I	2.594	3.187	3.271	2.653	2.531
BH 1034, BH 1026, IBON-HI-2021-85, DWRB 209, IBON-HI-2020-51, IBON-HI-2020-55, 7th GSBON-2020-101	7	Cluster II	3.187	2.346	3.312	2.896	3.028
BH 1035, BH 1036, BH 1018, IBON-HI-2021-52, RD 3002, IBYT-HI-2020-11, DWRB 123, DWRUB 64	8	Cluster III	3.271	3.312	2.311	2.692	2.331
BH 1025, BH 1027, IBYT-HI-2021-3, IBYT-HI-2021-15, IBON-HI-2021-81, IBON-HI-2021-102, IBYT-HI-2020-6	7	Cluster IV	2.653	2.896	2.692	1.955	2.667
IBYT-HI-2021-9, IBON-HI-2021-38, IBON-HI-2021-56, IBON-HI-2021-99, DWRB 197, IBON-HI-2020-71, 7th GSBON-2020-90, IBON-HI-2020-6, BH 946	9	Cluster V	2.531	3.028	2.331	2.667	1.830

Table 4. Performance of clusters for HSI of barley genotypes

	DH	DM	GFD	ETP	PH	PL	SL	GPS	TGW	BY	HI	GYP	SPAD 1	SPAD 2	NDVI 1	NDVI 2	CTD 1	CTD 2
C I	0.77	0.78	1.04	0.55	0.60	1.67	0.73	0.73	0.46	1.60	-0.28	1.44	0.03	0.38	0.20	0.50	3.70	3.38
C II	0.65	0.68	0.92	0.65	0.68	1.78	0.59	0.28	0.49	0.69	0.03	0.74	0.16	0.55	0.25	0.23	3.63	3.21
C III	0.62	0.74	1.25	0.35	0.71	1.61	0.64	0.42	0.35	1.05	-0.75	0.49	-0.06	0.25	0.15	0.38	3.70	3.42
C IV	0.77	0.78	0.99	0.62	0.41	0.85	0.43	0.64	0.28	1.12	-0.39	0.87	0.25	0.25	0.23	0.35	3.60	3.08
C V	0.65	0.76	1.32	0.42	0.82	1.55	0.83	0.53	0.92	1.36	-0.52	1.01	0.32	0.47	0.28	0.38	3.72	3.46

See Table 1 for details

number of grains per spike, biological yield per plant, harvest index and NDVI 2 towards grain yield under stress condition. The genotypes of cluster III portrayed better performance under stress for grain yield and other traits studied, could be incorporated in elite barley cultivars intended to develop new heat tolerant varieties.

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Grain Quality, Soil Fertility Status and Nutrient Uptake Pattern of Emmer Wheat (*Triticum dicoccum* L.) under System of Wheat Intensification

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***Abstract*:** Maintaining sustainable soil fertility level and enhancing emmer wheat production on smallholder farms is a great challenge in the Northern Dry Zone of Karnataka. Therefore, the present investigation on the grain quality, soil fertility status and nutrient uptake pattern of emmer wheat (*Triticum dicoccum* L.) under System of Wheat Intensification (SWI) in irrigated ecosystem conditions. Field experiment was conducted during *rabi* season of 2022-23 at Research field of Ugar Khurd, Belagavi, Karnataka. The experiment was laid out in a split plot design with four main plots *viz.,* Gokak local and DDK 1029 with and without seed priming and four planting geometries *viz.,* 30 × 15 cm; 45 × 15 cm; 20 × 20 cm and 20 cm (RPP) in sub plots under three replications. The primed seeds sown at 30 × 15 cm planting geometry recoded significantly higher number of effective tillers (463.83 m^{-2}), grain yield (44.13 q ha^{-1}), straw yield (70.64 q ha^{-1}), biological yield (114.77 q ha^{-1}), grain protein content (12.54 %), nitrogen, phosphorous and potassium content (2.65, 0.54 and 1.78 %) and total nitrogen, phosphorous and potassium uptake (133.63, 28.38 and 112.44 kg ha^{-1}) as compared to un-primed seeds with other planting geometries.

***Keywords*:** Emmer wheat, Nutrient contents and uptakes, Planting geometries, Seed priming, System of wheat intensification

Wheat is grown across a wide range of environmental conditions around the world. Cultivation of wheat dates back to more than 5000 years, during the period of Indus valley civilization during which the original species *Triticum sphaerococcum*, traditionally known as Indian wheat has vanished and replaced by modern day cultivars like *Triticum aestivum* (Bread wheat), *Triticum durum* (Macaroni wheat or Kathia wheat) and *Triticum dicoccum* (Emmer wheat or Khapli). Among different species of wheat, *Triticum aestivum* has 95 per cent production, *Triticum durum* has 4 per cent and *Triticum dicoccum* has one per cent production in India. Nearly, 82 to 85 per cent of the wheat grown in India is under irrigated situation, while the rest is grown under rainfed condition. The emmer wheat (*Triticum dicoccum* L.) is grown on a very restricted scale in Gujarat, Maharashtra and Karnataka. In general emmer wheat varieties are rich source of protein and complex carbohydrate (dietary fibre) as compared to bread wheat and it keeps one full for longer and hence helps in weight loss. The traditional products of emmer wheat varieties have better taste, texture and flavour (Singh, 2015).In India, wheat cultivation covers an extensive 30.47 million hectares and contributes significantly to food grain production, accounting for 36 per cent of the total output (Anonymous 2022). Lower wheat productivity is primarily due to delayed sowing, a short winter season, improper input management and terminal heat stress, particularly in the North Eastern Plain Zone of India, which leads to reduced tillering, inadequate crop establishment and shrivelled grains and yields. Traditionally, wheat cultivation has relied on the broadcasting and continuous sowing of seeds in rows without adhering to specific planting geometry. This approach has served well for extensive agricultural areas. However, it comes with limitations, such as the lack of uniformity in crop stand. This lack of uniformity results in the dilution effect of inputs and impacting on crop yield (Haque et al 2015). The System of Wheat Intensification (SWI) represents an innovative approach to wheat production on manipulating the soil environment with minimal external inputs and utilizing a very low seed rate. This technique aims to create optimal conditions for wheat cultivation, emphasizing the importance of maintaining an ideal plant population, SWI ensures adequate aeration, moisture, sunlight, and nutrient availability, which are crucial for fostering proper root system development during the early stages of crop growth. This holistic approach to wheat farming holds promise for improving yields and resource utilization while reducing external inputs.

The System of Wheat Intensification method was initially introduced in India, Africa, and Nepal by dedicated community workers on the fields of small and marginal farmers in the year 2006. These grassroots efforts yielded encouraging results, which played a pivotal role in inspiring and guiding systematic research initiatives involving farmers, government agencies and research workers in India. SWI, a synergistic wheat farming technique, involves reduced seed density and wider spacing, coupled with seed treatment using organic formulations like cow dung, cow urine, jaggery and curd, to enhance plant health and productivity. Under the SWI the management practices create more favourable conditions for wheat crop growth. This is achieved through the greater proliferation of root hair and increased root length compared to traditional wheat farming methods, (Haque *et al* 2015). Despite encouraging results, there is limited information available regarding the overall effect of the SWI technique on wheat growth and productivity. Further research and data collection in this area could provide valuable insights into the full potential and benefits of adopting SWI in wheat farming. Therefore, the present experiment was conducted to investigate the "Grain quality, soil fertility status and nutrient uptake pattern of emmer wheat (*Triticum dicoccum* L.) under System of Wheat Intensification (SWI).

MATERIAL AND METHODS

Experiment site: The present investigation was conducted at Research field of Ugar Khurd, Belagavi, Karnataka, during *rabi* 2022-2023 located in the Northern Dry Zone (Zone-3) of Karnataka. Geographically it lies between 16º 38' 30" N latitude, 74º 49' 39" E longitude and at an altitude of 561 m above mean sea level (MSL).

Soil status: Experiments were laid out on well drained, deep black calcareous soil taxonomically belonging to vertisol with a depth of 2.5 to 3.5 m and slightly saline in nature with pH of pH ranging from 8.0 with medium electrical conductivity (0.39 dS m^{-1}), low in organic carbon content (0.58 %), low in available nitrogen (279.1 kg ha^{-1}), high in available phosphorous (32.6 kg ha^{-1}) and potassium (371.2 kg ha^{-1}).

Treatment details: The experiment was laid out in split plot design with four main plots *viz.,*gokak local and DDK 1029 with and without seed priming and four planting geometries in sub plots *viz.,* S_1- 30 × 15 cm; S_2- 45 × 15 cm; S_3- 20 × 20 cm and S_4- 20 cm (RPP). The seed rate varies with respective planting geometries and crop was sown during 1^{st} week of November and harvest during 2^{nd} week of March.

Seed priming procedure: Seed priming formulation comprising of water, cow dung, cow urine, jaggery and curd in the ratio of 2.0: 0.5: 0.5: 0.1: 0.05 was used to treat the seeds before sowing. In this case for priming 10 kg of emmer wheat seed, 10 litres of water, 2.5 kg of cow dung, 2.5 litre of cow urine, 500 g of jaggery and 250 g curd was taken in a bucket and was kept overnight (Sunaratiya and Banik 2022). The priming material was stirred during preparation period. Thereafter, the material was sieved using cotton cloth and the resultant solution so obtained was used as priming formulation to treat the seeds. The seeds of wheat to be treated were first immersed in water contained in the tub to remove the chaffy seeds which were found floating on the surface of water. The seeds which settled in the bottom of the tub were collected and immersed in the priming solution for eight to ten hours. Took the seeds out of the priming solution and dried in shade. Thereafter were sown directly in the field.

Quality parameters analysis: i) Protein, nitrogen is determined by a method of chemical analysis known as the Kjeldahl procedure. Crude protein content was calculated by following formula: Crude protein of wheat = Per cent nitrogen × 5.7. ii) Grain N content was determined by Kjeldahl method described by (Kjeldahl, 1883) and expressed in percentage. iii) Grain P Content Total phosphorous on dry weight basis at harvest of wheat was estimated by Vanadomolybdo-phosphoric acid yellow colour method and expressed in percentage. iv) Grain K Content Available potassium in grain was extracted with neutral normal ammonium acetate and potassium content in the extract will be determined by using flame photometer (EelicoD-22) as outlined by (Jackson, 1973) and expressed in percentage.

Nutrient uptake by wheat: The uptake of nutrients by different parts of wheat was worked out by multiplying the nutrient content in seed and straw yield of the plant using the following formula:

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \frac{\text{Nutrient concentration in grain (\%)} \times \text{Grain yield (kg ha}^{-1}\text{)}}{100} + \frac{\text{Nutrient concentration in Straw (\%)} \times \text{Straw yield (kg ha}^{-1}\text{)}}{100}$$

Soil sample analysis: Soil samples were collected before sowing and after harvest from individual plots of experiment by taking slice of soil from the depth of 0-30 cm. Soil samples were shade dried, powdered using wooden pestle and mortar and sieved through 2 mm sieve and chemically analysed to estimate soil reaction (pH), EC (dS m^{-1}), organic carbon (OC %), available soil nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O).

Statistical analysis and interpretation of data: The data were analysed in MS EXCEL (var. 2020) by using DMRT.

RESULTS AND DISCUSSION

Yield and yield attributes of emmer wheat as influence by seed priming

Number of effective tillers (m^{-2}): Seed priming significantly influenced the number of effective tillers of emmer wheat. Primed seeds (M_4) recorded significantly higher number of effective tillers (422.14 m^{-2}) and was on par with M_2 and M_3. However, significantly lowest number of effective tillers (401.86 m^{-2}) was in un-primed seeds (M_1) (Table 1). This can be due to fact that cow urine contains physiologically active substances *viz.,* growth regulators and nutrients that promote profusely more number of tiller per plant. Bhoopathi et al (2001) also observed significant increase number of tillers per plant due to treating of seed with cattle urine than untreated seed.

Grain yield (q ha^{-1}): Grain yield differed significantly with respect to with and without seed priming. Primed seeds (M_4) recorded significantly higher grain yield (38. 53 q ha^{-1}) and was on par with M_2 and M_3. The, significantly lower grain yield (32.78 q ha^{-1}) was in un-primed seeds) (Table 1). Seed priming also imparted a positive influence on grain and straw yield of wheat as compared to un-primed seed. The increase in grain yield of wheat under seed priming might be due to its positive effect on growth and yield parameters *viz.,* crop emergence, complete crop emergence, both above and belowground plant growth and yield attributes over un-primed seeds. Khadka and Raut (2011) and Sarlach et al (2013) have also reported that seed priming improves emergence, stand establishment, tillering, grain and straw yields.

Straw yield (q ha^{-1}): Primed seeds (M_4) recorded significantly higher straw yield (64.26 q ha^{-1}). Whereas, significantly lower straw yield (58.88 q ha^{-1}) was recorded with respect to un-primed seeds (M_1) (Table 1). The higher

Table 1. Yield and yield attributes of emmer wheat as influenced by seed priming and different planting geometries

Treatment	Number of effective tillers m^{-2}	Grain yield (q ha^{-1})	Straw yield (q ha^{-1})	Biological yield (q ha^{-1})
Main plots:- (Two genotypes with and without seed priming)				
M_1-Gokak local (WOP)	401.86^{b}	32.78^{b}	58.88^{b}	91.65^{b}
M_2- Gokak local (WP)	412.88^{ab}	36.15^{ab}	61.09^{b}	97.24^{ab}
M_3-DDK 1029 (WOP)	409.51^{ab}	35.01^{ab}	61.42^{b}	96.43^{b}
M_4-DDK 1029 (WP)	422.14^{a}	38.53^{a}	64.26^{a}	102.79^{a}
Sub plots:- (Four planting geometries)				
S_1- 30 × 15 cm	452.85^{a}	40.20^{a}	66.30^{a}	106.50^{a}
S_2- 45 × 15 cm	357.61^{d}	34.08^{b}	60.06^{bc}	94.14^{bc}
S_3- 20 × 20 cm	433.58^{b}	36.74^{ab}	61.78^{b}	98.51^{ab}
S_4- 20 cm (RPP)	402.34^{c}	31.45^{c}	57.52^{c}	88.96^{c}
Interaction (M × S)				
M_1S_1	439.73^{bc}	36.31^{a-d}	63.01^{cd}	99.32^{cd}
M_1S_2	347.77^{g}	31.52^{cd}	57.93^{f}	89.45^{e-g}
M_1S_3	424.83^{cd}	34.06^{b-d}	59.88^{ef}	93.94^{d-f}
M_1S_4	395.10^{e}	29.21^{d}	54.68^{g}	83.89^{g}
M_2S_1	460.17^{a}	42.35^{ab}	65.99^{b}	108.34^{ab}
M_2S_2	356.87^{g}	34.13^{b-d}	59.20^{ef}	93.33^{d-g}
M_2S_3	434.70^{bc}	37.02^{a-d}	61.66^{de}	98.67^{c-e}
M_2S_4	399.77^{e}	31.11^{cd}	57.52^{fg}	88.64^{fg}
M_3S_1	447.68^{ab}	38.01^{a-c}	65.55^{bc}	103.56^{bc}
M_3S_2	350.77^{g}	35.00^{b-d}	60.16^{ef}	95.16^{c-f}
M_3S_3	434.87^{bc}	35.47^{b-d}	61.89^{de}	97.36^{c-f}
M_3S_4	404.73^{e}	31.56^{cd}	58.07^{f}	89.62^{e-g}
M_4S_1	463.83^{a}	44.13^{a}	70.64^{a}	114.77^{a}
M_4S_2	375.03^{f}	35.68^{b-d}	62.94^{cd}	98.62^{c-e}
M_4S_3	439.93^{bc}	40.40^{ab}	63.68^{b-d}	104.08^{bc}
M_4S_4	409.77^{de}	33.90^{b-d}	59.80^{ef}	93.70^{d-f}

Mean followed by the same letter(s) did not differ significantly by DMRT (p= 0.05)

straw yield in primed seeds compared to un-primed seeds can be attributed to increased seedling vigour, stronger vegetative growth, greater dry matter production and improved growth parameters. This collective effect results in enhanced straw biomass, making seed priming with organic formulations a valuable method for boosting wheat straw yield. Similar results were also obtained by Khadka and Raut (2011) and Sarlach et al (2013).

Biological yield (q ha^{-1}): Primed seeds (M_4) recorded significantly higher biological yield (102.79 q ha^{-1}) and it was recorded on par with M_2 (97.24 q ha^{-1}). The significantly lowest biological yield (91.65 q ha^{-1}) was recorded with respect to un-primed seeds (M_1) (Table 1). The increase in grain and straw yields in primed seeds as compared to un-primed seeds can be attributed to improved seedling vigour, early growth and enhanced vegetative development. Seed priming proves effective in boosting overall crop performance, leading to higher yields in both grain and straw in wheat cultivation. Similar results were also obtained by Sharma (2020).

Quality Parameters of Emmer Wheat as Influenced by Seed Priming

Grain crude protein content of emmer wheat: Significant differences in grain crude protein content were observed with respect to with and without seed priming methods. Primed seeds (M_4 and M_2) recorded significantly higher grain crude protein content (12.05 and 11.96 %, respectively). The significantly lowest grain crude protein content (11.08 %) was with respect to un-primed seeds (M_1) (Table 2). These might be due to higher grain nitrogen content in primed seeds and

Table 2. Grain crude protein and nitrogen content of emmer wheat as influenced by seed priming and different planting geometries

Treatment	Grain crude protein content (%)	Nitrogen content in (%)		
		Grain	Straw	Total
Main plots:- (Two genotypes with and without seed priming)				
M_1-Gokak local (WOP)	11.08^{c}	1.62^{b}	0.48^{b}	2.09^{b}
M_2- Gokak local (WP)	11.96^{a}	1.78^{a}	0.51^{ab}	2.29^{a}
M_3-DDK 1029 (WOP)	11.53^{b}	1.79^{a}	0.53^{ab}	2.32^{a}
M_4-DDK 1029 (WP)	12.05^{a}	1.87^{a}	0.56^{a}	2.43^{a}
Sub plots:- (Four planting geometries)				
S_1- 30 × 15 cm	12.13^{a}	1.90^{a}	0.60^{a}	2.50^{a}
S_2- 45 × 15 cm	11.71^{b}	1.75^{ab}	0.50^{b}	2.24^{bc}
S_3- 20 × 20 cm	11.89^{ab}	1.83^{ab}	0.56^{a}	2.39^{ab}
S_4- 20 cm (RPP)	10.91^{c}	1.59^{b}	0.41^{c}	2.00^{c}
Interaction (M × S)				
M_1S_1	11.65^{d-f}	1.78^{a-c}	0.57^{bc}	2.35^{b-e}
M_1S_2	11.05^{gh}	1.58^{cd}	0.42^{ef}	2.00^{gh}
M_1S_3	11.26^{fg}	1.64^{b-d}	0.53^{cd}	2.17^{d-g}
M_1S_4	10.37^{i}	1.47^{d}	0.38^{f}	1.85^{h}
M_2S_1	12.32^{ab}	1.87^{ab}	0.58^{bc}	2.45^{a-c}
M_2S_2	12.11^{bc}	1.77^{a-c}	0.51^{d}	2.28^{b-f}
M_2S_3	12.17^{a-c}	1.84^{a-c}	0.54^{cd}	2.38^{a-d}
M_2S_4	11.25^{fg}	1.64^{b-d}	0.40^{ef}	2.04^{f-h}
M_3S_1	12.01^{b-d}	1.92^{a}	0.61^{ab}	2.53^{a-c}
M_3S_2	11.51^{ef}	1.76^{a-c}	0.51^{d}	2.27^{c-f}
M_3S_3	11.83^{c-e}	1.87^{ab}	0.58^{bc}	2.45^{a-c}
M_3S_4	10.79^{hi}	1.61^{b-d}	0.41^{ef}	2.02^{f-h}
M_4S_1	12.54^{a}	2.01^{a}	0.64^{a}	2.65^{a}
M_4S_2	12.16^{a-c}	1.87^{ab}	0.54^{cd}	2.41^{a-d}
M_4S_3	12.28^{ab}	1.95^{a}	0.60^{ab}	2.55^{ab}
M_4S_4	11.24^{fg}	1.64^{b-d}	0.45^{e}	2.09^{e-h}

Mean followed by the same letter(s) did not differ significantly by DMRT (p= 0.05)

seed priming acts as a catalyst for several physiological and biochemical processes, creating a conducive environment for higher grain protein content and improved protein quality in emmer wheat. These results are in conformity with the finding of Muchhadiya et al (2021).

Nitrogen content in grain, straw and total content (%): Primed seeds (M_4) recorded higher grain, straw and significantly higher total nitrogen content (1.87, 0.56 and 2.43 %, respectively) which was on par with M_3 and M_2. The lower nitrogen content in grain, straw and significantly lower total nitrogen content (1.62, 0.48 and 2.09 %, respectively) was in un-primed seeds (M_1) (Table 2). These might be due to seed priming with cow dung and cow urine contributes to higher grain nitrogen content in wheat through a combination of nutrient enrichment, beneficial microbial activity, hormonal stimulation, improved root development, enhanced water retention, reduced nitrogen loss and increased stress tolerance. This holistic approach harnesses the organic properties of these substances to optimize nitrogen availability and utilization for improved wheat crop performance. This was in conformity with the finding of (Sharma 2020).

Phosphorous content in grain, straw and total content (%): Primed seeds (M_4) recorded significantly higher grain, straw and total phosphorous content (0.34, 0.17 and 0.50 %, respectively). The significantly lower grain, straw and total phosphorous content (0.30, 0.13 and 0.43 %, respectively) was recorded in un-primed seeds (M_1) (Table 3). These might be due to organic substances offer a comprehensive approach to enhance phosphorus availability and utilization during key growth stages. Similar type of results was recorded by (Sharma 2020).

Potassium content in grain, straw and total content (%): Primed seeds recorded higher grain, straw and total potassium content (0.46, 1.30 and 1.76 %, respectively) as compared to un-primed seeds (0.44, 1.23 and 1.66, respectively) (Table 3). These might be due to organic substances provide a holistic approach to improve potassium availability, offering insights for sustainable and quality-focused agricultural practices. Similar type of results was recorded by (Sharma 2020).

Nutrient Uptake by Emmer Wheat as Influenced by Seed Priming

Nitrogen uptake in grain, straw and total uptake (kg ha^{-1}): Primed seeds (M_4) recorded significantly higher nitrogen uptake in grain, straw and total uptake. The significantly lower nitrogen uptake in grain, straw and total uptake was in un-primed seeds (Table 4). This may be due to seed treatment helps in increasing the absorbing surface of root system causes increased plant growth and yield attributes and nutrient absorption by roots (N, P_2O_5 and K_2O). This was in conformity with the finding of Zheng et al (2013).

Phosphorous uptake in grain, straw and total uptake (kg ha^{-1}): Primed seeds (M_4) recorded significantly higher phosphorous uptake in grain, straw and total uptake (as compared to un-primed seeds (Table 4). These might be due to higher grain yield, straw yield, higher phosphorous content in grain, straw and total phosphorous content was in primed seeds as compared to un-primed seeds. This was in conformity with the finding of (Kumar et al 2021).

Potassium uptake in grain, straw and total uptake (kg ha^{-1}): Primed seeds (M_4) recorded significantly higher potassium uptake in grain, straw and total potassium uptake as compared to un-primed seeds (Table 4). This may be due to seed treatment helps in increasing the absorbing surface of root system causes increased plant growth and yield attributes and nutrient absorption by roots (N, P_2O_5 and K_2O). This was in conformity with the finding of Zheng et al (2013).

Influence of seed priming on soil chemical properties after harvest of emmer wheat crop: The chemical properties of soil *viz.,* soil reaction (pH), electrical conductivity (dS m^{-1}) and organic carbon (%) of the soil after harvest of crop as influenced by seed priming are furnished. The seed priming, did not significantly influence the soil pH, electrical conductivity (dS m^{-1}) and organic carbon (%) (Table 5). This lack of significant influence on soil chemical properties through seed priming may be attributed to the limited impact observed in this particular context. Similar results were obtained by Sharma (2022).

Influence of Seed Priming on Available Nitrogen, Phosphorus and Potassium Status in Soil after Harvest of the Emmer Wheat Crop

Available nitrogen in soil: Seed priming significantly influenced the available nitrogen in the soil. Un-primed seeds recorded significantly higher available nitrogen in soil (246.30 kg ha^{-1}) and was on par with M_1 [1]. The significantly lower available nitrogen in soil was in primed seeds (M_2 and M_4) (234.70 and 237.64 kg ha^{-1}, respectively) (Table 5). This could be attributed to the increased nitrogen uptake in primed seeds as compared to un-primed seeds. Similar results were obtained by Dhar et al (2016).

Available phosphorous in soil: The available phosphorus in the soil was significantly influenced by seed priming. Un-primed seeds recorded significantly higher available phosphorous in soil (30.24 kg ha^{-1}) and was on par with M_3. The, significantly lower available phosphorous in soil was recorded in primed seeds M_2 and M_4 (Table 5). This could be attributed to the enhanced phosphorus uptake in primed seeds as compared to un-primed seeds (Sharma 2022).

Available potassium in soil: The seed priming did not significantly influence the available potassium in soil. The available potassium was higher in un-primed seeds (292.00 kg ha^{-1}) as compared to primed seeds (284.83 kg ha^{-1}) (Table 5).

Yield and Yield Attributes of Emmer Wheat as Influence by different Planting Geometries

Number of effective tillers (m^{-2}): Significantly higher number of effective tillers (452.85 m^{-2}) were recorded in 30 × 15 cm planting geometry (S_1) and significantly lower effective tillers were in S_2 (45 × 15 cm planting geometry - 357.61 m^{-2}) (Table 1). These might be due to wider spacing facilitates plants for better utilization of nutrient, water, light and space leading to produced maximum number of effective tillers per unit area than conventional practices and under wider row spacing number of plant population should be decreases as compared to narrow row spacing. Similar results were obtained by Muchhadiya et al (2021).

Grain yield (q ha^{-1}): Significantly higher grain yield (40.20 q ha^{-1}) was recorded by the 30 × 15 cm planting geometry (S_1). However, was on par with (S_3) 20 × 20 cm planting geometry. Significantly lower grain yield was in (S_4) 20 cm (RPP) planting geometry (31.45 q ha^{-1}) (Table 1). These might be due to higher yield attributes *viz.,* number of effective tillers, number of grains per spike, spike weight, grain weight per spike and thousand grain weight was recorded in wider row spacing as compared to conventional practices. Similar results were obtained by Haque et al (2015).

Straw yield (q ha^{-1}): The 30 × 15 cm planting geometry (S_1)

Table 3. Phosphorous and potassium content of emmer wheat as influenced by seed priming and different planting geometries

Treatment	Phosphorous content in (%)			Potassium content in (%)		
	Grain	Straw	Total	Grain	Straw	Total
Main plots:- (Two genotypes with and without seed priming)						
M_1-Gokak local (WOP)	0.30^{c}	0.13^{b}	0.43^{d}	0.44^{a}	1.23^{a}	1.66^{a}
M_2- Gokak local (WP)	0.31^{bc}	0.14^{b}	0.45^{c}	0.44^{a}	1.27^{a}	1.71^{a}
M_3-DDK 1029 (WOP)	0.32^{b}	0.16^{a}	0.48^{b}	0.45^{a}	1.26^{a}	1.71^{a}
M_4-DDK 1029 (WP)	0.34^{a}	0.17^{a}	0.50^{a}	0.46^{a}	1.30^{a}	1.76^{a}
Sub plots:- (Four planting geometries)						
S_1- 30 × 15 cm	0.34^{a}	0.16^{a}	0.50^{a}	0.46^{ab}	1.28^{a}	1.74^{a}
S_2- 45 × 15 cm	0.31^{a}	0.16^{a}	0.46^{b}	0.49^{a}	1.29^{a}	1.78^{a}
S_3- 20 × 20 cm	0.32^{a}	0.15^{ab}	0.47^{b}	0.43^{ab}	1.26^{a}	1.70^{a}
S_4- 20 cm (RPP)	0.30^{a}	0.14^{c}	0.44^{b}	0.40^{b}	1.22^{a}	1.62^{a}
Interaction (M × S)						
M_1S_1	0.31^{b-e}	0.14^{de}	0.45^{de}	0.46^{a-d}	1.25^{ab}	1.71^{a-c}
M_1S_2	0.29^{de}	0.14^{de}	0.43^{ef}	0.48^{a-c}	1.27^{ab}	1.75^{ab}
M_1S_3	0.30^{c-e}	0.13^{ef}	0.43^{ef}	0.43^{a-d}	1.23^{ab}	1.66^{a-c}
M_1S_4	0.28^{e}	0.12^{f}	0.40^{f}	0.38^{d}	1.15^{b}	1.53^{c}
M_2S_1	0.33^{a-d}	0.15^{cd}	0.48^{b-d}	0.44^{a-d}	1.27^{ab}	1.71^{a-c}
M_2S_2	0.30^{c-e}	0.15^{cd}	0.45^{de}	0.49^{ab}	1.29^{ab}	1.78^{ab}
M_2S_3	0.31^{b-e}	0.14^{de}	0.45^{de}	0.42^{a-d}	1.26^{ab}	1.68^{a-c}
M_2S_4	0.29^{de}	0.13^{ef}	0.42^{ef}	0.40^{cd}	1.25^{ab}	1.65^{a-c}
M_3S_1	0.35^{ab}	0.16^{bc}	0.51^{b}	0.47^{a-c}	1.29^{ab}	1.76^{ab}
M_3S_2	0.31^{b-e}	0.16^{bc}	0.47^{cd}	0.48^{a-c}	1.30^{a}	1.78^{a-c}
M_3S_3	0.33^{a-d}	0.15^{cd}	0.48^{b-d}	0.43^{a-d}	1.27^{ab}	1.70^{a-c}
M_3S_4	0.30^{c-e}	0.15^{cd}	0.45^{de}	0.41^{b-d}	1.19^{ab}	1.60^{bc}
M_4S_1	0.36^{a}	0.18^{a}	0.54^{a}	0.48^{a-c}	1.30^{a}	1.78^{ab}
M_4S_2	0.33^{a-d}	0.17^{ab}	0.50^{bc}	0.50^{a}	1.31^{a}	1.81^{a}
M_4S_3	0.34^{a-c}	0.16^{bc}	0.50^{bc}	0.45^{a-d}	1.29^{ab}	1.74^{ab}
M_4S_4	0.32^{a-e}	0.15^{cd}	0.47^{cd}	0.42^{a-d}	1.28^{ab}	1.70^{a-c}

Mean followed by the same letter(s) did not differ significantly by DMRT (p= 0.05)

recorded significantly higher straw yield (66.30 q ha^{-1}) and significantly lower straw yield was in (S_4) 20 cm planting geometry (57.52 q ha^{-1}) (Table 1). These might be due to reduction in straw yield at wider row spacing's were mainly be ascribed to the decrease in overall number of plants per unit area rather than number of tillers per hill at wider row spacing's. Wider row spacing permitted better performance per hill than narrow row spacing due to decreased competition between plant for nutrient, water, space and light but decreased overall grain and straw yields might be due to lesser plant biomass production at wider row spacing's. The results corroborate with the finding of Jayawardena and Abeysekera (2011).

Biological yield (q ha^{-1}): The 30 × 15 cm planting geometry (S_1) recorded significantly higher biological yield (106.50 q ha^{-1}) and was shown on par with S_3 (98.51 q ha^{-1}). However, significantly lower biological yield was in (S_4) 20 cm (RPP) planting geometry (88.96 q ha^{-1}) (Table 1). These might be due to higher grain and straw yields was recorded in wider row spacing as compared to conventional practices (Dhar et al 2016).

Quality Parameters of Emmer Wheat as Influenced by Planting Geometries

Grain crude protein content of emmer wheat: The 30 × 15 cm planting geometry (S_1) recorded significantly higher grain crude protein content (12.13 %) and on par with S_3 (11.89 %). Significantly lower grain crude protein content was in (S_4) 20 cm (RPP) planting geometry (10.91 %) (Table 2). This is due

Table 4. Nitrogen, phosphorous and potassium uptake by emmer wheat as influenced by seed priming and different planting geometries

Treatment	N uptake (kg ha^{-1})			P uptake (kg ha^{-1})			K uptake (kg ha^{-1})		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
Main plots:- (Two genotypes with and without seed priming)									
M_1-Gokak local (WOP)	53.91^{c}	28.21^{c}	82.12^{c}	9.67^{b}	7.82^{c}	17.48^{c}	14.30^{b}	72.25^{c}	86.55^{c}
M_2- Gokak local (WP)	64.20^{b}	31.23^{bc}	95.43^{b}	11.17^{b}	8.76^{bc}	19.93^{bc}	15.77^{b}	77.66^{b}	93.43^{b}
M_3-DDK 1029 (WOP)	63.43^{b}	32.58^{b}	96.01^{b}	11.38^{ab}	9.52^{ab}	20.90^{b}	15.75^{b}	77.59^{b}	93.34^{b}
M_4-DDK 1029 (WP)	73.38^{a}	36.01^{a}	109.39^{a}	12.98^{a}	10.56^{a}	23.54^{a}	17.68^{a}	82.96^{a}	100.64^{a}
Sub plots:- (Four planting geometries)									
S_1- 30 × 15 cm	76.60^{a}	39.88^{a}	116.48^{a}	13.62^{a}	10.49^{a}	24.11^{a}	18.62^{a}	84.84^{a}	103.46^{a}
S_2- 45 × 15 cm	61.19^{c}	29.80^{c}	91.00^{c}	10.44^{c}	9.32^{b}	19.76^{c}	16.39^{b}	77.72^{b}	94.11^{b}
S_3- 20 × 20 cm	66.85^{b}	34.74^{b}	101.59^{b}	11.76^{b}	8.94^{c}	20.71^{b}	15.86^{b}	77.87^{b}	93.73^{b}
S_4- 20 cm (RPP)	50.28^{d}	23.60^{d}	73.88^{d}	9.37^{d}	7.90^{d}	17.27^{d}	12.65^{c}	70.02^{c}	82.66^{c}
Interaction (M × S)									
M_1S_1	66.04^{de}	35.94^{d}	101.98^{c}	11.12^{ef}	8.83^{f}	19.95^{e}	16.32^{e}	78.83^{d}	95.15^{c}
M_1S_2	49.83^{h}	24.39^{i}	74.22^{g}	9.22^{hi}	8.13^{g}	17.36^{h}	15.23^{f}	73.88^{ef}	89.12^{e}
M_1S_3	56.49^{g}	31.70^{f}	88.19^{e}	10.18^{g}	7.73^{h}	17.91^{gh}	14.57^{g}	73.34^{f}	87.91^{e}
M_1S_4	43.28^{i}	20.80^{k}	64.08^{h}	8.15^{j}	6.57^{i}	14.72^{j}	11.08^{j}	62.93^{h}	74.02^{g}
M_2S_1	75.54^{b}	38.36^{c}	113.89^{b}	14.16^{b}	9.96^{cd}	24.13^{b}	18.94^{b}	84.23^{bc}	103.17^{b}
M_2S_2	62.73^{f}	30.20^{g}	92.93^{d}	10.17^{g}	8.89^{ef}	19.06^{f}	16.52^{e}	76.45^{de}	92.97^{cd}
M_2S_3	68.46^{cd}	33.34^{e}	101.80^{c}	11.36^{de}	8.70^{f}	20.06^{e}	15.29^{f}	77.98^{d}	93.27^{cd}
M_2S_4	50.08^{h}	23.02^{j}	73.10^{g}	8.98^{i}	7.49^{h}	16.47^{i}	12.34^{i}	71.96^{f}	84.30^{f}
M_3S_1	76.34^{b}	40.07^{b}	116.41^{b}	13.46^{c}	10.55^{b}	24.01^{b}	18.28^{c}	84.82^{b}	103.10^{b}
M_3S_2	62.88^{f}	30.69^{fg}	93.57^{d}	10.77^{f}	9.64^{d}	20.42^{de}	16.33^{e}	78.29^{d}	94.62^{c}
M_3S_3	64.33^{ef}	35.80^{d}	100.13^{c}	11.76^{d}	9.23^{e}	20.99^{d}	15.36^{f}	78.35^{d}	93.71^{cd}
M_3S_4	50.16^{h}	23.76^{ij}	73.92^{g}	9.55^{h}	8.65^{f}	18.19^{g}	13.04^{h}	68.90^{g}	81.94^{f}
M_4S_1	88.47^{a}	45.15^{a}	133.63^{a}	15.75^{a}	12.62^{a}	28.38^{a}	20.95^{a}	91.49^{a}	112.44^{a}
M_4S_2	69.34^{c}	33.94^{e}	103.27^{c}	11.61^{d}	10.61^{b}	22.22^{c}	17.45^{d}	82.27^{bc}	99.73^{b}
M_4S_3	78.12^{b}	38.13^{c}	116.25^{b}	13.75^{bc}	10.11^{c}	23.86^{b}	18.21^{c}	81.81^{c}	100.02^{b}
M_4S_4	57.58^{g}	26.82^{h}	84.40^{f}	10.80^{f}	8.90^{ef}	19.70^{ef}	14.11^{g}	76.27^{de}	90.38^{de}

Mean followed by the same letter(s) did not differ significantly by DMRT (p= 0.05)

to the higher uptake of nitrogen in turn resulting in higher grain crude protein content. Higher protein content was also recorded in the system of wheat intensification when compared to normal practices also highlighted by Muchhadiya et al (2021).

Nitrogen content in grain, straw and total content (%): The 30 × 15 cm planting geometry (S_1) exhibited significantly higher nitrogen content in grain, straw and total content (1.90, 0.60 and 2.50 %, respectively) which was comparable with S_3 (1.83, 0.56 and 2.39 %, respectively). Conversely, significantly lower nitrogen content in grain, straw and total content was observed in the 20 cm planting geometry (S_4) (Table 2). The right planting geometry promotes efficient nutrient uptake, minimizes nutrient competition, enhances soil conditions for nitrogen availability and reduces nitrogen loss, all of which collectively contribute to higher nitrogen content in wheat grain. Similar results were obtained by Sharma (2020).

Phosphorous content in grain, straw and total content (%): Numerically higher phosphorous content in grain, straw and significantly higher total phosphorous content was recorded in 30 × 15 cm planting geometry (0.34, 0.16 and 0.50 %, respectively). The significantly lower phosphorous content in grain, straw and total content was recorded in 20 cm (RPP) planting geometry (0.30, 0.14 and 0.44 %, respectively) (Table 3). The right planting geometry supports efficient phosphorus uptake by promoting optimal root development, minimizing competition, enhancing fertilizer

Table 5. Soil chemical properties and nutrient available status in soil after harvest of emmer wheat as influenced by seed priming and different planting geometries

Treatment	Soil pH	EC (dS m^{-1})	OC (%)	Avai. N (kg ha^{-1})	Avai. P (kg ha^{-1})	Avai. K (kg ha^{-1})
Main plots:- (Two genotypes with and without seed priming)						
M_1-Gokak local (WOP)	7.80^{a}	0.37^{a}	0.54^{a}	240.15^{ab}	30.24^{a}	292.00^{a}
M_2- Gokak local (WP)	7.73^{a}	0.37^{a}	0.55^{a}	234.70^{b}	27.82^{b}	284.83^{a}
M_3-DDK 1029 (WOP)	7.80^{a}	0.37^{a}	0.54^{a}	246.30^{a}	29.21^{ab}	290.63^{a}
M_4-DDK 1029 (WP)	7.75^{a}	0.37^{a}	0.54^{a}	237.64^{b}	28.11^{b}	286.42^{a}
Sub plots:- (Four planting geometries)						
S_1- 30 × 15 cm	7.80^{a}	0.37^{a}	0.54^{a}	234.52^{b}	26.20^{d}	274.10^{b}
S_2- 45 × 15 cm	7.75^{a}	0.37^{a}	0.54^{a}	241.23^{ab}	29.55^{b}	293.18^{a}
S_3- 20 × 20 cm	7.78^{a}	0.37^{a}	0.54^{a}	235.93^{b}	27.89^{c}	287.80^{a}
S_4- 20 cm (RPP)	7.75^{a}	0.38^{a}	0.55^{a}	247.12^{a}	31.74^{a}	298.81^{a}
Interaction (M × S)						
M_1S_1	7.80^{ab}	0.37^{ab}	0.55^{ab}	234.61^{ef}	27.39^{f-h}	281.90^{de}
M_1S_2	7.70^{ab}	0.38^{a}	0.54^{bc}	241.90^{b-e}	31.58^{ab}	295.40^{a-c}
M_1S_3	7.80^{ab}	0.36^{bc}	0.53^{c}	235.40^{ef}	29.41^{c-e}	290.54^{a-e}
M_1S_4	7.90^{a}	0.37^{ab}	0.55^{ab}	248.67^{ab}	32.59^{a}	300.14^{ab}
M_2S_1	7.90^{a}	0.37^{ab}	0.54^{bc}	234.60^{ef}	25.48^{i}	269.36^{f}
M_2S_2	7.70^{ab}	0.38^{a}	0.55^{ab}	234.10^{ef}	28.16^{e-g}	289.90^{a-e}
M_2S_3	7.70^{ab}	0.36^{bc}	0.54^{bc}	228.70^{f}	27.16^{gh}	284.39^{c-e}
M_2S_4	7.60^{b}	0.38^{a}	0.56^{a}	241.39^{b-e}	30.48^{bc}	295.68^{a-c}
M_3S_1	7.90^{a}	0.36^{bc}	0.53^{c}	239.40^{cde}	26.45^{hi}	278.67^{ef}
M_3S_2	7.80^{ab}	0.35^{c}	0.54^{bc}	248.30^{ab}	29.48^{cd}	293.89^{a-d}
M_3S_3	7.70^{ab}	0.37^{ab}	0.53^{c}	243.90^{b-d}	28.46^{d-f}	288.45^{b-e}
M_3S_4	7.80^{ab}	0.38^{a}	0.56^{a}	253.61^{a}	32.45^{a}	301.50^{a}
M_4S_1	7.60^{b}	0.36^{bc}	0.53^{c}	229.45^{f}	25.48^{i}	266.45^{f}
M_4S_2	7.80^{ab}	0.36^{bc}	0.54^{bc}	240.60^{b-e}	28.97^{de}	293.51^{a-d}
M_4S_3	7.90^{a}	0.37^{ab}	0.54^{bc}	235.70^{d-f}	26.54^{hi}	287.80^{b-e}
M_4S_4	7.70^{ab}	0.38^{a}	0.53^{c}	244.80^{bc}	31.45^{ab}	297.90^{ab}

Mean followed by the same letter(s) did not differ significantly by DMRT (p= 0.05)

utilization, reducing soil fixation, encouraging beneficial associations, optimizing plant density and improving water use efficiency all of which collectively contribute to higher phosphorus content in wheat grain. Similar results were obtained by Sharma (2020).

Potassium content in grain, straw and total content (%): Planting geometry of 45 × 15 cm recorded significantly higher grain potassium content and numerically higher straw and total potassium content (0.49, 1.29 and 1.78 %, respectively) as compared to 20 cm (RPP) planting geometry (Table 3). The right planting geometry supports efficient potassium uptake by promoting optimal root development, minimizing competition, enhancing fertilizer utilization, reducing soil fixation, facilitating root soil interactions, optimizing plant density and improving water use efficiency all of which contribute to higher potassium content in wheat grain.

Nutrient Uptake by Emmer Wheat as Influenced by Planting Geometries

Nitrogen uptake in grain, straw and total N uptake (kg ha^{-1}): The 30 × 15 cm planting geometry (S_1) recorded significantly higher nitrogen uptake in grain, straw and total N uptake (76.60, 39.88 and 116.48 kg ha^{-1}, respectively). Significantly lower nitrogen uptake in grain, straw and total N uptake was in (S_4) 20 cm (RPP) planting geometry (50.28, 23.60 and 73.88 kg ha^{-1}, respectively) (Table 4). The right planting geometry supports efficient nitrogen uptake by promoting optimal root development, minimizing competition, enhancing fertilizer utilization, reducing nitrogen loss, facilitating symbiotic nitrogen fixation, optimizing plant density and improving water use efficiency all of which contribute to higher nitrogen uptake by wheat (Chatterjee et al 2016).

Phosphorous uptake in grain, straw and total P uptake (kg ha^{-1}): Significantly higher phosphorus uptake in grain, straw and total uptake (13.62, 10.49 and 24.11 kg ha^{-1}, respectively) was recorded by the 30 × 15 cm planting geometry (S_1). The significantly lower phosphorous uptake in grain, straw and total uptake was recorded in (S_4) 20 cm (RPP) planting geometry (9.37, 7.90 and 17.27 kg ha^{-1}, respectively) (Table 4).

Potassium uptake in grain, straw and total K uptake (kg ha^{-1}): The 30 × 15 cm planting geometry (S_1) recorded significantly higher potassium uptake in grain, straw and total uptake (18.62, 84.84 and 103.46 kg ha^{-1}, respectively) and significantly lower potassium uptake in grain, straw and total uptake was in (S_4) 20 cm (RPP) planting geometry (12.65, 70.02 and 82.66 kg ha^{-1}, respectively) (Table 4). Similar results were obtained by Chatterjee et al (2016).

Influence of planting geometry on soil chemical properties after harvest of emmer wheat crop

The planting geometries, did not significantly influence the soil pH, electrical conductivity (dS m^{-1}) and organic carbon (%) (Table 5). This lack of significant influence on soil chemical properties through planting geometries may be attributed to the limited impact observed in this particular context. The non-significant impact of planting geometries on soil chemical properties post-harvest may be due to the inherent stability of the soil system under the studied configurations. Similar results were obtained by Sharma (2020).

Influence of planting geometries on available nitrogen, phosphorus and potassium status in soil after harvest of the emmer wheat crop

The 20 cm (RPP) planting geometry (S_4) recorded significantly higher available nitrogen, phosphorous and potassium in soil (247.12, 31.74 and 298.81 kg ha^{-1}, respectively) and was found on par with S_2 . In converse, significantly lower available nitrogen, phosphorous and potassium in soil was recorded in 30 × 15 cm planting geometry (S_1) (234.52, 26.20 and 274.10 kg ha^{-1}, respectively). These might be due to lower nutrients uptake *viz.,* nitrogen, phosphorous and potassium was recorded in 20 cm (RPP) planting geometry as compared to other planting geometries. Similar results were obtained by Dharet al (2015).

Table 6. Correlation coefficient between grain protein, nitrogen, phosphorous and potassium content and economics of emmer wheat

Parameter	Grain protein content (%)	Total grain N content (%)	Total grain P content (%)	Total grain K content (%)	Gross returns (Rs. ha^{-1})	Net returns (Rs. ha^{-1})	B:C ratio
Grain protein content (%)	1						
Total grain N content (%)	0.937**	1					
Total grain P content (%)	0.781**	0.873**	1				
Total grain K content (%)	0.734**	0.670**	0.690**	1			
Gross returns (Rs. ha^{-1})	0.875**	0.912**	0.833**	0.550**	1		
Net returns (Rs. ha^{-1})	0.900**	0.932**	0.803**	0.644**	0.972**	1	
B:C ratio	0.880**	0.9070**	0.742**	0.688**	0.909**	0.9808**	1

**Significant at 5 %

Combined influence of seed priming and planting geometries on yield, quality parameters and nutrient uptake by emmer wheat

Yield and yield attributes: Primed seeds sown with 30 × 15 cm planting geometry (M_4S_1) recorded significantly higher grain (44.13 q ha^{-1}) and straw yields (70.64 q ha^{-1}) and grain yield was found on par with M_4S_3 , M_3S_1 , M_2S_1, M_2S_3 and M_1S_1 (Table 1). The significantly lower grain yield was in M_1S_4 (conventional line sown at 20 cm (RPP) planting geometry). This increase in grain yield might be due to the synergistic effect of seed priming with bio-formulation along with optimum planting geometry and increased yield attributes *viz.,* number of effective tillers (463.83 m^{-2}), number of grain per spike, spike weight, grain weight per spike, thousand grain weight and spike length and is on par with M_2S_1, M_4S_3 and M_4S_2. These findings are consistent with the outcomes reported by Haqueet al (2015) and Chatterjee et al (2016).

Grain crude protein content: The primed seeds sown with 30 × 15 cm planting geometry (M_4S_1) recorded significantly higher grain crude protein content (12.54 %) and was on par with M_4S_2 , M_4S_3 , M_2S_1 and M_2S_3 (Table 2). The significantly lower grain crude protein content was recorded in M_1S_4 (un-primed seed with 20 cm (RPP) planting geometry). This was due to higher uptake of nitrogen in grain increasing the grain protein content.

Nitrogen, phosphorous and potassium content in grain, straw and total content of emmer wheat: The primed seeds sown with 30 × 15 cm planting geometry (M_4S_1) recorded numerically higher nitrogen and phosphorous content in grain, straw and total content. However, higher potassium content in grain, straw and total content was recorded in primed seeds sown with 45 × 15 cm planting geometry (M_4S_1) as compared to un-primed seeds sown with 20 cm (RPP) planting geometries (Table 2 , 3). These might be due to the combination of seed priming and strategic planting geometries positively influences nutrient content in wheat grain by improving germination efficiency, optimizing root development, enhancing nutrient uptake systems, minimizing competition, facilitating soil-root interactions, promoting efficient fertilizer utilization and reducing nutrient loss. This is in accordance with the findings of Sharma (2020)

Nutrient uptake patterns of emmer wheat: The primed seeds sown with 30 × 15 cm planting geometry (M_4S_1) recorded significantly highest uptake of N, P and K by grain, straw and total uptake and lowest uptake of N, P and K was recorded in M_1S_4 (un-primed seed with 20 cm (RPP- planting geometry) (Table 4). The system of wheat intensification recorded higher uptake of N, P and K as compared to conventional method of cultivation which could be ascribed to better vegetative and reproductive growth under SWI method of cultivation. Wider spacing reduced the above and below ground competition, well developed and healthy root system causes increase N, P and K uptakes. Further primed seed recorded higher nutrient uptake than un-primed seed. This may be due to the fact that seed treatment helps in increasing the absorbing surface of root system causes increased plant growth and yield attributes and nutrient absorption by roots (N, P_2O_5 and K_2O). This is in accordance with the findings of Chandrapala et al (2010) and Zheng et al (2013).

Soil fertility status as influenced by varied planting geometries and seed priming: Combination of un-primed seeds sown with 20 cm (RPP) planting geometry (M_3S_4) recorded significantly higher soil available N , P , and K , after harvest of emmer wheat and it was on par with M_3S_2 , M_1S_4 , M_1S_2 and M_4S_4 . The significantly lower soil available N, P and K after harvest of wheat was in M_4S_1 and M_2S_1 (primed seed with 30 × 15 cm planting geometry) (Table 5). This might be due to higher uptake of N, P and K in primed seed sown with 30 × 15 cm planting geometry. Similar results were obtained by Sharma (2022).

Influence of seed priming and planting geometries on economics: Among the main plots, primed seeds (M_4) recorded significantly higher gross return (₹1,41,915 ha^{-1}), net returns (₹92,033 ha^{-1}), and B:C ratio (2.88) and was on par with M_2 and M_3. The significantly lower gross returns, net

Table 7. Correlation coefficient between Macro nutrient uptake by emmer wheat and available macro nutrient in soil after harvest of emmer wheat

Parameter	Total N uptake (kg ha^{-1})	Total P uptake (kg ha^{-1})	Total K uptake (kg ha^{-1})	Available N in soil (kg ha^{-1})	Available P in soil (kg ha^{-1})	Available K in soil (kg ha^{-1})
Total N uptake (kg ha^{-1})	1					
Total K uptake (kg ha^{-1})	0.961**	1				
Total K uptake (kg ha^{-1})	0.958**	0.959**	1			
Available N in soil (kg ha^{-1})	-0.669**	-0.512**	-0.625**	1		
Available P in soil (kg ha^{-1})	-0.937**	-0.830**	-0.874**	0.795**	1	
Available K in soil (kg ha^{-1})	-0.870**	-0.817**	-0.838**	0.745**	0.911**	1

**Significant at 5 %

Table 8. Economics of emmer wheat as influenced by seed priming and different planting geometries

Treatment	Cost of cultivation (Rs ha^{-1})	Gross returns (Rs ha^{-1})	Net returns (Rs ha^{-1})	B:C ratio
Main plots:- (Two genotypes with and without seed priming)				
M_1-Gokak local (WOP)	48400^{a}	121192^{b}	72792^{b}	2.53^{b}
M_2- Gokak local (WP)	49022^{a}	133253^{ab}	84231^{ab}	2.76^{ab}
M_3-DDK 1029 (WOP)	48511^{a}	129284^{ab}	80773^{ab}	2.70^{ab}
M_4-DDK 1029 (WP)	49883^{a}	141915^{a}	92033^{a}	2.88^{a}
Sub plots:- (Four planting geometries)				
S_1- 30 × 15 cm	46247^{b}	147989^{a}	101742^{a}	3.20^{a}
S_2- 45 × 15 cm	45834^{b}	125890^{c}	80056^{c}	2.75^{c}
S_3- 20 × 20 cm	47162^{b}	135377^{b}	88215^{b}	2.87^{b}
S_4- 20 cm (RPP)	56572^{a}	116388^{d}	59816^{d}	2.06^{d}
Interaction (M × S)				
M_1S_1	46082^{d}	134009^{ef}	87927^{ef}	2.91^{b}
M_1S_2	45702^{d}	116698^{h}	70996^{j}	2.55^{h}
M_1S_3	46234^{d}	125807^{g}	79573^{h}	2.72^{g}
M_1S_4	55582^{b}	108254^{i}	52672^{l}	1.95^{k}
M_2S_1	46362^{d}	155474^{b}	109112^{b}	3.35^{b}
M_2S_2	45926^{d}	125963^{g}	80037^{h}	2.74^{fg}
M_2S_3	46536^{d}	136344de	89808^{e}	2.93^{de}
M_2S_4	57262^{ab}	115229^{h}	57967^{k}	2.01^{jk}
M_3S_1	46132^{d}	140234^{d}	94102^{d}	3.04^{c}
M_3S_2	45742^{d}	129102^{fg}	83360^{g}	2.82^{ef}
M_3S_3	46288^{d}	130965^{f}	84677^{fg}	2.83^{ef}
M_3S_4	55882^{ab}	116836^{h}	60954^{k}	2.09^{ij}
M_4S_1	46412^{d}	162240^{a}	115828^{a}	3.50^{a}
M_4S_2	45966^{d}	131798^{ef}	85832^{fg}	2.87^{e}
M_4S_3	49590^{c}	148392^{c}	98802^{c}	2.99^{cd}
M_4S_4	57562^{a}	125232^{g}	67670j	2.18^{i}

Mean followed by the same letter(s) did not differ significantly by DMRT (p= 0.05)

returns and B:C ratio was recorded in un-primed seeds (M_1). Within the sub plot, 30 × 15 cm planting geometry (S_1) recorded significantly higher gross return (₹1,47,989 ha^{-1}), net returns (₹1,01,742 ha^{-1}), and B:C ratio (3.20) when compared to (S_4) conventional line sown at 20 cm (RPP) planting geometry. Among the interaction effect, primed seeds sown with 30 × 15 cm planting geometry (M_4S_1) recorded significantly higher gross return (1,62,240 ha^{-1}), net returns (1,15,828 ha^{-1}), and B:C ratio (3.50) (Table 8) when compared to un-primed seeds with conventional line sown at 20 cm (RPP) planting geometry (M_1S_4). This might be due to lower usage of external input *viz.,* very low seed rate, higher grain yield, straw yield and less labour requirement *etc.* Similar type of results was also obtained by Kumar et al (2015) and Bhargava et al (2016).

CONCLUSION

Among the different treatment combinations, primed seeds sown with 30 × 15 cm planting geometry recorded significantly increased number of effective tillers, grain yield, straw yield, biological yield, grain crude protein content, macro nutrients content with greater uptake and higher economics. Thus, system of wheat intensification is best suitable option for resource poor farmers for getting higher yield and profit in irrigated ecosystem of Northern Dry Zone of Karnataka (Zone-3).

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Nutrient Release Rate of *Crotolaria juncea* Degradation with Incorporation of Ligno-cellulolytic Bioinoculant under Dry and Flooded Conditions

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Abstract: The application of green manure in the field needs fallow period of 20-30 days so as to allow decomposition, the application of bacterial culture that can enhance the degradation rate can decrease the fallow period and allow early sowing of next crop thereby saving time. The present study was conducted to evaluate the nutrient release during decomposition of *Crotolaria juncea* with application of efficient lignin-cellulose degrading bacterial consortium in laboratory under dry and flooded conditions. The study reported 15 times higher decomposition during first eight days of incubation under aerobic conditions with application of bacterial consortium. Application of consortium culture was more effective in degradation as compared to control and single culture application. Significant increase in NO_3^--N content was observed during incubation period whereas, NH_4^+-N content showed peak increase at 45 days of incubation. Aerobic conditions supported rapid release of both NH_4^+-N and NO_3^--N content during initial days of incubation. In flooded water regimes nitrogen release (NH_4^+-N + NO_3^--N) was low owing to more denitrification activity in water logged conditions. The phosphorus (P) and potassium (K) content showed positive relation with decomposition of green manure. The application of bacterial consortium has further enhanced the release of P and K as compared to control treatment. This might be due to enhanced degradation that led to release of these nutrients. There was significant impact of water regimes on phosphorous release, as remarkable increase was in P value under flooded conditions. The study showed that application of ligno-cellulolytic consortium bioinoculant enhanced the decomposition as well as nutrient release form *Crotolaria juncea*.

Keywords: Bacterial consortium, Decomposition, Nutrient release, NH_4^+-N, Phosphorous

Environmental contamination has the potential to be a major threat to the survival of living organisms. The misuse of chemical fertilizers and pesticides can contribute to the deterioration of the environment. This can affect soil fertility resulting in a loss of productivity, and this realization has led to the adoption of sustainable farming practices (Vogel et al 2019). Green manure crops have an increasingly important role in sustainable crop production. The incorporation of green manure in soil plays a key role in the nutrient cycling in the soil ecosystems. Their incorporation in soil causes recycling of nutrients bound in plant biomass through microbial decomposition (Kalita et al 2022), thus making them available for crop uptake (Lei et al 2022). The overall nutritional impact of green manure on crop primarily depend on its efficient decomposition and nutrient release. Organic material decomposition is a complex process determined by three main interacting groups of factors: biotic (microorganisms and invertebrates that take part in litter decomposition), chemical (composition of the litter) and physical such as climate and environment surrounding the litter (Berg and Laskowski 2006). There are several naturally occurring microorganisms that are able to decompose organic waste leading to nutrient mineralisation. These microorganisms are also important to maintain nutrient flows from one system to another and to minimize ecological imbalance (Umsakul et al 2010). Microbes utilize organic waste for their growth and nutrition, when their requirements are met or microbial cells are lysed, excess ions got released into the soil pore water, which is accessible to plant roots. Thus, playing vital role in organic matter decomposition and nutrient mineralization (Duan et al 2021).

Decomposition of organic inputs is depended on survival, colonization and growth of microorganisms associated with it. Although, number of soil microorganisms are able to degrade organic inputs, but; scarce number or limited biodegradation capacity of the autochthonous microbes may result in inefficient and delayed decomposition rates (Xu et al 2019). Therefore, the *in-situ* degradation of organic amendments can be enhanced by augmentation of potential ligno-cellulolytic microorganisms into the system (Bhattacharjya et al 2021). The discovery of novel bacterial cultures for biodegradation of lignocellulosic materials is gaining much attention because of their inherent metabolic diversity, higher growth rate, genome variability, biotechnological significance and immense environment stability (Zhao et al 2019). This paper will focus on studying the role of bacterial inoculants in boosting the decomposition and nutrient mineralization from *Crotolaria juncea* in lab conditions.

MATERIAL AND METHODS

The experiments were carried out in the Department of Microbiology, Punjab Agricultural University, Punjab, India. The soil used in the experiment had a pH of 8.46, 5.29 mg/kg available N, 1.32 mg kg^{-1} Olsen P, 1.60 mg/kg exchangeable potassium and an electrical conductivity of 0.20dS/m. The bulk soil sample was collected fresh from the experimental field and was air-dried to sieve through 2 mm pore size. The experiment was conducted in two types of soil *i.e.,* sterilized and unsterilized soil. The fresh soil was autoclaved at 15psi (121°C) for 30 minutes, cooled and again autoclaved for three consecutive days. The experiments was carried out in polypropylene bags (18”×12”) in triplicate.

Organic amendments: The green manure crop (*Crotolaria juncea)* was grown to the age of 45 days in the experimental field of School of Organic Farming, PAU, Ludhiana. The freshly collected green-manure plants were chopped into pieces (3.5-5.5 cm long) for use in this study. Green manure and soil were mixed in 1:2 ratio and contents were thoroughly hand-mixed into the soil.

Bacterial cultures: Three bacterial culture were isolated from different soil samples, screened and selected for their cellulose degrading ability namely BC1, BC2 and BC3 which were applied singly and in mixture of three known as consortium bioinoculants. The control treatment devoid of any bacterial culture was also kept during the study. The bacterial culture was identified molecularly as BC1-*Lysinibacilllus sp.* VKM B-751 (MT539731.1); BC-2-*Glutamicibacter mishrai* strain S5 (CP032549.1); and BC3-*Paenibacillus sp.* A3 (HG003584.2).

Moisture regime: The nutrient transformations in the amended soil were studied at 37±5°C (room temperature) at two moisture regimes using a completely randomized design with two replications. The two moisture regimes were: (i) Aerobic condition (field capacity): The soil was maintained at around 14.0% moisture (w/w). The soil moisture was maintained by adding water after every week. (ii) Flooding conditions: A 1.0 cm layer of water was maintained at the surface of the soil throughout the study period by adding water every 2 days. Total of ten treatments were designed to determine decomposition and nutrient mineralization pattern of *Crotolaria juncea* in two different water regimes (aerobic and flooding) as follows-

Soil sampling and analysis: Decomposition of green manure was monitored by the loss of green manure weight at 2 days interval upto 14^{th} day. Soil samples (10 g) were taken at 2, 4, 6, 8, 10, 12, 14 day and analysed for available phosphorous and exchangeable potassium whereas mineral N (NH^+-N + NO_3^--N) was recorded at 16, 30, 45 and 60^{th} day from each treatment (Table 1). The soil phosphorous, potassium content and Mineral nitrogen were determined using methods given by Olsen et al. (1954), Jackson (1967) and Page et al. (1982), respectively.

Statistical analysis: The mean values recorded for different observation and results were subjected to analysis of variance and difference between treatments were analysed by Tukey' b test using SPSS 16.0 software.

RESULTS AND DISCUSSION

Green manure decomposition: Decomposition was recorded in terms of green manure weight loss during the studies. Weight of green manure was significantly affected by the application of bacterial culture in the aerobic conditions than flooding conditions. However, the significant amount of weight loss occurred during the first eight day of green manure incubation with unsterilized soil + consortium culture (Fig. 1a). In sterilized soil, green manure weight loss rate was 4.49 % day^{-1} with the application of the consortium culture which was significantly higher over its uninoculated control i.e., 3.56% day^{-1}. Irrespective of the inoculation, there was a higher weight-loss rate in unsterilized soil treatments as compared to sterilized soil. The application of consortium in unsterilized soil increased weight loss rate by 12 times than that of sterilized conditions. Application of consortium culture increased the green manure weight loss during first week by 5.7 % day^{-1}which was significantly higher than its uninoculated control (4.14% day^{-1}) in sterilized soil. In unsterilized soil this value further increased to 6.38% $day^{-1}$with consortium as compared to 5.37% day^{-1} in its uninoculated control. The present study revealed that application of consortium to green manure accelerated the decomposition in terms of weight loss rate during first week of incubation. Silva et al (2008) observed the decomposition process associates with the compounds that are degraded in each phase, as a result decomposition occurs faster in the early stages when easily assimilable substrates are available to microbes and slows down when only complex material was available to microbes.

Decomposition of green manure significantly affected by the moisture regimes. Weight loss in flooding conditions

Table 1. Details of experimental treatments

Treatment	Details	Treatment	Details
T1	SS+ GM	T6	US+ GM
T2	SS+ GM+BC1	T7	US+ GM+BC1
T3	SS+ GM+BC2	T8	US+ GM+BC2
T4	SS+GM+BC3	T9	US+GM+BC3
T5	SS+GM+C	T10	US+GM+C

*SS-Sterilized soil; GM-Green manure; US-Unsterilized soil; BC-Bacterial culture; C- Consortium indicated that the application of bacterial culture (single /consortium) positively affected the decomposition but not to the extent in aerobic condition (Fig. 1b). Application of single culture in sterilized soil enhanced the weight loss by 1.40-1.46 % day^{-1}, whereas application of consortium enhanced the weight loss by 2.22% day^{-1}. Use of unsterilized soil significantly enhanced the weight loss of organic matter in each case, like in its uninoculated control treatment weight loss enhanced by 0.08% day^{-1}as compared to uninoculated control in sterilized soil. Application of consortium culture significantly enhanced the percent weight loss day^{-1} (2.71) as compared to the control treatment (2.31) during first eight days of incubation. Awasthi et al (2018) reported that bacterial assisted composting of food waste has attained early maturation as compared to uninoculated control; thereby improving C/N ratio, extractable nitrogen (ammonium) content, pH and EC. Manu et al (2019) concluded that microbial inoculation caused early waste stabilization and statistically impacted the degradation rate. Similarly, Greff et al (2022) also mentioned an improved biodegradation of organic inputs using ligninolytic or cellulolytic microbial inoculants. The inoculation with efficient microbes may help in promoting decomposition by reducing the initial lag phase, increasing the concentration of degrading enzymes, promoting the degree of humification and various nutrient transformations (Xu et al 2019, Chi et al 2020).

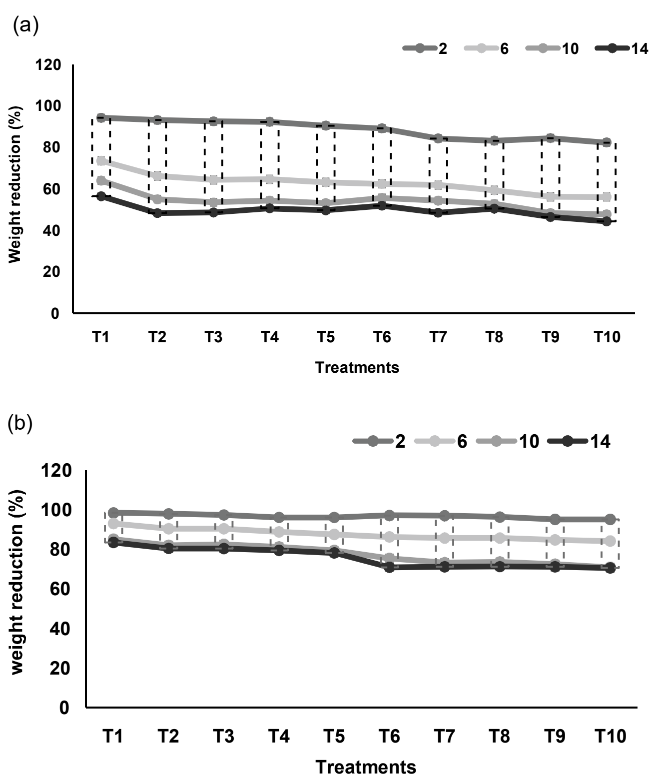

Fig. 1. Weight reduction of green manure using cellulose degrading bacteria in sterilized and unsterilized soil at different time intervals in a) aerobic conditions and b) in flooding conditions

Effect of bacterial inoculants on mineral nitrogen content of soil: In present investigations, an increase in the concentration of mineral nitrogen was brought by decomposition of organic matter bound nitrogen which was mediated by inoculated and indigenous microorganisms present under different soil and moisture regimes.

Nitrogen release under aerobic conditions: The NH_4^+-N content was significantly increased after the incorporation of green manure as compared to the 0 day content (5.29 mg/kg. In all treatments, during the first two weeks, NH_4^+-N content increased significantly over the control afterwards it increased slowly in all treatment. The rapid rise in NH_4^+-N during early period might be due to decomposition of the easily decomposable nitrogenous substances present in *Crotolaria juncea*. In sterilized soil, the highest mineralization rate of NH_4^+-N was observed with the inoculation of BC1 as compared to sole application of other bacterial culture, this might be attributed to the inherent capacity of ammonia released by bacteria (Table 2). However, application of culture as consortium showed further increase in the rate of NH_4^+-N release which indicated the combined efficiency of culture in decomposition of *Crotolaria juncea*. The release of NH_4^+-N was higher in unsterilized soil as compared to sterilized soil in all treatments showing that the inoculated bacterial culture had worked coordinatively with the natural microflora of soil and positively affected the release of nitrogen. As compared to ammoniacal nitrogen, the NO_3^--N content of the soil increased gradually throughout the incubation period (Table 2). The maximum increase in the nitrification was recorded during the 8^{th} to 12^{th} day of incubation in all treatments. The rapid increase in soil NO_3-N content was observed after the 30^{th} day indicating that nitrification dominated over the process of ammonification and may be due to stimulation of nitrifying bacteria in response to higher availability of ammoniacal substrate and aerobic soil condition during decomposition of *Crotolaria* in soils.

The uninoculated control soil also showed a considerable increase in the mineral N content during incubation. This might be due to decomposition of added organic materials that had a positive priming action in increasing mineral N. Present results corroborated with Trinsoutrot et al (2000) that residues having C/N ratio ≤24 induced a surplus of mineral N following addition to soil. Mohanty et al (2011) also reported an immediate nitrogen mineralization on application of

Gliricidia (green manure crop) to soil as rate of nutrient mineralization also dependent on chemical composition of the residue and green manures having low C/N ratio and polyphenols were expected to be easily degraded by soil microbes; releasing nutrients (N) into the soil. In present study an increased N mineralization was recorded under consortium inoculation than uninoculated controls. This could be related to the inherent ability of the inoculated bacterial strains to produce and excrete ammonia or their synergistic effect on the improved degradation of nitrogenous substrates. Resende et al (2000) observed that N contained in stems and leaves of *Crotalaria juncea* was linked to more easily decomposable compounds. Awasthi et al (2020) reported enhanced the extractable ammonium content from food waste with bacterial inoculation as compared to uninoculated control, by supporting degradative and maturation processes. Wu et al (2019) reported that mixed culture of *Trichoderma viride* and *T. harzianum* improved total N, P and K content of corn straw – pig manure and rice straw – pig manure compost over the uninoculated control.

Nitrogen release under flooding condition: Ammoniacal nitrogen content of soil-organic matter mixtures increased during incubation under flooding conditions but, to a lesser extent as compared to the aerobic conditions and can be due to decomposition of organic materials takes place under flooding conditions at slower rate as compared to aerobic conditions. The application of consortium bioinoculant significantly increased NH_4^+-N content at all-time intervals as compared to uninoculated control treatment. Highest NH_4^+-N was observed at 45th day of incubation and then declined progressively. The NO_3-N content too has risen slightly only during the 1st week under flooded conditions. After the 8th day of inoculation, an immediate decrease was observed in NO_3-N content in all treatments (Table 2). The results could be supported in terms that nitrification is an oxidation process occurring under aerobic conditions whereas, slight increase could possibly due to the aerobic conditions prevailed at some void areas making the process feasible for a short period. Additionally, increase in NH_4^+-N up to 45 days of incubation might have favour denitrification under flooding conditions. Higher availability of nitrate N was for BC1 culture and might be due to higher NH_4^+-N produced with application of this culture that acted as precursor for the nitrate production. Degradation of green manure in the presence of microbial inoculants could significantly improve mineral nitrogen content. The flooded soil is a dynamic heterogeneous soil-water system that has three distinct soil layers established mainly by the prevailing oxidation-reduction or redox potential (Eh or pE) of the system. soil NO_3–N concentrations decreased and soil NH_4–N concentrations increased with flooding as expected under the anaerobic soil conditions reached under flooding. Under anaerobic conditions, three main N transformations occur: (i) ammonification (the conversion of organic N into NH_4–N), (ii) nitrate reduction (conversion of NO_3–N into NH_4–N), or (iii) denitrification (conversion of NO_3–N into N_2). Therefore, under flooded conditions, NH_4–N is being produced (ammonification and nitrate reduction) while NO_3–N is being lost (nitrate reduction and denitrification). Nitrate is a mobile form of N and thus it can also be leached from the system under flooded conditions. Unger et al. (2009) also observed that decrease in NO_3–N and an increase in NH_4–N was observed in the 5-week flood treatments, however no differences were observed between the flowing and stagnant treatments. Hefting et al. (2004) demonstrated that the height of the water table can affect the outcome of N mineralization. In their study, when the water table was within 10 cm of the soil surface, ammonification was the primary N mineralization reaction taking place while net nitrification was insignificant.

Effect of bacterial inoculants on soil phosphorus availability

under aerobic conditions: Application of green manure significantly increased the phosphorous content in soil as

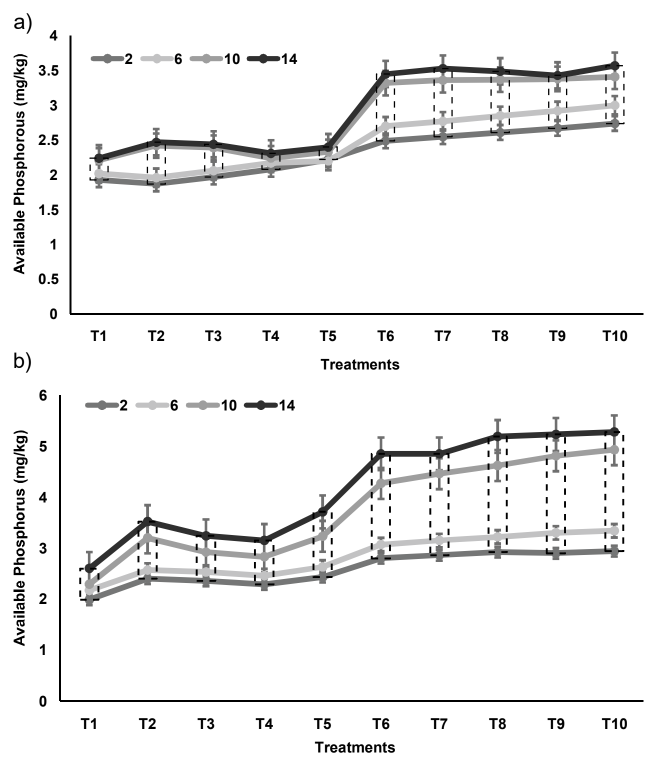

Fig. 2. Effect of different bacterial cultures on phosphorous mineralization from green manure in a) in aerobic conditions, b) in flooding conditions

compared to the 0 day (1.60 mg/kg). The phosphorous content was increased up to the 14th days of incubation however, application of bacterial culture positively influenced phosphorous levels in soil. Among the sole inoculants, BC3 culture significantly enhanced the phosphorous level as compared to uninoculated control treatments. The highest phosphorous content was in treatment having application of consortium culture. In sterilized soil conditions, there was about 6.0% increase in the phosphorous level with consortium inoculation over its uninoculated control (Fig. 2). This could be directly related to the enhanced decomposition of green manure due to combined activity of cultures present in consortium in sterile soil. However, the phosphorous content in treatments with unsterilized soil was found to be higher than sterilized soil, which indicated the cooperation derived from indigenous microbial flora in degradation biomass and phosphorous mineralization. Decomposition of green manure causes release of high chelation capacity products which lowers the activity of polyvalent that form insoluble salt with phosphorous thus liberates P from the basic phosphates of these elements. In present study, the phosphorous availability positively correlated with the nitrogen content. This might be due to the fact that soils with high ammonification activities usually favour the processes resulting in rapid release of phosphorous in soil.

Soil phosphorous availability under flooding conditions: The different water regimes significantly affected the soil available phosphorous content during green manure decomposition. The available phosphorous increased markedly in the soil maintained under flooding conditions as compared with aerobic conditions. However, in accordance to aerobic conditions, the highest available phosphorous was in treatment having bacterial consortium. The bacterial inoculation was more effective in improving phosphorous availability from green manure decomposition, indicating that bacterial inoculant effectively coordinated with the indigenous microbial flora (Fig. 2).

Chimouriya et al. (2018 and) Kumar et al (2020) also documented that green manures can affect soil P availability through several mechanisms, such as (i) mineralization of biomass P; (ii) increased soil microbial activity due to release of phytases or phosphatases may transform the unavailable P to available P; (ii) Decomposition released CO_2 that react with water to form carbonic acid in soil solution thereby facilitating dissolution of P (iv) Released organic compounds may mask various P adsorption sites in soil or may release P from these sites by anion exchange method. Zhou et al (2021) observed rapid P release from green manure (milk vetch) during first five days, followed by a gradual increase up to 125 days. This rapid release of unstructured P (40-60 % of the total plant P) may be attributed to nucleic acid or other ionic forms of P in plant residues (Mubarak et al 2002). Sun et al (2021) reported that the P release rate from animal manure-maize straw mixture increased gradually; showing a rapid release initially and slow in the latter stages of decomposition. Moreover, the increasing soil P availability with increase in incubation indicated that supply of P from residues remained higher than microbial demand throughout 60 days (Chimouriya et al 2018).

Effect of bacterial inoculants on exchangeable potassium content: The exchangeable potassium content of soil showed positive correlation with the weight loss of green manure. Potassium content increased up to the 14th day after inoculation (Fig. 3). Application of consortium culture significantly increased the potassium as compared to the control treatment. Potassium contained in green manure was also thought be the nutrient that evenly releases as the decomposition process proceeds and become available to plants. The extent and rate of K release from crop residues was usually considered greater than residue dry matter decomposition and N or P release (Lupwayi et al 2006). Talgre (2014) observed negative relation of potassium with the C/N ratio of organic matter, i.e., lower the C/N ratio higher release of potassium. Potassium being not a structural constituent of cell , so got easily solubilized by water in early stages of decomposition of organic residues, thus have

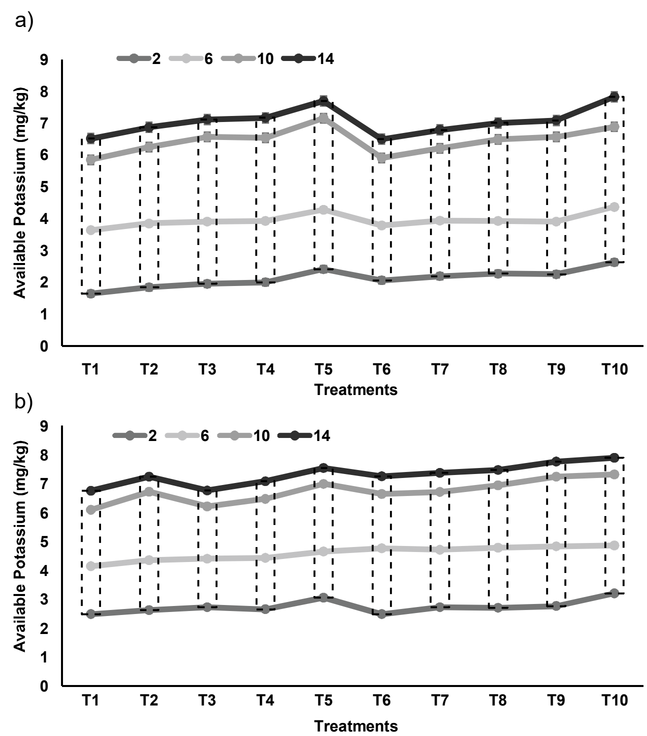

Fig. 3. Effect of different bacterial cultures on exchangeable potassium mineralization from green manure in a) in aerobic conditions, b) in flooding conditions

highest release rate among major nutrients (Mubarak et al 2002). Green manure (such as milk vetch) had been suggested as quick acting K fertilizer as it released 70-84 % of K within first 5 days of application (Zhou et al 2021). Kaur (2018) reported that increase in soil K content following green manuring might be due to the release of Fe^{2+} and Mn^{2+} under highly reduced conditions created during decomposition. Present results of higher soil available K in consortium inoculated treatments indicated that addition of effective microorganism can influence soil macronutrient content by improving the processes of nutrient mineralization (Wu et al. 2019).

In flooding conditions, the potassium content was low as compared to the aerobic conditions indicating the greater contribution to oxidative degradation reaction towards potassium release and availability. The maximum potassium content was with consortium application in unsterilized soil. Increase in soil solution K concentration might be due to release of Fe^{2+} and Mn^{2+} under highly reduced conditions created by green manure (Fig. 3). K release rate could also be highly conditioned by the precipitation during the decomposition period (Rodrı´guez-Lizana et al 2010). Lupwayi et al (2004) observed that intensive root decomposition and K release occurred from June to August with much rain received during these months and this effect was less prominent in above ground mass decomposition. Periera et al (2016) also observed that the rate of release of K could be correlated with the rate of decomposition of dry matter. Likewise, Gao et al (2015) used complex biological agent (fungi + bacteria) capable of increasing the total K content of the final corn stalk-swine waste compost compared to control. Wan et al (2020) reported that inoculation of 25

Table 2. Effect of cellulose degrading bacteria on nitrate and ammoniacal nitrogen in sterilized and unsterilized soil at different time intervals during green manure decomposition

	Nitrate nitrogen (mg/kg) at different days											
	Under aerobic conditions						Under flooding conditions					
	2	8	16	30	45	60	2	8	16	30	45	60
T1	0.01^{I}	0.38^{J}	6.52^{J}	9.57^{J}	11.43^{J}	16.88^{J}	0.01^{H}	0.98^{I}	0.90^{H}	0.89^{G}	0.91^{H}	0.93^{H}
T2	0.22^{F}	4.44^{E}	10.86^{F}	15.29^{F}	17.98^{H}	22.73^{G}	0.12^{E}	1.12^{E}	1.08^{E}	1.07^{E}	1.11^{E}	1.13^{I}
T3	0.03^{H}	2.12^{G}	10.60^{H}	14.66^{H}	17.76^{I}	21.18^{I}	0.07^{G}	1.01^{H}	0.95^{G}	1.00^{F}	1.02^{G}	1.08^{F}
T4	0.04^{G}	1.54^{I}	10.62^{G}	15.19^{G}	18.00^{G}	22.60^{H}	0.09^{F}	1.07^{G}	1.02^{F}	1.01^{F}	1.06^{F}	1.09^{F}
T5	0.34^{C}	3.31^{F}	11.33^{E}	15.51^{E}	19.22^{F}	22.81^{F}	0.22^{C}	1.16^{D}	1.10^{D}	1.09^{D}	1.13^{D}	1.15^{D}
T6	0.22^{F}	1.54^{H}	9.33^{I}	14.02^{I}	19.35^{E}	24.62^{E}	0.13^{E}	1.10^{F}	1.02^{F}	1.01^{F}	1.03^{G}	1.05^{G}
T7	0.38^{B}	6.42^{B}	14.71^{B}	19.45^{B}	25.28^{B}	28.69^{B}	0.24^{B}	1.24^{B}	1.20^{B}	1.19^{B}	1.23^{B}	1.25^{B}
T8	0.27^{E}	5.38^{D}	13.80^{C}	18.70^{C}	23.63^{C}	26.51^{D}	0.19^{D}	1.13^{E}	1.07^{B}	1.12^{C}	1.14^{D}	1.22^{C}
T9	0.29^{D}	5.82^{C}	13.15^{D}	18.54^{D}	23.28^{D}	26.53^{C}	0.21^{C}	1.19^{C}	1.14^{C}	1.13^{C}	1.18^{C}	1.21^{C}
T10	1.54^{A}	6.93^{A}	15.52^{A}	19.88^{A}	26.53^{A}	29.00^{A}	0.34^{A}	1.28^{A}	1.22^{A}	1.21^{A}	1.25^{A}	1.27^{A}
	Ammoniacal nitrogen (mg/kg) at different days											
	Under aerobic conditions						Under flooding conditions					
	2	8	16	30	45	60	2	8	16	30	45	60
T1	5.8^{I}	7.4^{H}	11.4^{J}	16.4^{J}	13.5^{J}	13.2^{J}	5.3^{F}	6.9^{F}	9.8^{I}	11.7^{H}	11.1^{H}	10.9^{G}
T2	6.5^{F}	8.8^{F}	13.6^{F}	18.4^{I}	16.3^{I}	16.1^{I}	5.6^{EF}	7.3^{BCD}	11.7^{E}	14.0^{F}	13.1^{E}	12.8^{E}
T3	6.1^{H}	8.0^{G}	12.8^{G}	19.2^{F}	16.8^{G}	16.5^{G}	5.3^{F}	7.2^{CDF}	11.4^{EF}	14.5^{F}	12.5^{F}	12.5^{E}
T4	6.1^{H}	7.8^{G}	12.3^{I}	18.8^{H}	16.5^{H}	16.1^{H}	5.4^{F}	7.0^{DF}	11.1^{FG}	13.4^{G}	12.1^{G}	11.7^{F}
T5	6.7^{E}	9.1^{E}	14.1^{E}	21.2^{D}	17.6^{E}	16.9^{F}	5.8^{DE}	7.5^{BC}	12.6^{D}	17.5^{C}	14.0^{D}	13.8^{D}
T6	6.4^{G}	7.8^{H}	12.7^{H}	18.9^{G}	17.4^{F}	17.4^{E}	6.0^{CD}	7.5^{BC}	11.0^{G}	17.1^{D}	15.4^{C}	15.8^{C}
T7	7.4^{B}	10.0^{D}	18.7^{D}	21.0^{E}	19.6^{D}	19.2^{D}	6.5^{AB}	9.1^{A}	13.8^{B}	18.6^{AB}	17.3^{AB}	17.8^{A}
T8	7.0^{D}	10.4^{C}	20.7^{C}	23.0^{C}	20.6^{C}	20.3^{C}	6.2^{BC}	8.6^{B}	13.1^{C}	18.3^{B}	17.1^{B}	16.8^{B}
T9	7.3^{C}	11.0^{B}	21.3^{B}	23.2^{B}	21.0^{B}	21.1^{B}	6.3^{BC}	9.1^{A}	13.6^{B}	18.8^{A}	17.4^{AB}	17.7^{A}
T10	7.8^{B}	11.2^{A}	23.7^{A}	24.6^{A}	22.4^{A}	22.0^{A}	6.7^{A}	8.8^{A}	15.3^{A}	20.8^{A}	17.6^{A}	18.0^{A}

**Different letter shows significant differences at p=0.05 using post hoc text Tukey's B within treatments different cellulosic isolates improved co-decomposition of maize straw and chicken manure, resulting in higher nutrient content (NPK) and GI index compared to control.

CONCLUSION

Decomposition and nutrient mineralization from green manure can be improved with the application of microbial inoculants. The application of consortium significantly improved the decomposition and nutrient release in aerobic condition. Decomposed the green manure 7 days earlier than uninoculated control, thus have potential to decrease the fallow period between green manure incorporation and crop sowing (particularly maize). In this aspect, microbial consortium is more effective than individual culture and can be integrated with green manure practices to enhance soil nutrient availability as well as it can minimize ecological imbalance by maintaining nutrient flows from one system to another.

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Productivity and Biological Efficiency Indices of Sesamum + Cowpea Intercropping System in Response to Row Ratio and Nutrient Management

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***Abstract*:** Field experiment on sesamum + cowpea intercropping system was carried out to assess the yield advantage of the system using biological indices, *viz.,* land equivalent ratio (LER), relative crowding coefficient (RCC), aggressivity (A), competition index (CI), competition ratio (CR), sesamum equivalent yield (SEY) and percentage yield difference (PYD). The study was conducted at College of Agriculture, Vellayani, Thiruvananthapuram during the summer season of 2023. The experiment treatments comprised of combinations of three factors, *viz.,* three levels of nitrogen (N) (n_1- 100 % RDN; n_2- 75 % RDN; n_3- 50 % RDN), two row ratios (R) (r_1- 4:2; r_2- 6:3) and application of AMF (A) (a_1- without AMF; a_2- with AMF). The seed yield of sesamum and cowpea were significantly influenced by individual and interaction effects of treatments. Irrespective of the treatments applied all the intercropping systems showed advantage in terms of LER, CI and PYD. The component crop cowpea was observed with positive (+) aggressivity and higher (>1) CR indicates the dominance of cowpea over sesamum. The intercropping system with the treatment combination 100 % RDN at 6:3 row ratio without AMF ($n_1r_2a_1$) resulted in higher LER (2.40), RCC (66.18), SEY (1801), and PYD (139.87%).

Keywords: Sesamum intercropping, Biological indices, Productivity, Row ratio, AMF, levels of nitrogen

Sesamum stands as a traditionally significant and culturally influential crop with widespread impact on agriculture and nutrition. However, sesamum has been recognized as an exhaustive crop based on its ability to utilize and deplete soil nutrients at an accelerated rate, if not managed properly can lead to decline in soil fertility. Sesamum, being a crop highly susceptible to waterlogging, unprecedented rainfall is always a risk for sole cropping. Intercropping involving compatible crops is regarded as a risk alleviator with sustained yield advantage compared to sole cropping (Aulakh et al 2019). In general, pulses are perfect candidates for intercropping due to their short duration and relatively lower sensitivity to light and temperature. Further, they fix atmospheric nitrogen and also share a portion of the fixed nitrogen to the intercropped oilseeds (Jiwan et al 2021). Cowpea (*Vigna unguiculata* (L.) Walp) is one of pulses with high adaptability and consumer preference in Kerala. Several studies have shown cowpea to be a suitable crop for intercropping. However, cowpea is an aggressive legume and its performance in combination with sesamum has yielded contrasting results. Guedes et al (2010) reporting yield reduction of cowpea and Bhatti et al (2005) reporting reduction in yield of sesamum. Crop density and row configuration are important agronomic considerations for attaining the objectives of intercropping (Afe 2017). Both additive series and replacement series have been tested in several intercropping systems. With increasing demand for more sustainable crop production practices, supplying more nitrogen through nitrogen-fixation than by using synthetic chemical fertilizers has become a lucrative choice (Fustec et al 2010). Interplant nitrogen transfer, though a bi-directional process, nitrogen tends to get transferred from nitrogen-fixers to non-nitrogen fixers (Carlsson and Huss-Danell 2014). Arbuscular mycorrhizal fungi (AMF) are obligate symbionts that transport considerable amount of nutrients and water through the hyphal network to the associating crop (Chen et al 2018). This study therefore concentrates on the individual and interactive effects of various factors, *viz.,* nitrogen, row ratios, and AMF, on the productivity and biological efficiency of sesamum + cowpea intercropping system.

MATERIAL AND METHODS

The experiment conducted at, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala, India located at 8°25'41.3"N latitude and 76°59'16.7"E longitude, at an altitude of 29 m above mean sea level, during February to May 2023. The soil of the experimental field was sandy clay loam with a moderate acidic pH (5.8), moderate level of organic carbon (0.81%), low status of nitrogen (250.88 kg/ha), high availability of phosphorus (49.68 kg/ha), and medium in potassium (253.57 kg/ha) status. The sesamum variety

Thilak (ACV-3) released from College of Agriculture, Vellayani, Thiruvananthapuram and cowpea variety PGCP – 6 (Pant lobia - 3) released from G. B. pant University of Agriculture and Technology, Pantnagar were used for the study. The experiment was laid out in randomised block design with 3 x 2 x 2 treatments replicated thrice. The three factors were, levels of nitrogen (n_1- 100 % recommended dose of nitrogen (RDN); n_2- 75 % RDN; n_3- 50 % RDN), row ratios (r_1- 4:2; r_2- 6:3) and application of arbuscular mycorrhizal fungi (AMF) (a_1- without AMF; a_2- with AMF). All cultural practices followed as per the KAU package of practices recommendations (KAU 2016). Sole crops of sesamum and cowpea were raised for computing intercropping indices. The sesamum was harvested when the seeds of tenth capsule turned black and cowpea was harvested when 70 to 80 % of the pods turned brown with hard seeds inside. The sesamum and cowpea were harvested separately from the net plot area and the seeds were sun-dried and weight was expressed as seed yield in kg/ha. Biological indices were computed using yield data obtained from the intercropping system and sole crops.

Seed yield: Net plot area was harvested and the seeds were sun-dried and weight was expressed as seed yield in kg/ha.

Land equivalent ratio (LER): Land equivalent ratio was calculated as per the formula suggested by Willey (1979).

$$LER = L_s + L_c = \frac{Y_{sc}}{Y_{ss}} + \frac{Y_{cc}}{Y_{cs}}$$

where, L_s, L_c- LER for sesamum and cowpea, Y_{sc}- intercrop yield of sesamum

Y_{cs}- intercrop yield of cowpea, Y_{ss} - sole crop yield of sesamum

Y_{cc}- sole crop yield of cowpea

Relative crowding coefficient (RCC): Relative crowding coefficient denoted as 'K' was computed (de Wit 1960).

$$K_{sc} = \frac{Y_{sc} \times Z_{cs}}{(Y_{ss} - Y_{sc})Z_{sc}}$$

$$K_{cs} = \frac{Y_{cs} \times Z_{sc}}{(Y_{cc} - Y_{cs})Z_{cs}}$$

$$K = K_{sc} \times K_{cs}$$

where, K_{sc} and K_{cs}- relative crowding coefficient of sesamum intercropped with cowpea and sesamum, Y_{ss}- sole crop yield of sesamum, Y_{sc} - intercrop yield of sesamum , Y_{cc}- sole crop yield of cowpea, Y_{cs}- intercrop yield of cowpea

Z_{sc}- sown proportion of sesamum, Z_{cs}- sown proportion of cowpea

Aggressivity (A): Aggressivity was computed by using the formula proposed by McGilchrist (1965).

$$A_{sc} = \frac{Y_{sc}}{Y_{ss} \times Z_{sc}} - \frac{Y_{cs}}{Y_{cc} \times Z_{cs}} \qquad A_{cs} = \frac{Y_{cs}}{Y_{cc} \times Z_{cs}} - \frac{Y_{sc}}{Y_{ss} \times Z_{sc}}$$

where, A_{sc}- aggressivity of sesamum, A_{cs}- aggressivity of cowpea, Y_{ss}- sole crop yield of sesamum, Y_{cs} - intercrop yield of cowpea, Y_{cc}- sole crop yield of cowpea, Y_{sc}- intercrop yield of sesamum , Z_{sc}- sown proportion of sesamum, Z_{cs}- sown proportion of cowpea

Competition index (CI): Competition index was computed as suggested by Donald (1963).

$$CI = \frac{(Y_{ss} - Y_{sc}) \times (Y_{cc} - Y_{cs})}{Y_{ss} \times Y_{cc}}$$

where, Y_{ss}- sole crop yield of sesamum, Y_{sc}- intercrop yield of sesamum

Y_{cc}- sole crop yield of cowpea, Y_{cs}- intercrop yield of cowpea

Competition ratio (CR): Competition ratio was calculated (Willey et al 1980).

$$CR_s = \frac{Y_{sc}}{Y_{ss} \times Z_{sc}} \div \frac{Y_{cs}}{Y_{cc} \times Z_{cs}}$$

$$CR_c = \frac{Y_{cs}}{Y_{cc} \times Z_{cs}} \div \frac{Y_{sc}}{Y_{ss} \times Z_{sc}}$$

where,

CR_s, CR_c - competition ratio of sesamum and cowpea

Y_{ss}- sole crop yield of sesamum, Y_{sc}- intercrop yield of sesamum

Y_{cc}- sole crop yield of cowpea, Y_{cs}- intercrop yield of cowpea

Z_{sc}- sown proportion of sesamum, Z_{cs}- sown proportion of cowpea

Sesamum equivalent yield (SEY): Sesamum equivalent yield was computed based on the seed yield of the intercropped cowpea and prevailing market price of sesamum and cowpea, based on the crop equivalent yield (Lal and Ray 1976. Verma and Modgal 1983).

$$SEY = Y_{sc} + Y_{cs} \times \left\{\frac{P_c}{P_s}\right\}$$

where,

Y_{sc}- intercrop yield of sesamum, Y_{cs}- intercrop yield of cowpea

P_c- market price of cowpea, P_s- market price of sesamum

Percentage yield difference (PYD): Percentage yield difference was computed (Afe and Atanda 2015).

$$PYD = 100 - \left[\left\{\frac{Y_{SS} - Y_{SC}}{Y_{SS}} + \frac{Y_{CC} - Y_{CS}}{Y_{CC}}\right\}\right] \times \frac{100}{1}$$

where,

Y_{ss}- sole crop of sesamum, Y_{cc}- sole crop of cowpea

Y_{sc}- intercrop yield of sesamum, Y_{cs} - intercrop yield of cowpea

RESULTS AND DISCUSSION

Seed yield: Seed yield of both sesamum and cowpea were significantly influenced by individual and interaction effects (Tables 1, 2 3). The highest seed yield (1193 kg/ha) of sesamum was observed with 75 % RDN (n_2), whereas, the

Table 1. Effect of levels of nitrogen, row ratios and AMF on seed yield of sesamum and cowpea

Treatment	Seed yield (kg/ha)	
	Sesamum	Cowpea
Levels of nitrogen (N)		
n_1 – 100 % recommended dose of nitrogen	947^b	1647^a
n_2 – 75 % recommended dose of nitrogen	1193^a	1292^b
n_3 – 50 % recommended dose of nitrogen	802^c	1170^b
CD (p=0.05)	97.6	257.3
Row ratios (R)		
r_1 – 4:2	953	1355
r_2 – 6:3	1009	1384
CD (p=0.05)	NS	NS
AMF (A)		
a_1 – without AMF	994	1292
a_2 – with AMF	967	1447
CD (p=0.05)	NS	NS

AMF- Arbuscular mycorrhizal fungi; NS – Not significant

Table 2. Effect of N x R, R x A and N x A interactions on seed yield of sesamum and cowpea

Treatment	Seed yield (kg/ha)	
	Sesamum	Cowpea
Levels of nitrogen (N) x Row ratios (R)		
n_1r_1	814^b	1442^b
n_1r_2	1081^a	1852^a
n_2r_1	1216^a	1415^b
n_2r_2	1171^a	1168^b
n_3r_1	829^b	1207^b
n_3r_2	775^b	1132^b
CD (p=0.05)	138.1	363.9
Row ratios (R) x AMF (A)		
r_1a_1	892^c	1220
r_1a_2	1014^{ab}	1489
r_2a_1	1097^a	1364
r_2a_2	921^{bc}	1404
CD (p=0.05)	112.7	NS
Levels of nitrogen (N) x AMF (A)		
n_1a_1	970^{bc}	1602
n_1a_2	924^c	1692
n_2a_1	1311^a	1145
n_2a_2	1076^b	1439
n_3a_1	701^d	1129
n_3a_2	902^c	1210
CD (p=0.05)	137.968	NS

See Table 1 for treatment details

Table 3. Effect of N x R x A interactions on seed yield of sesamum and cowpea

Treatment	Seed yield (kg/ha)	Seed yield (kg/ha)
	Sesamum	Cowpea
Levels of nitrogen (N) x Row ratios (R) x AMF (A)		
$n_1r_1a_1$	729	1378
$n_1r_1a_2$	898	1507
$n_1r_2a_1$	1211	1827
$n_1r_2a_2$	950	1877
$n_2r_1a_1$	1240	1173
$n_2r_1a_2$	1192	1658
$n_2r_2a_1$	1382	1116
$n_2r_2a_2$	959	1221
$n_3r_1a_1$	706	1111
$n_3r_1a_2$	952	1304
$n_3r_2a_1$	696	1148
$n_3r_2a_2$	853	1116
CD (p=0.05)	NS	NS
Sole crop of sesamum without AMF	1138	1369
Sole crop of sesamum with AMF	1218	1649

See Table 1 for treatment details

treatment n_1 (100 % RDN) resulted in highest seed yield (1647 kg/ha) of cowpea. Considering the interaction effects, n_2r_1, r_2a_1, and n_2a_1 observed to have significantly higher seed yield (1216 kg/ha, 1097 kg/ha, and 1076 kg/ha respectively) of sesamum. The highest seed yield (1852 kg/ha) in cowpea was observed with the treatment n_1r_2 (100 % RDN at 6:3 row ratio). The 75 % RDN improved the yield of sesamum instead of growth. The combination of 75 % RDN with 6:3 row ratio, and without AMF application was favourable for increased yield in sesamum. Cowpea, as a high nitrogen requiring crop, it might have also used part of nitrogen that supplied for sesamum under full dose recommendation. The treatment, n_1r_2 (100 % RDN at 6:3 row ratio) proved its significance on seed yield of cowpea.

Land equivalent ratio: Irrespective of the treatments, all the sesamum + cowpea system resulted in LER of >1 indicates the yield advantage of the system, hence cowpea can be regarded as better component crop for sesamum. Among the treatment combinations, 100 % RDN at 6:3 row ratio without AMF ($n_1r_2a_1$) resulted in higher LER (2.40) followed by $n_2r_2a_1$ (2.03) (Table 4). Kotadiya et al (2023) reported the yield advantage of sesamum – pulse intercropping system in terms of LER.

Relative crowding coefficient: The 'K' value for sesamum, cowpea and the intercropping system varied among treatments (Table 4). The higher K value for sesamum (2.92) and cowpea (21.14) observed with $n_2r_1a_2$ and $n_1r_1a_2$ respectively, whereas RCC of the sesamum + cowpea intercropping system was observed to be higher (66.18) with 100 % RDN at 6:3 row ratio without AMF ($n_1r_2a_1$). When comparing to sesamum, cowpea was higher K value. The similar results were reported by Bhatti et al (2006). Aggressivity, RCC and CR revealed superior competitiveness of cowpea over sesamum when compared to other leguminous intercrops tested. This showed that when planted with sesamum, cowpea outperformed all other intercrops in terms of competitiveness by effectively utilizing the available resources.

Aggressivity: Irrespective of the treatment combinations, the aggressivity value (Table 4) of cowpea was positive (+) and that of sesamum negative (-) indicating the dominant behavior of cowpea over sesamum. The treatment, $n_1r_2a_2$ recorded higher (2.40) value of aggressivity for cowpea followed by $n_3r_2a_1$ (2.25) .The findings on aggressivity of cowpea are akin to the results of Bindhu et al (2014) and Bhatti et al (2006). Bhatti et al (2005) reported yield reduction in sesamum due to the luxuriant vegetative development of cowpea compared to other pulse crops.

Competition index: The competition index for all the treatment combinations were observed to lesser than unity (Table 5), indicating yield advantage of the sesamum + cowpea intercropping system. This indicates that, even if

Table 4. Effect of intercropping on land equivalent ratio (LER), relative crowding coefficient (K) and aggressivity (A)

Treatment	LER	Relative crowding coefficient			Aggressivity	
		K_{sc}	K_{cs}	K	A_{sc}	A_{cs}
$n_1r_1a_1$	1.65	0.89	-324.12	-288.85	-1.64	+1.64
$n_1r_1a_2$	1.65	1.40	21.14	29.67	-1.52	+1.52
$n_1r_2a_1$	2.40	-8.29	-7.98	66.18	-2.21	+2.21
$n_1r_2a_2$	1.92	1.77	-16.50	-29.24	-2.40	+2.40
$n_2r_1a_1$	1.95	-6.08	11.97	-72.76	-1.19	+1.19
$n_2r_1a_2$	1.98	2.92	-190.00	-554.80	-1.54	+1.54
$n_2r_2a_1$	2.03	-2.83	-7.74	21.91	-0.34	+0.34
$n_2r_2a_2$	1.53	1.85	5.70	10.55	-0.57	+0.57
$n_3r_1a_1$	1.43	0.82	8.59	7.02	-0.99	+0.99
$n_3r_1a_2$	1.57	1.79	7.55	13.50	-0.80	+0.80
$n_3r_2a_1$	1.45	0.79	10.39	8.19	-2.25	+2.25
$n_3r_2a_2$	1.38	1.17	4.19	4.88	-0.83	+0.83

See Table 1 for treatment details; K_{sc}, A_{sc} and K_{cs}, A_{cs} – relative crowding coefficient and aggressivity of sesamum in combination with cowpea respectively and cowpea in combination with sesamum respectively

Table 5. Effect of intercropping on competition index (CI), competition ratio (CR), sesamum equivalent yield (SEY), percentage yield difference (PYD)

Treatment	CI	Competition ratio		SEY (kg/ha)	PYD (%)
		CR_s	CR_c		
$n_1r_1a_1$	0.05	0.32	3.12	1133	64.68
$n_1r_1a_2$	0.03	0.37	2.71	1389	70.27
$n_1r_2a_1$	0.02	0.53	1.88	1801	139.87
$n_1r_2a_2$	-0.04	0.39	2.56	1617	97.28
$n_2r_1a_1$	-0.01	0.54	1.84	1679	94.65
$n_2r_1a_2$	0.00	0.49	2.04	1753	105.26
$n_2r_2a_1$	-0.06	0.61	1.65	1717	102.96
$n_2r_2a_2$	0.09	0.39	2.54	1286	58.29
$n_3r_1a_1$	0.14	0.31	3.22	1004	43.16
$n_3r_1a_2$	0.07	0.39	2.56	1321	62.70
$n_3r_2a_1$	-0.02	0.31	3.27	1188	45.06
$n_3r_2a_2$	0.11	0.35	2.86	1203	42.59

See Table 1 for treatment details
CR_s – competition ratio of sesamum; CR_c – competition ratio of cowpea

there exists dominance of cowpea over sesamum, over all it provides a favorable environment for higher productivity of the intercropping system. Kumar et al (2021) concluded that, short duration grain legumes with sesamum in an intercropping system could be advantageous, resulting in a synergistic relationship where both crops benefit from shared resources, further enhanced the overall productivity of the system.

Competition ratio: Cowpea recorded higher CR value than sesamum in all treatment combinations (Table 5). The $n_3r_2a_1$ (50 % at 6:3 row ratio without AMF) recorded higher CR for cowpea (3.27) followed by $n_3r_1a_1$ (3.22). The higher CR value indicates more competition between sesamum and cowpea. Superiority of cowpea in the intercropping systems was reported by Bhatti et al (2006).

Sesamum equivalent yield: The $n_1r_2a_1$ (100% RDN at 6:3 row ratio without AMF) resulted in significantly higher (1801 kg/ha) SEY (Table 5) followed by $n_1r_1a_2$ and $n_2r_2a_1$.This could be solely attributed to the higher overall seed yield (Table 3) observed in these treatment combinations. The combined individual and interactive effects of the treatments played a significant role in enhancing the yield attributes of both sesamum and cowpea ultimately leading to a comparatively higher total seed yield for the sesamum + cowpea intercropping system, hence the higher SEY.

Percentage yield difference: Percentage increase in yield was higher (139.87 %) for $n_1r_2a_1$ (100 % RDN at 6:3 row ratio without AMF) followed by $n_2r_1a_2$and $n_2r_2a_1$. The percentage yield difference was the least (42.59 %) in $n_3r_2a_2$ (50 % RDN at 6:3 row ratio with AMF). The yield reduction of sesamum was compensated by increase in the yield of cowpea. Percentage yield difference can be taken as a parameter to interpret the efficiency of intercropping system as it follows the trend of LER.

CONCLUSION

This study reveals the potential of growing sesamum and cowpea together as an intercropping system, showing improved productivity and biological efficiency. The intercropping system outperforms individual crops in terms of overall productivity and resource use efficiency, regardless of the specific treatment conditions. Among the various treatment combinations, the sesamum + cowpea intercropping system planted at 6:3 row ratio, provided with 100% recommended dose of fertilizers and without AMF application observed to be better.

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Influence of Potassium and Phosphate Solubilizing Bacteria on Growth and Development of Davana (*Artemisia Pallens* Bees)

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Abstract: The study assessed the impact of KSB and PSB application on *Artemisia pallens* growth, yield, and its impact on endophytic and rhizosphere bacterial populations. The plant height and flower diameter of davana were increased due to the application of T_7: 100% RDF+PSB+KSB over control and Recommended Dose of Fertilizer. Significantly higher plant height and flower diameter was 100% RDF+PSB+KSB compared to RDF alone. Treatments 75% RDF+PSB+KSB exhibited higher fresh plant weight than RDF alone. Soil samples from T_7 showed the highest bacterial population (49×104 Cfu/ml), enhancing plant yield and essential oil quality. Endophytic bacteria were predominantly Gram-negative with rod and cocci shapes. RDF with PSB and KSB increased respiration rate, indicating faster nutrient mineralization. Overall, 75% RDF with PSB and KSB benefits davana performance, bacterial population, and soil nutrient mineralization, reducing reliance on synthetic fertilizers and environmental risks.

Keywords: Davana, Essential oil, PSB, KSB, Endophytes

Artemisia pallens Bees (Davana) is an aromatic annual herb, belonging to the Compositae family, indigenous to India and cultivated in Karnataka, Tamil Nadu, and Andhra Pradesh. The genus Artemisia contains more than 480 species around the world, out of which about 45 species are found in India (Singh et al 2021). It is a short-season crop from November to March, prefers red-loamy and well-drained soil performs better during moderate winter conditions; however, it cannot withstand heavy rain. Davana has high economic value due to its aromatic essential oil, commercially used to replace artificial flavoring agents with natural flavoring in food products like cakes, candy, chewing gum, and ice creams (Trendafilova et al 2020). The essential oils are also used widely in the aroma industry for making perfumes on the other side davana extract is used in the beverage industry. Monoterpenes, sesquiterpenes, and derivatives of fatty acids make up the essential oil constituents. More than ninety components were identified, with *cis*-davanone, bicyclo germacrene, *trans*-ethyl cinnamate, davana ether isomer, and spathulenol being the main ones. These constituents have also been shown to be effective against certain pathogenic microbes (Singh et al 2021).

Chemical fertilizers are widely employed in large-scale commercial davana production to boost output and meet customer demand, which lowers the amount of nutrients that are readily available in the soil and microflora (Kumar et al 2019). Every nutrient that the plant absorbs from various sources plays a specific role that none of the others can provide. The three main nutrients-nitrogen (N), phosphorus (P), and potassium (K) are needed in high concentrations for the majority of crops and are essential to plant metabolism. The majority of primary minerals are insoluble due to their complex structure, which renders them unavailable for plant uptake. Potassium is designated as a macronutrient because plants absorb substantial amounts of it. Little amount of potash is primarily obtained in India from bedded marine evaporite deposits, glauconite, polyhalite, and sylvite, as well as surface and subsurface potash-rich brines. In addition to minerals, many other microorganisms coexist in symbiotic relationships with plants, including endophytic and rhizosphere microbes. Because of the reported advantages of these microbes, scientists have been interested in them. These microbes have an innate connection to their host plant and are capable of developing endogenously. Within the rhizosphere, bacteria identified as plant growth-promoting bacteria (PGPB) have the capacity to directly enhance plant growth by increasing the absorption of macronutrients and minerals, along with elevating essential hormone concentrations. Additionally, these bacteria can indirectly support plant growth by mitigating the harmful impacts of pathogens. Numerous plant tissues, such as leaves, stems, roots, and flowers, have been found to have endophytic bacteria (Kobayashi and Palumbo 2000). These tissues are a potential but not utilized source of phyto-constituents. Bacterial strains found in association with roots can contribute to the improvement of plant health and growth through mechanisms such as phyto-stimulation, biofertilization, and biocontrol. *Pseudomans, Pantoea*, and

Bacillus (Andreolli et al 2016), are advantageous for plant growth. This pot experiment uncovered a significant gap in research regarding the effects of applying potassium-solubilizing bacteria (KSB) and phosphate-solubilizing bacteria (PSB) on the economically important davana crop.

MATERIAL AND METHODS

Pot experiments followed by analytical lab procedures were conducted to evaluate the effect of phosphate and potassium solubilizing bacteria on the growth, development, and essential oil yield of *Artemisia pallens* followed by the identification and characterization of endophytes and various microorganisms in a soil sample from the rhizosphere of davana.

Study area: The pot experiment was conducted at CSIR-Central Institute of Medicinal and Aromatic Plants, Research Centre Bengaluru, Karnataka during 2022-23. Geologically the experiment site was located at 77º33′30″ East longitude and 13º05′06″ North latitude with a mean sea level of about 920 meters under the southern plateau and hilly zone.

Experimental design: The pot experiment consisted of eight treatments including T_1 (control), T_2 (RDF), T_3 (100% RDF+KSB), T_4 (75% RDF+KSB), T_5 (100% RDF+PSB), T_6 (75% RDF+PSB), T_7 (100% RDF+PSB+KSB) and T_8 (75% RDF+PSB+KSB) which were replicated thrice in randomized block design. The weather parameter did not affect the growth due to the pots were kept under a glass house to maintain a stable environment.

Crop husbandry: The experiment was performed in pots capable of filling 5 kg of soil using davana as a test crop. The 35 days old seedlings of davana raised in the nursery have been transplanted into pots containing sand, soil, and manure in equal proportions (1:1:1). The required quantity of microbial inoculation was applied at the rate of 10 kg/ha on hectare soil weight basis to respective pots along with RDF. Regular watering was done to maintain the soil moisture as and when required. No signs of pest or disease incidence were noted throughout the crop growth period; however, the precautionary spray of pesticide was taken accordingly. The crop was harvested at physiological maturity followed by drying and extraction of essential oil.

Extraction of essential oil: The herbage from each treatment was extracted individually, and using a Clevenger-type apparatus (Soxhlet extraction unit manufactured by Super Scientific Company Bengaluru), the herbage was hydro-distilled for six hours in a 2000 ml flask (Kumara et al 2023). The Triplicate of each treatment sample was obtained and the mean essential oil yield values were taken for the computation. The extracted essential oil was collected over glass vial contains anhydrous sodium sulphate and kept in cold and dark place until further analysis. To identify various components, gas chromatography analysis was also performed on essential oils.

Microbial Analysis of Plant and Soil Samples

Soil and plant sample collection: The soil samples for determination of the microbial population were collected at a depth of 10–15 cm below the surface from each treatment. The isolation of PSB was carried out from the rhizosphere soil. The well-grown plants are identified and plucked by gentle pulling. It was possible to isolate endophytic bacteria from the davana plant's leaves, stems, buds, and roots. Therefore, the mentioned samples were all taken straight to the lab and stored in labelled sterile polythene bags. We ran an hour-long analysis on these samples to get better findings.

Bacterial population count and isolation of bacteria: The bacterial population present in the rhizosphere soil was counted at the beginning, and after harvest. Phosphate-solubilizing bacteria were isolated and the bacterial count was estimated in each sample by using the serial dilution technique in nutrient agar media and incubated at 30 °C for 24 hours. The microbial growth was recorded by the colony count parameter. Each colony that appeared on the plate was considered one colony-forming unit (CFU) (Creach et al 2003). The different colonies according to color, shape, and size were further subjected to the identification of genera using staining techniques. As per morphological and biochemical features, the isolates were characterized and classified up to the genus level on Pikovskaya's and Aleksandrov's agar media respectively.

$$CFU = \frac{\text{Number of colonies counted on plate}}{\text{Volume of the sample x Dilution factor}}$$

Isolation of phosphate solubilizing bacteria: 1g of davana crop rhizospheres soil sample was collected and serially diluted and poured on pikovskaya medium agar (Himedia M520-100G), and incubated at 30˚C until halazone appeared. Halazone appearance indicates the presence of phosphate solubilization, and it was recorded as a phosphate solubilization index (SI) (Pande et al 2017).

$$PSI = \frac{\text{Colony diameter + Halozone diameter}}{\text{Colony diameter}}$$

Isolation of endophytic bacteria: Davana plant sample was dissected into roots, stems, and leaves and then thoroughly washed. Surface-sterilized tissues were inoculated on nutrient media (NA) and incubated for 24 hours at 30˚C. Plates were sub cultured to gain pure culture isolate and to revive bacteria. Each issue sample's colonies were selected (Based on morphological appearance) for further genera identification by biochemical analysis (Duhan et al 2020).

Microbial respiration: The 250 g of soil mixed with the respective solubilizers with and without RDF were prepared. A 50 ml centrifugal tube containing 25 ml of 0.5N NaOH suspended inside the conical flask was incubated at 32ºC for 24 hours and carbon dioxide emitted due to the respiration of bacteria was trapped in NaOH which converted to sodium carbonate. Unused NaOH was back titrated against standard sulfuric acid (H_2SO_4 0.5M) in the presence of phenolphthalein indicator. After every 24-hour cycle, fresh NaOH was filled and repeated the above procedure for 10 days. The respiration rate was calculated (Dehsheikh et al (2020).

$$MR = \frac{(N \times (V1 - V2) \times 22}{(T \times DW)}$$

Where, MR represents the microbial respiration of the soil, expressed in terms of mg of emitted CO_2 per gram per day. N denotes the normality of the acid, V1 is the volume of H_2SO_4 used for titrating the remaining NaOH in the standard control solution (without inoculants), V2 is the volume of H_2SO_4 used for titrating the remaining NaOH in the sample, T represents time in days, and DW stands for the weight of the inoculants.

Statistical analysis: Statistical analyses were performed using SPSS, version 16.0 for the Duncan's Multiple Range Test (DMRT), and data visualization was conducted using GraphPad Prism, version 8.0.2.

RESULTS AND DISCUSSION

Effect on Growth, Development, and Yield of Davana

Growth attributes: The RDF along with biofertilizers alone or in combination have a significant effect on the growth and yield of davana as compared to control the statistical analysis of different growth attributes such as plant height and numbers of branches (Table 1). Application of 100% RDF+PSB+KSB increase significant plant height (47.40 cm) over control treatment (35.08 cm) and RDF (39.38cm) which was on par with treatment of 100% RDF+PSB+KSB. The sole application of 75% RDF+KSB, 100% RDF+KSB, 100% RDF+PSB, and 75% RDF+KSB was significant in increasing plant height over RDF and control. Biofertilizers like VAM (Vesicular Arbuscular Mycorrhizae) and Azospirillum significantly enhanced the growth and development of Kadam seedlings. These biofertilizers notably increased as shoot length, collar diameter, number of leaves per plant, total leaf area per plant, root length, as well as fresh and dry biomass (Chauhan 2023). The number of branches of davana did not vary significantly due to the application of different solubilizers with recommended doses of fertilizers. The better availability and assimilation of nutrients from the soil by plants enhanced the better photosynthetic activity, build-up of cells, and their elongation where the better availability was aided by the nutrient solubilizing action of PSB and KSB application to the soil (Olaniyan 2022) probably caused the better growth of davana plant.

Yield attributes: An increment of 22.8 and 21.40% enlargement in flower diameter in treatment 75% RDF+PSB+KSB and 100% RDF+PSB+KSB respectively over the untreated plants (Table 1), which was statistically significant over untreated (2.76 mm) and RDF (3.24 mm). Where the different proportions (75 and 100%) of chemical fertilizer with the sole application of PSB and KSB significantly influenced the flower diameter of davana over RDF alone treatment. The least yield was recorded in the control treatment. Kumari et al (2019) also reported a significantly higher flower diameter of marigolds on application of PSB with RDF. The significant rise in davana single plant weight was observed due to the application of RDF, increasing from 33.27 g (control) to 39.43 g. This further increased to 48.14 g and 46.78 g with 100% and 75% RDF+PSB+KSB, respectively. Comparatively, 75% RDF with PSB (42.38 g) or KSB (43.53 g) was similar to 100% RDF with

Table 1. Effect of PSB and KSB inoculation on growth, development, and yield of davana in a pot experiment

Treatment	Plant height (cm)	No. of branches	Flower diameter (mm)	Single plant fresh weight (g)	Oil recovery (%)
T_1	35.08 e	18.67 a	2.76 d	33.27 d	0.21 c
T_2	39.38 d	21.00 ab	3.24 c	39.43 c	0.22 bc
T_3	43.78 bc	22.67 b	3.63 b	43.93 b	0.23 a
T_4	42.49 c	22.33 b	3.56 b	43.53 b	0.24 a
T_5	44.90 abc	21.47 ab	3.62 b	43.65 b	0.22 a
T_6	45.02 abc	22.17 b	3.47 bc	42.38 b	0.22 ab
T_7	47.40 a	21.33 ab	4.14 a	48.14 a	0.23 a
T_8	46.21 ab	21.00 ab	4.20 a	46.78 a	0.23 a
CD (1%)	2.85	NS	0.28	2.47	NS

The common letter(s) in a column shows no difference at the level of 5% probability as per DMRT; T_1: Control, T_2: RDF, T_3: 100% RDF+KSB, T_4: 75% RDF+KSB, T_5: 100% RDF+PSB, T_6: 75% RDF+PSB, T_7: 100% RDF+PSB+ KSB, T_8: 75% RDF+PSB+ KSB

PSB (43.65 g) or KSB (43.93 g), all significantly higher than control and RDF. The improved nutrient uptake, growth, photosynthesis, and biomass accumulation in davana were due to the mobilization of sparingly soluble P and K minerals or chelating ions, aligning with findings in geranium (Prasad et al 2012) and Sabja (Cheena et al 2021).

Essential oil recovery: The chemical composition of davana essential oil showed little variation among different treatments (Table 2). The major constituent, *cis*-davanone, ranged from 48.82% to 51.25%, with the highest content in the RDF treatment, followed by 75% RDF+PSB. The combined application of 100 and 75% RDF+PSB+KSB recorded *cis*-davanone levels of 50.88% and 49.78%, respectively. Davana ether (Isomer-1) was the second major constituent, ranging from 11.15% to 13.25%, with the highest levels in 75% followed by 100% RDF+KSB. Bicyclogermacrene content was highest in 75% RDF+PSB+KSB (5.32%) and lowest in the control treatment (4.05%). Other constituents, such as trans-davanone + trans-nerolidol, humulene epoxide-II, epi-alpha-cadinol, cis-methyl jasmonate, davanol acetate, and cis-hydroxy davanone, showed minimal variation among treatments.

Effect Microbiological Parameters of Soil and Plant Sample

Isolation of phosphate and potassium solubilizing bacteria from rhizosphere soil: A single phosphate-solubilizing bacterial colony was isolated, characterized, and identified. The organism was Gram-negative, white-coloured, and irregular in the shape of the colony; whereas the cell was in rod shape and rough surface with flat elevation. The colony exhibited clear halo zones around the bacterial growth; this isolate had a high phosphate solubilization index (PSI) of 2.5 mm. The isolates might be attributed to rhizosphere colonization, and better nutrient availability reported by Rafique et al (2012). The ability of PSB to solubilize insoluble phosphorus in Pikovaskya's agar medium by observing the halo zone thus concluding that bacteria tend to solubilize the insoluble phosphorous (Yaghoubi et al 2018).

Isolation of endophytic bacteria from leaf, bud, stem, and root of davana: Bacterial species were isolated based on the distinctive features of the colonies. Based on the findings, a variety of bacteria were identified in the leaf, stem, and root. In terms of morphological characterization, the endophytic bacterial isolates showcased a range of colony attributes, including diverse shapes (circular and irregular), colours (orange, white, and yellowish), margins (regular and wavy), and textures (Fig. 1). Concerning gram staining, 6 isolates demonstrated Gram-negative characteristics, while 2 exhibited Gram-positive features. In the biochemical and physiological characterization, all isolates underwent various tests including catalase, IMViC, H2S production, methyl red, and oxidase tests. Positive results were observed in certain isolates, (Table 3). Majority of bacterial endophytes might belong to the genus *Bacillus* and *Streptococcus*. Davana possesses a diverse taxonomic range of endophytes, with numerous studies (Suryanarayanan et al 2009) primarily concentrating on fungal endophytes, and there has been limited exploration of endophytic bacteria in this context.

Impact on bacterial population: The initial soil sample of the pot experiment count of bacteria was 25×10^4 Cfu/ml and varied significantly in soil sampled before harvest of the crop in each treatment. The highest bacterial count was in the combined application of 100% RDF+ PSB+KSB treatment T_7 (49×10^4 Cfu/ml), which was followed by 75% RDF+ PSB+KSB T_8 (49×10^4 Cfu/ml). The lowest bacterial count was in RDF alone T_2 (7×10^4 Cfu/ml) and control (7×10^4 Cfu/ml). Similarly, the impact of the sole application of KSB and PSB along with a recommended dose of inorganic fertilizer (75% and 100% RDF) on bacterial count was obtained after the application of T_4 (34×10^4 Cfu/ml) was similar to T_6, T_3 and T_5 (Fig. 2). The synergic effect of combined application in improving microbial population. Based on observation of both the combination and sole application of PSB and KSB

Table 2. Effect of PSB and KSB on essential oil constituents of *Artemisia pallens*

Treatment	Bicyclo germacne	Davana ether (Isomer -1)	*Cis*-davanone	Davanol acetate	*Cis*-hydroxy davanone	Davana ether (Isomer -2)	*Trans*-davanone + *trans*-nerolidol	*Cis*-methyl jasmonate
T_1	4.05	11.15	48.86	2.6	2.54	2.98	1.78	2.5
T_2	4.1	11.25	52.56	2.86	2.85	2.99	1.83	3
T_3	4.65	12.65	48.82	2.57	2.6	4.85	1.78	2.28
T_4	4.85	13.25	49.85	2.78	2.47	3.97	1.86	2.57
T_5	4.25	12.45	50.65	2.72	2.38	4.23	1.09	2.74
T_6	4.98	12.83	51.25	3.43	2.43	3.02	1.09	2.3
T_7	5.1	11.35	50.88	3.94	2.44	3.15	1.86	2.76
T_8	5.32	11.35	49.48	2.63	2	3.92	1.76	2.57

See Table 1 for details

along with inorganic fertilizer, positive synergistic effects with soil bacteria were observed, which promoted each other's growth. However, the combined application exhibited an overall greater bacterial population as compared to the initial RDF alone and controlled the bacterial population. Aswathy et al (2017) observed that the rapid growth in rhizosphere microbial population, which may be attributed to the multiplication of the strains in the rhizosphere, uses root exudates produced by the plants and synergistic interactions between introduced microbial inoculants and also the microorganisms in the root zone of the crop. In their study on rose-scented geranium, Negi et al (2022) noted that the presence of plant growth-promoting bacteria contributes to maintaining soil ecological balance, simultaneously improving both yield and essential oil quality. The use of microbial inoculants has the potential to mitigate the negative effects of chemical fertilizers and as a result, promote both the quantity and the quality of plant yield. Microbial inoculants offer a more sustainable way of delivering plant nutrients, and their utilization is environmentally beneficial too.

Microbial respiration: Among all the treatments RDF+PSB+KSB was the first to attain the highest peak of respiration i.e., on 3rd day whereas the sole application of RDF+PSB and RDF+KSB was on the 4th day. Among sole applications of PSB and KSB without RDF, inflated emission was recorded in KSB than in PSB with peak respiration on the 6th and 5th day respectively; whereas with RDF it was 4th day in both RDF+PSB and RDF+KSB treatments (Fig. 3). On the 10th day, RDF+PSB+KSB have a lower amount of carbon evolution than all other treatments indicating quick recession of respiration and more mineralization of substrate. The high

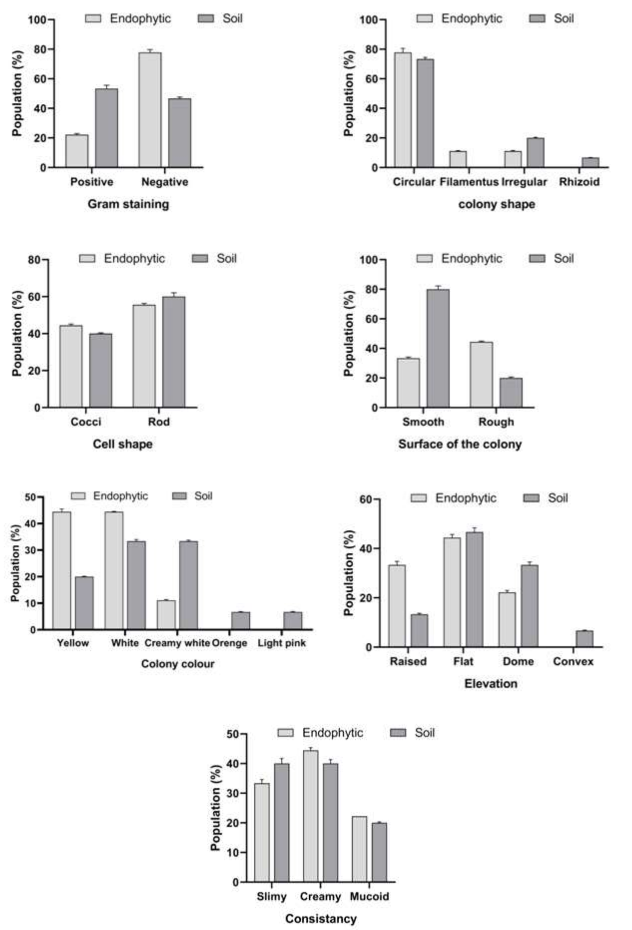

Fig. 1. Morphological characterization of endophytic bacteria

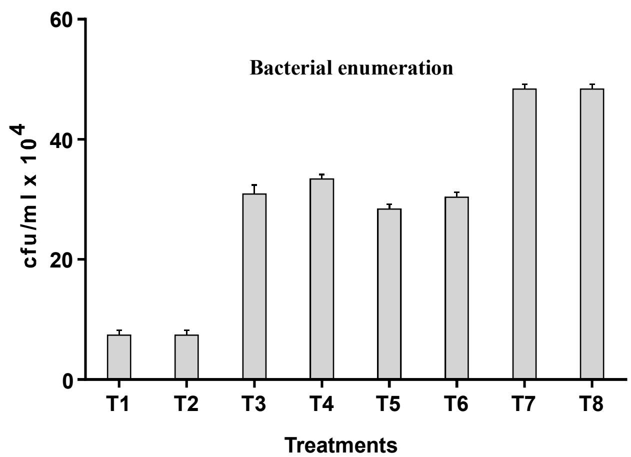

Fig. 2. Effect of PSB and KSB on Bacterial enumeration

Table 3. Biochemical characterization of endophytes and PSB in soil

Biochemical test	Endophytes		Soil	
	G-Positive	G-Negative	G-Positive	G-Negative
Catalase	100.00	0.00	46.67	53.33
Soxidase	50.00	50.00	40.00	60.00
Starch hydrolysis	62.50	37.50	53.33	46.67
Phenol red	62.50	37.50	46.67	53.33
Urease test	50.00	50.00	46.67	53.33
Indole test	37.50	62.50	66.67	33.33
Methyl red test	50.00	50.00	53.33	46.67

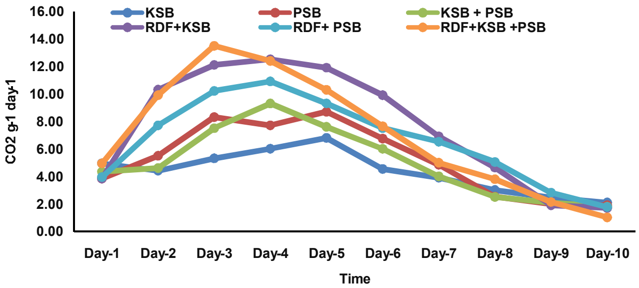

Fig. 3. Respiration study of different solubilizers effect

rate of respiration represents the more activity of microbes intern the rapid mineralization of nutrients (Jacoby et al 2017). The application of RDF showed more rapid respiration in both organisms indicating the significance of bio-fertilizers instead of using chemical fertilizers for the cultivation of crops. The study describes KSB as having a quicker mineralization capacity than PSB.

CONCLUSION

Application of 75% of recommended dose of fertilizer (RDF) with KSB and PSB had saved 25% chemical fertilizer compared to 100% RDF which may increase the annual income by improving the growth parameters, yield, and essential oil content of davana by the symbiotic bacterial effect. The symbiotic bacterial effect increases the crop productivity by the solubilization ability which reduce the fertilizer utility up to 25% might be valuable to economic and environmental viewpoint while using biofertilizers along with chemical fertilizer.

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Productivity and Economic Assessment of Diverse Rice (*Oryza sativa* L.) Varieties with Varied Nitrogen Levels in Eastern Indo-Gangetic Plains

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Abstract: During the *Kharif* seasons of 2020 and 2021, a field experiment was performed at the Indian Agricultural Research Institute (ICAR), Regional Station, Pusa, Bihar, to investigate the impact of different rice varieties and nitrogen levels on growth, yield, and economic aspects. Five varieties of rice, namely PNR 381, Rajendra Sweta, Sugandha-5, Pusa Sambha-1850, and Pusa-44, along with five nitrogen levels (0, 60, 120, 180, and 240 kg N/ha), were assessed. A progressive improvement in growth parameters and yield as nitrogen levels increased from the control to 200% recommended dose of nitrogen (RDN) equivalent to 240 kg/ha. The application of nitrogen at 240 kg N/ha resulted in significantly elevated plant height (102.1 cm), panicle length (27.1 cm), 1,000 grain weight (21.3 g), grains per panicle (200.9), grain yield (4.94 t/ha), net returns (₹ 61104/ha), and B:C ratio (2.27), as well as increased gross energy output, net energy return, energy use efficiency, and energy productivity. The Pusa-44 variety demonstrated superior performance compared to the other varieties tested. In conclusion, for the calcareous soil of the Indo-Gangetic Plains, cultivating the Pusa-44 rice variety along with the application of 150% RDN (180 kg N/ha) emerges as the optimal strategy to improve productivity, profitability and energetic.

Keywords: Economics, Energetics, Nitrogen levels, Rice, Varieties, Yield

Rice (*Oryza sativa* L.) constitutes a fundamental dietary staple for over half of the South Asian population and serves as a principal energy source in the North-Eastern Plain Zone of India (Hashim et al 2021). Despite being a water-intensive crop, it is cultivated across diverse ecosystems in the Indo-Gangetic Plains of India. The demand for rice continues to escalate, with projections estimating a requirement of approximately 140 million tons by 2025 (Singh et al 2019). In order to endure current food production and meet future demands, India must enhance rice productivity by approximately 3% annually (Kumar et al 2017). Rice is highly responsive to nutrient management, and the judicious application of fertilizers is critical for achieving sustainable and increased rice production. Improper nutrient use, particularly the indiscriminate application of major nutrients and intensive cropping, can result in a negative nutrient balance (Nadeem and Farooq, 2019). The sustainability and productivity of the rice-wheat cropping system are jeopardized by declining soil health, leading to diminished grain yields (Kumar et al 2016, Singh et al 2015).

The continuous cultivation of intensive rice-wheat sequences, coupled with discriminatory nutrient application, has contributed to the degradation of soil fertility, including the depletion of primary, secondary, and micronutrients (Prasad et al 2019). Given rice's substantial reliance on nitrogenous fertilizers, it is imperative to address the varied nitrogen (N) requirements in transplanted rice due to continuous flooding during cultivation. Substantial losses, exceeding 40–50% of applied nitrogen, occur through mechanisms such as ammonia volatilization, denitrification, leaching, and runoff after fertilizer application (Hakeem et al 2012, Fu et al 2023, Kumari et al 2022). These losses not only diminish yield and economic efficiency but also pose severe environmental ramifications (Houlton et al 2019, Xu et al 2020, Cowan et al 2021).

Therefore, it is imperative to ascertain optimal nitrogen levels and identify high-yield varieties. Limited research has been conducted on determining the ideal nitrogen levels for diverse rice varieties cultivated in calcareous lowland soil. Consequently, this study aims to evaluate the performance of different rice varieties in calcareous soil within the Indo-Gangetic Plains under varying nitrogen levels.

MATERIAL AND METHODS

Experimental site: Two-year field experiment, encompassing the consecutive rainy seasons of 2020 and 2021, was executed at the ICAR-Indian Agricultural Research Institute, Regional Station, Pusa, Samastipur, Bihar, India. The experimental site is characterized by geographical coordinates of 25°58'49'' N latitude, 85°40'48''

E longitude, and an elevation of 52.12 meters above mean sea level. The region experiences a subtropical, humid climate characterized by hot summers and cold winters. The recorded rainfall during 2020 and 2021 was 1633.2 mm and 1883.6 mm, respectively (Fig. 1). The soil at the experimental site exhibited a sandy loam texture, low organic carbon content (0.36%), a pH of 8.3, an electrical conductivity (EC) of 0.25 dS/m, and an available nitrogen content of 185 kg/ha.

Treatment details and crop management: Twenty-five treatment combinations, involving five levels of nitrogen application (control, 50% RDN, 100% RDN, 150% RDN, and 200% RDN) in the main-plot and five rice varieties (PNR-381, Rajendra Sweta, Sugandha-5, Pusa Sambha-1850, and Pusa-44) in the sub-plot, were examined using a split-plot design with three replications. The experiment spanned two consecutive years, with rice planted in a fixed plot and treatments superimposed on the same plot each year. Seedlings, grown in a well-prepared nursery bed and transplanted after 21 days in the main field with spacing of 20 cm × 15 cm. The recommended nitrogen doses was applied, with half as basal and the remaining half top-dressed in two equal split doses at active tillering and panicle initiation stage. Uniform doses of phosphorus and potassium were applied at 60 kg P_2O_5 and 40 kg K_2O, respectively, as basal doses.

Growth parameters, yield and economics: Upon reaching maturity, one border row surrounding the experimental plots was harvested, and the remaining net plot area was manually harvested using sickles to determine grain and straw yields. Dry matter efficiency (DME) was calculated using the methodology proposed by Kumar et al (2017). By multiplying the grain yield with the minimum support price (MSP) and incorporating the market value of by-products (such as straw) for the specific year, the gross return was determined. Net income, denominated in ₹/ha, was then computed as the disparity between gross returns and cultivation costs.

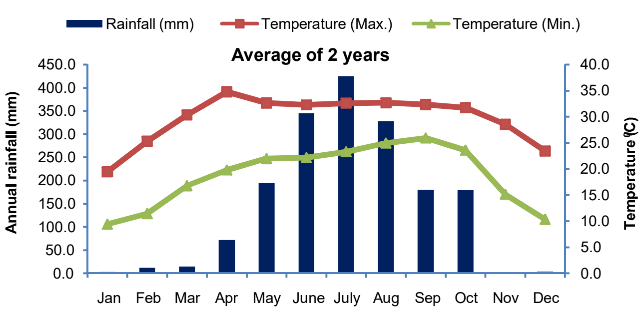

Fig. 1. Monthly average rainfall (mm), average maximum and minimum temperature (°C) in study locations (Pusa). Data were collected from the weather stations of the IARI, RS Pusa Bihar. Lines with filled triangles and squares represent the average minimum and maximum monthly temperatures, respectively, and bars represent the monthly average total rainfall

Energy calculation: Energy-use efficiency (EUE) was subsequently calculated as per Mittal and Dhawan (1988).

$$EUE = \frac{\text{Energy output (MJ/ha)}}{\text{Energy input (MJ/ha)}}$$

Net energy (MJ/ha) = Energy Output (MJ/ha) - Energy input (MJ/ha)

Statistical analysis: The data were analyzed by analysis of variance using OPSTAT Software (Sheoran et al 1998).

RESULTS AND DISCUSSION

Growth parameters: Diverse nitrogen levels exerted a pronounced influence on the height of rice plants, exhibiting a range from 72 cm to 102.1 cm across the various treatments (Table 1). Specifically, plots treated with 200% of the recommended dose of nitrogen (RDN) dosage, equivalent to 240 kg/ha of nitrogen, demonstrated the greatest plant height at 102.1 cm. This elevation in height was comparable to those observed with 100 and 150% nitrogen application, signifying a statistically significant increase compared to both the control and the 50% RDN treatment. The observed augmentation in plant height, attributed to the application of nitrogen, can be attributed to the efficient uptake and concentration of nitrogen, thereby enhancing rice growth and facilitating the production of dry matter. Comparable findings were reported by Hasanuzzaman et al (2012), Ritesh et al (2014), Nayak et al (2022), Zidan (2017). Conversely, control plots, characterized by an insufficient supply of nitrogen, exhibited the lowest plant height at 72.0 cm significantly lower than all other treatments. Rice varieties exhibited distinct variations in plant height at the maturity stage. Pusa Sugandha 5 manifested the tallest plants at 99.7 cm, followed by Pusa Sambha 1850 at 93.7 cm, both significantly surpassing the plant heights of other tested rice varieties. These differences are likely attributable to genetic variations influencing growth attributes, particularly plant height. In contrast, the PNR-381 variety displayed the lowest plant height at 86.3 cm, with Pusa-44 following closely at 87.7 cm.

Yield attributing characters: The panicle length demonstrated increase with elevated nitrogen levels, particularly at 200% RDN, suggesting a potential augmentation in nutrient availability conducive to panicle development (Bahuguna et al 2023, Mondal et al 2013). Panicle length exhibited a range from 21.3 cm in the control group to 27.1 cm at 200% RDN. Furthermore, distinct rice varieties displayed variability in panicle length, with Pusa Sugandha-5 exhibiting the longest panicles (28.0 cm), followed by Pusa-44, while Rajendra Sweta presented the shortest panicles (22.5 cm). Genetic variations likely contribute to the observed differences in panicle length among diverse genotypes, corroborating findings in distinct genotypes (Sultana et al 2014). Similar trend was observed in earlier research (Bahuguna et al 2023, Sultana 2014, Mondal et al 2013, Nayak et al 2022 and Mohapatra et al 2024).

The influence of varying nitrogen levels on grain weight (1,000 grain weight) was notably apparent, with an increase from 18.1 g in the control to 21.3 g at 200% RDN, a value significantly higher than the control and equivalent to other nitrogen levels. The augmentation in panicle length, 1,000 grain weight, filled and total grains was particularly pronounced with elevated nitrogen levels up to 240 kg N/ha. This implies that nitrogen fertilization led to heightened metabolite synthesis in rice plants, contributing to the superior outcomes in terms of the number of filled grains per panicle, panicle length, and 1,000 grain weight. Conversely, control plots exhibited the highest number of chaffy or unfilled grains (47.2), whereas plots treated with 200% N/ha displayed the lowest count (Table 1). These findings resonate with previous studies (Hasanuzzaman et al 2012, Ritesh et al 2014, Zidan 2017, Ninju et al 2018, Bahuguna et al 2023). The rice genotypes exerted a substantial impact on both grain weight and the number of grains per panicle. Pusa Sugandha-5 demonstrated the highest grain weight (24.5 g/1000 grain), a statistically significant difference from other varieties, while Rajendra Sweta exhibited the lowest grain weight (15.7 g/1000 grain). This opinion aligns with the research of Renuka et al (2013), underscoring the role of genetics in determining rice test weight. Pusa Sambha-1850 documented the significantly maximum total number of grains per panicle (230.8/panicle), coupled with the highest count of unfilled or chaffy grains, surpassing even Rajendra Sweta. Pusa-44 displayed the lowest number of unfilled grains (27.2). This divergence in unfilled grain counts may contribute to the superior yield observed in Pusa-44.

Productivity: The influence of varying nitrogen levels on rice productivity is discernible through the data presented here. The augmentation in grain yield with the elevation of nitrogen levels, reaching its zenith at 200% of the recommended dose, registering at 4.94 t/ha (Table 2). Application of 200% RDN (240 kg N/ha) exhibited substantial elevated yield of grain (4.94 t/ha), straw (9.12 t/ha), and biological yield (14.05 t/ha), respectively, on par with 150% RDN (180 kg N/ha). The application of 200% RDN resulted in a 64.59, 31.42, 10.65, and 4.00% increased grain yield compared to control, 50%, 100%, and 150% RDN, respectively. The application of 150% RDN yielded 58.38, 26.36, and 6.39% higher grain yields compared to control, 50%, and 100% RDN, primarily attributed to heightened growth yield attributes with amplified levels of nitrogen application, as reported by Kumar et al (2018). The 4% increment in yield was with the fertilization of 200% RDN in comparison to 150% RDN and may be due to efficient vegetative growth and sink development, in alignment with earlier studies (Salahuddin et al 2009, Nayak et al 2022, Kumar et al 2014. Consequently, overall yield

Table 1. Effect of nitrogen rates on growth and yield attributing characters of rice genotypes under transplanted condition in calcareous soil (Pooled data of 2 years)

Treatment	Plant height (cm)	Panicle length (cm)	1000-grain weight (g)	Grains/panicle			Harvest Index
				Filled	Un-filled	Total	
Nitrogen level							
Control	72.0	21.3	18.1	130.8	47.2	178.0	36.21
50% RDN	85.0	23.6	19.9	148.2	41.2	189.4	35.08
100% RDN	96.8	25.6	20.6	158.4	40.4	198.8	35.12
150% RDN	99.4	26.5	20.9	161.2	38.2	199.4	35.19
200% RDN	102.1	27.1	21.3	166.8	34.1	200.9	35.11
CD (p=0.05)	7.7	1.1	1.5	9.4	7.9	12.2	0.07
Varieties							
PNR-381	86.3	23.9	21.6	133.5	41.3	174.9	35.39
Rajendra Sweta	88.1	22.5	15.7	139.5	44.3	183.7	35.24
Pusa Sugandha-5	99.7	28.0	24.5	131.8	42.9	174.7	35.34
Pusa-44	87.7	25.2	21.8	175.2	27.2	202.4	35.35
Pusa Sambha-1850	93.7	24.4	17.3	185.4	45.4	230.8	35.40
CD (p=0.05)	3.5	1.2	0.9	12.9	5.7	14.8	0.04

Control (0 kg N), 50% RDN (60 Kg N), 100% RDN (120 Kg N), 150% RDN (180 Kg N), 200% RDN (240 Kg N) increased as a result of an augmented number of panicles per unit area and heavier grains per panicle.

Similar to grain yield, straw yield exhibited an increase up to 200% RDN, leading to taller plants, augmented tiller density, and increased biomass production, consistent with the observations of Kumar et al (2018, 2019). Significantly heightened crop productivity (36.73 kg/ha/day) and DME (104.60 kg/ha/day) were recorded with the application of 200% RDN, comparable with 150% RDN, and significantly surpassed the remaining treatments. Incremental levels of nitrogen correspondingly improved crop productivity and DME up to the maximum applied nitrogen levels (200% RDN) due to higher yields within the same treatment.

In addition to nitrogen rates, rice varieties also exerted a significant influence on rice yields. Pusa-44 demonstrated substantial increased yield of grain (5.21 t/ha), straw (9.56 t/ha), and biological yield (14.77 t/ha) compared to remaining varieties tested. Pusa Sambha 1850 emerged as the second-highest yielding variety. These findings align with the results reported by earlier researchers (Danish et al 2022, Nayak et al 2022, Bahuguna et al 2023).

Economics: The aggregated data from two consecutive years indicates that the highest cultivation cost was observed in the 200% RDN treatment, amounting to ₹ 48,004/ha, followed by the 150% RDN. Conversely, the control plots, devoid of nitrogen application, exhibited the lowest cultivation cost., the application of 200% RDN resulted in significantly elevated gross returns (₹ 109,108/ha) and net returns (₹ 61,104/ha) with a corresponding benefit-cost (B: C) ratio of 2.27, a performance that was on par with the 150% RDN treatment (Table 2). The 150% RDN application demonstrated 26.27 and 6.35% higher gross returns and 10.60 and 54.52% higher net returns compared to the 50% and 100% RDN treatments, respectively. However, the 200% RDN application yielded only a 5.84% increase in net returns compared to the 150% RDN treatment, possibly attributable to the higher yield achieved under the same treatment conditions. Similar inclination was previously reported by Kumar et al (2019). Significant disparities were evident among rice varieties concerning gross returns, net returns, and the B: C ratio. Pusa-44 exhibited notably higher gross returns (₹ 115,090/ha), net returns (₹ 68,602/ha), and a B: C ratio of 2.47, followed by Pusa Sambha-1850. The net returns of Pusa-44 surpassed those of Pusa Sambha-1850, Pusa Sugandha 5, Rajendra Sweta, and PNR-381.

Energetics: Combined data from two years demonstrated an escalating trend in input energy consumption corresponding to increasing nitrogen levels. The minimum input energy consumption was at lower nitrogen levels, and this increased progressively in the order of control <50% RDN <100% RDN <150% RDN <200% RDN, primarily attributed to heightened input requirements, notably nitrogen fertilization (Table 3). The highest energy input was registered at 200% RDN, followed by 150% RDN. Kumar et al (2018, 2019) also observed similar trend. The application of 200% RDN resulted in the highest net energy returns

Table 2. Effect of nitrogen levels on yields and economics of rice genotypes under transplanted condition in calcareous soil (Pooled data of 2 years)

Treatment	Productivity (t/ha)			Crop productivity (kg/ha/day)	Dry matter efficiency (kg/ha/day)	Cost of Production (₹/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	B:C ratio
	Grain yield (t/ha)	Straw yield (t/ha)	Biological yield (t/ha)						
Nitrogen level									
Control	3.00	5.29	8.28	22.36	61.79	45235	65748	20513	1.45
50% RDN	3.76	6.95	10.70	27.95	79.65	45681	83045	37364	1.82
100% RDN	4.46	8.24	12.70	33.26	94.69	46390	98597	52207	2.13
150% RDN	4.75	8.74	13.49	35.38	100.54	47128	104862	57734	2.23
200% RDN	4.94	9.12	14.05	36.73	104.60	48004	109108	61104	2.27
CD (p=0.05)	0.21	0.39	0.61	1.62	4.61	-	4735	4735	0.10
Varieties									
PNR-381	3.55	6.50	10.05	30.86	87.41	46487.6	78364	31876	1.68
Rajendra Sweta	3.67	6.78	10.45	26.62	75.74	46487.6	81196	34708	1.74
Pusa Sugandha-5	4.12	7.56	11.68	32.46	91.96	46487.6	91021	44533	1.95
Pusa-44	5.21	9.56	14.77	35.22	99.79	46487.6	115090	68602	2.47
Pusa Sambha-1850	4.34	7.93	12.27	30.53	86.38	46487.6	95690	49203	2.05
CD (p=0.05)	0.30	0.55	0.84	2.25	6.39	-	6542	6542	0.14

Table 3. Effect of nitrogen levels on energetics of rice genotypes under transplanted condition in calcareous soil (Pooled data of 2 years)

Treatment	Energy input (MJ/ha)	Energy output (MJ/ha)			Net energy returns (MJ/ha)	Energy ratio (Energy use efficiency)	Energy productivity (kg /MJ/ha)
		Grain	Straw	Total			
Nitrogen level							
Control	13210	44044	66080	110124	96914	8.34	0.227
50% RDN	16870	55203	86818	142022	125152	8.42	0.223
100% RDN	20506	65557	102950	168507	148001	8.22	0.217
150% RDN	24142	69752	109270	179022	154880	7.42	0.197
200% RDN	27778	72543	113954	186497	158719	6.71	0.178
CD (p=0.05)	-	3150	4927	8077	8077	0.56	0.015
Varieties							
PNR-381	20501	52173	81283	133457	112956	6.60	0.176
Rajendra Sweta	20501	53993	84733	138726	118225	6.87	0.182
Pusa Sugandha-5	20501	60593	94464	155058	134557	7.80	0.208
Pusa-44	20501	76614	119459	196074	175573	9.67	0.258
Pusa Sambha-1850	20501	63725	99133	162857	142356	8.16	0.218
CD (p=0.05)	-	4351	6823	11173	11173	0.58	0.015

Table 4. Renewable and non-renewable input energy of rice genotypes under different nitrogen levels (Pooled data of 2-years)

Source of energy	Renewable and non-renewable input energy (MJ/ha)					Percentage				
	N_1	N_2	N_3	N_4	N_5	N_1	N_2	N_3	N_4	N_5
Direct renewable (Human & water)	4547	4571	4571	4571	4571	34	27	22	19	16
Direct non-renewable (Diesel)	5321	5321	5321	5321	5321	40	32	26	22	19
Indirect renewable (Seed)	625	625	625	625	625	5	4	3	3	2
Indirect non-renewable (Machinery, fertilizer, chemicals)	2717	6353	9989	13625	17261	21	38	49	56	62

N_1: Control, N_2: 50% RDN, N_3: 100% RDN, N_4: 150% RDN, N_5: 200% RDN

(158719 MJ/ha) and gross energy output (186497 MJ/ha), comparable to 150% RDN and significantly superior to other nitrogen levels. Comparing 200% RDN with 150% RDN, the latter exhibited the highest EUE (7.42) and energy productivity (0.197 kg/MJ/ha), signifying a more judicious utilization of energy . This discrepancy is attributed to the intensified energy input consumption at higher nitrogen levels.

Within the array of rice varieties examined, Pusa-44 stood out with significantly elevated gross energy output (196074 MJ/ha), net energy returns (175573 MJ/ha), energy use efficiency (9.67), and energy productivity (0.258 kg/MJ/ha). This superiority is attributed to the variety's higher grain and straw yields coupled with lower energy utilization, consistent with findings reported by Kumar et al (2019). Examining different energy sources, the distribution among direct renewable, direct non-renewable, indirect renewable and indirect non-renewable sources varied across nitrogen levels. The percentage share of direct renewable, direct non-renewable and indirect renewable energy sources decreased from control to 200% RDN. However, the share was increasing from control to 200% RDN (Table 4).

CONCLUSION

Based on the findings of the two-year investigation, it is deduced that cultivating the Pusa-44 rice variety in conjunction with 150% recommended dose of nitrogen (RDN) application proves to be a more advantageous and optimal strategy for attaining heightened levels of productivity, profitability, and energetic efficiency in the context of calcareous soils prevalent in the Indo-Gangetic Plains of India.

AUTHOR'S CONTRIBUTIONS

Mohammad Hashim: Conceptualization, writing-original draft; Man Mohan Deo: Statistical Analysis; Sanjeev Kumar: Writing, reviewing and editing. The final version was approved by all authors.

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Source- Sink Regulation in Red Gram through Foliar Nutrition of Potassium and Growth Promoters in the Warm Humid Tropics of Kerala

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Abstract: The study was conducted to assess the influence of potassium and growth regulators on the source-sink efficiency in red gram [*Cajanus cajan* (L.) Millsp.]. The field experiment was laid out at College of Agriculture, Vellayani during 2019-2021 with combinations of four levels of potassium (0.5 % K_2SO_4, 1.0 % K_2SO_4, 0.25 % KNO_3, 0.5 % KNO_3) and three growth regulators (gibberellic acid 75 mg kg^{-1}, brassinosteroid 0.1 mg kg^{-1} and humic acid 100 mg kg^{-1}) as treatments, along with a control of conventional practice with no foliar nutrition. Foliar application of KNO_3 and GA_3 significantly enhanced the growth attributes. Seed yield (1081.33 kg ha^{-1}) and haulm (4837.27 kg ha^{-1}) yields were superior with foliar application of KNO_3 (0.5 %) and GA_3. The interaction effects of KNO3 (0.5 %) x GA3 revealed the significantly highest values for yield attributes and seed yield revealing efficient source- sink regulation compared to the conventional practice of sole nutrient application in soil.

Keywords: Brassinosteroids, Gibberellic acid, Potassium, Red gram, Sink-efficiency

Pulses are climate smart crops can be imbibed in any cropping system and also act as catch crops on account of their deep rooting system, phenotypic plasticity, dehydration tolerance, high moisture retention capacity, and a wide range of photothermal sensitivity (Gull et al 2020). Red gram [*Cajanus cajan* (L.) Millsp.] belonging to the family Fabaceae is a perennial, woody shrub usually grown as an annual for its edible seeds. It is the second most important pulse crop after chickpea in India. Apart from its nutritional importance, red gram is also valued for its adaptability to arid conditions and is also considered a lifeline of subsistence agriculture. The crop enhances soil fertility by fixing atmospheric nitrogen and contributing organic matter and micronutrients through leaf fall (Bano 2015). Despite the several advantages, red gram is constrained by its low yield which is mainly attributed to its cultivation on poor soils with inadequate and imbalanced nutrient application, excessive vegetative growth, indeterminate growth habit and poor source-sink relationship (Patil et al 2018). Major physiological constraint limiting red gram productivity is abscission of flower and fruits (Kulkarni et al 2019). Among the major nutrients, potassium is of utmost significance, on account of its role in various plant growth functions such as enzyme activity, photosynthesis, mobilization of carbohydrates, fruit set, quality and disease resistance (Prajapati and Modi 2012). Use of plant growth regulators is one of the latest trends in agriculture. Plant growth regulators are chemically synthesized compounds, which mimic natural hormones in their action and play an important role in shaping plant growth and development. The experiment was formulated to assess the influence of potassium and growth regulators on the source-sink efficiency in red gram.

MATERIAL AND METHODS

Experimental location: The field experiment was conducted at College of Agriculture, Vellayani, Thiruvananthapuram, Kerala during January to May 2021. The site located at 8.43° N latitude, 76.99° E longitude and at an altitude of 29 m above mean sea level, enjoys a humid tropical climate with the soil belonging to the order Ultisols. The soil nutrient status revealed medium organic carbon (1.21%), available K (121.6 kg ha^{-1}), low available N (257.15 kg ha^{-1}) and high available P (103.2 kg ha^{-1}) status.

Experimental details: The experiment was laid out in randomised block design with 12 combinations of two factors, four levels of potassium (a_1 - 0.5 % K_2SO_4, a_2 - 1.0 % K_2SO_4, a_3 - 0.25 % KNO_3, a_4 - 0.5 % KNO3) and three growth regulators (b_1– gibberellic acid (GA_3) 75 mg kg^{-1}, b_2 - brassinosteroid (BR) 0.1 mg $kg^{-1,}$ b_3 - humic acid (HA) 100 mg kg^{-1} as treatments in three replications. A control with recommended dose of nutrients without foliar application was also maintained short duration variety, APK 1 of Regional Research Station (RRS), Aruppokotai, Tamil Nadu was used for the study with an NPK dose of 40: 80: 40 kg ha^{-1}

(Devaraj and Isaac, 2021). Foliar sprays were given twice, potassium, at flower bud and pod formation stages and growth regulators, 30 days after sowing (DAS) and at flower bud stage. Urea, rock phosphate and muriate of potash were used as the sources of N, P and K respectively. The entire dose of P was applied as basal, N and K, in two splits, basal and 30 DAS. Threshing and winnowing were done manually to separate seeds. The growth and yield attributes were recorded and the seeds weighed after harvest. The yields per net plot area were used to compute the per hectare yields.

Statistical analysis: OP STAT software developed by Chaudhary Charan Singh Haryana Agricultural University was used for data analysis. Control *vs* treatment comparison was statistically analysed as contrast analysis using GRAPES software developed by the Department of Agricultural Statistics, College of Agriculture, Vellayani.

RESULTS AND DISCUSSION

Effect on Growth Characters

Plant height: Foliar application of potassium improved the various growth characters *viz.,* plant height, number of branches, leaf area and LAI in red gram (Table 1). The plant height at 30 DAS did not vary significantly with potassium treatments whereas at 60 DAS, plants were the tallest (94.59 cm) in a_4 (KNO_3 @ 0.5 % application) on par with a_3 (KNO_3 @ 0.25 %) and a_1 (K_2SO_4 @ 0.5 %). At 90 DAS, the significantly lowest plant height (139.96 cm) was in 0.25 per cent KNO_3 application and the maximum (148.87 cm) was in a_4 (0.5 % KNO_3). Growth regulators showed non-significant variations at 30 DAS, whereas b_1 (GA_3 @ 75 mg kg^{-1}) recorded the tallest plants at 60 and 90 DAS (100.84 and 150.31 cm respectively). It was significantly superior to BR and humic acid application. The interactions exerted significant influence on plant height at 60 and 90 DAS. The combination, a_4b_1 (KNO_3@ 0.5 % x GA_3 75 mg kg^{-1}) recorded the maximum plant height (101.42 cm) at 60 DAS and was on par with a_1b_1, a_3b_1, a_2b_1, but at 90 DAS, plants were the tallest (153.94 cm) in a_4b_1 and superior to all other combinations. Comparing the treatment effects with the control, at 30 DAS, the effect was non-significant. However, at 60 and 90 DAS, the treatments were significantly superior to the control.

Number of branches per plant: Foliar application of potassium sources at different concentrations recorded significant influence on number of branches per plant at flowering (Table 1). Superior number (8.73) was in a_4 (KNO_3 @ 0.5 %) and the lowest number (7.64) in a_2 (K_2SO_4 @ 1 %). Among growth regulators, b_1 produced the highest number of branches (9.95 per plant) and was significantly superior to BR and humic acid application. Among interactions the maximum number (11.81) was in a_4b_1 and was significantly higher than the other combinations. The lowest number of branches (6.80) was in a_3b_2. The treatment effects were significantly superior to the control.

Leaf area per plant: Potassium sources applied on the foliage had significant influence on leaf area per plant. The significantly superior leaf area (1662.76 cm^2) was in a_4 (0.5 % KNO_3) and the lowest in a_2 (1.0 % K_2SO_4) (1430.59 cm^2). Growth regulators also had significant influence on leaf area. Leaf area (2068.75 cm^2) was maximum in b_1 (GA_3 75 mg kg^{-1}), followed by BR (1296.06 cm^2) and humic acid (1175.76 cm^2) and were markedly different from each other. The treatment interactions could not produce significant effect on leaf area per plant at flowering. However, the treatments were significantly superior to the control.

Leaf area index: The superior LAI (2.08) was in a_4 (0.5 % KNO_3) and the lowest LAI (1.79) in a_2 (1.0% K_2SO_4 (Tables 1,

Table 1. Effect of potassium and growth regulators on growth and yield in red gram

Treatments	Plant height (cm) (Days after sowing)			No. of branches per plant	Leaf area (cm^2 per plant)	Leaf area index	Number of pods per plant	Average pod length (cm)	Average pod weight (g)	Seed yield (kg ha^{-1})	Haulm yield (kg ha^{-1})
	30	60	90								
Potassium (a)											
a_1 (0.5% K_2SO_4)	48.72	93.96	144.72	7.89	1451.33	1.81	43.57	5.43	0.39	1040.41	4399.17
a_2 (1.0% K_2SO_4)	47.51	92.76	144.84	7.64	1430.59	1.79	42.74	5.47	0.38	1006.13	4199.82
a_3 (0.25 % KNO_3)	48.70	93.53	139.96	7.94	1509.41	1.89	43.97	5.44	0.39	1014.44	4140.25
a_4 (0.5 % KNO_3)	48.23	94.59	148.87	8.73	1662.76	2.08	44.42	5.62	0.44	1081.33	4837.27
CD (p=0.05)	NS	1.205	0.730	0.407	124.816	0.156	0.998	0.049	0.023	14.804	189.769
Growth regulators (b)											
b_1 (GA_3)	48.32	100.84	150.31	9.95	2068.75	2.59	48.24	5.64	0.45	1100.13	4780.82
b_2 (BR)	49.25	91.09	144.82	7.07	1296.06	1.62	45.37	5.37	0.38	1072.74	4618.95
b_3 (HA)	47.30	88.65	134.48	7.30	1175.76	1.47	37.41	5.46	0.37	934.02	3781.86
CD (p=0.05)	NS	1.043	0.633	0.352	108.094	0.135	0.864	0.042	0.020	12.821	164.345

2). Among growth regulators, LAI was maximum (2.59) in b_1 ($GA_3$75 mg kg^{-1}). It was significantly superior to BR and humic acid application. Interactions could not exhibit any significant effect on LAI. Effects of treatments were superior to control of no foliar applications.

Potassium in plants has regulatory roles in numerous plant physiological processes *viz*. seed germination and emergence, stomatal regulation, phloem transport, cation-anion balance, protein synthesis, photosynthesis, energy transfer, osmoregulation, enzyme activation, nutrient balance, and stress resistance (Marschner 2012). Foliar application over and above the recommended dose in soil had beneficial effects on the growth attributes in red gram. Potassium nitrate was found to be superior to K_2SO_4. Nitrogen is pivotal in promoting leaf growth, aids in photosynthesis and increases protein content (Olivar et al 2014). The significant increase in the plant height, number of branches and leaf area per plant might be due to the fact that nitrate of potash provided both potassium and nitrogen, two of the major nutrients that are crucial for crop growth. The positive interaction of the two nutrients within the plant when applied with the same source would also have bestowed favourable effect on growth.

Red gram being a leguminous crop is capable of nitrogen fixation which ensures the availability of the nutrient for the crop during its growth. However, after flowering the nodules are known to degrade that leads to a lowered nitrogen supply, and as vegetative and reproductive growth occurred simultaneously, this had an impact on the growth attributes. The foliar nutrition with KNO_3 at this juncture ensured an adequate supply of both the nutrients for proper growth, balancing the source and sink development. This is supported by the reports of Lenka (2020) which elucidate that, as the active nodulation of pulse crop stops after 45 to 50 DAS, a foliar feeding of fertilizers containing nitrogen helps in providing supplementary nitrogen to the crop, enhancing growth and yield. Thalooth et al (2006) observed that potassium and nitrogen added *via* KNO_3 augmented cell division and cell expansion in plants thereby stimulating the biological activity of photosynthetic pigments and enzymes, which in turn promoted the vegetative growth. The increment in the plant height and number of branches is possibly due to the favourable effects of GA_3 on cell division and internodal elongation. Similar results were elucidated by Giri et al (2018). The synergistic effect of gibberellin (GA) and potassium in combination has been reported by Dev et al (2020). The treatment effects on growth were superior to the control as the additional supply and effective absorption of the nutrients (nitrogen/sulphur and potassium) *via* foliar application and the inclusion of growth promoting substances favoured growth and growth attributes.

Yield Attributes and Yield

Number of pods per plant: The maximum number of pods (44.42) was in a_4 (0.5 % KNO_3) and comparable with a_1 and a_3,

Table 2. Interaction effect of potassium and growth regulators on growth and yield in red gram.

Treatments	Plant height (cm) (Days after sowing)			No. of branches per plant	Leaf area (cm^2 per plant)	Leaf area index	Number of pods per plant	Average pod length (cm)	Average pod weight (g)	Seed yield (kg ha^{-1})	Haulm yield (kg ha^{-1})
	30	60	90								
a_1b_1	47.06	100.87	149.86	9.81	1986.88	2.48	48.74	5.72	0.48	1114.67	4760.33
a_1b_2	51.66	91.17	150.05	6.91	1223.04	1.53	44.12	5.19	0.34	1071.83	4589.85
a_1b_3	47.46	91.72	134.27	6.92	1144.07	1.43	37.86	5.37	0.35	934.83	3874.33
a_2b_1	46.28	99.98	150.10	8.89	1877.99	2.35	46.49	5.75	0.49	1064.57	4214.60
a_2b_2	48.49	89.63	146.53	6.91	1287.11	1.61	44.37	5.43	0.35	1019.70	4489.06
a_2b_3	47.77	88.69	138.00	7.11	1126.68	1.41	37.37	5.25	0.33	932.53	3892.80
a_3b_1	49.60	101.10	147.33	9.28	2144.47	2.68	47.64	5.30	0.34	1071.83	4333.30
a_3b_2	47.17	91.76	136.90	6.80	1212.31	1.51	46.15	5.40	0.41	1034.20	4525.27
a_3b_3	49.32	87.73	135.65	7.73	1171.44	1.47	38.15	5.63	0.41	937.13	3562.19
a_4b_1	50.36	101.42	153.94	11.81	2265.67	2.84	50.11	5.78	0.51	1186.33	5815.05
a_4b_2	49.67	91.81	145.80	7.66	1461.77	1.82	46.84	5.46	0.42	1127.60	4871.63
a_4b_3	46.68	88.65	130.02	7.45	1260.84	1.58	36.30	5.61	0.42	930.10	3825.13
CD (p=0.05)	NS	2.087	1.265	0.704	NS	NS	1.728	0.084	0.040	25.642	328.689
Control (C)											
C (RDF)	46.78	84.33	120.55	6.05	1076.60	1.34	34.14	5.16	0.32	916.7	4049.5
Treatment vs Control	NS	S	S	S	S	S	S	S	S	S	S

but superior to a_2 (42.74). The growth regulators, b_1 (GA_3 @ 75 mg kg^{-1}) recorded the highest number of pods per plant (48.24) and was significantly superior to BR and humic acid application. Interaction of potassium and growth regulators exerted significant influence on the number of pods per plant, with the maximum number of pods (50.11) in a_4b_1, on par with a_1b_1 (48.74). Pod number was the lowest number (36.30) in a_4b_3. The treatments were found to be significantly higher than control.

Average pod length: The significantly longest pods (5.62 cm) were in a_4 and the shortest pods (5.43 cm) in a_1. Variations in pod length with growth regulators were also significant. GA_3 application proved superior with the longest pods (5.64 cm). In response to the interactive effects, pods were the longest (5.78 cm) in a_4b_1 and was on par with a_1b_1 (5.72 cm) and a_2b_1 (5.75 cm) whereas, the shortest pods (5.19 cm) was in a_1b_2. Except in combination with 0.25 percent KNO_3, b_1 recorded the longest pods with a_1, a_2 and a_4. The treatments were significantly superior to control.

Average pod weight: Pod weight was significantly higher in a_4 (0.5 % KNO_3), GA_3 application (b_1) and the combination a_4b_1 (0.51 g). The lowest weight (0.33 g) was in a_2b_3. The treatments were significantly superior to control.

Seed yield: The highest yield (1081.33 kg ha^{-1}) was with 0.5 % KNO_3 spray. The higher concentration of K_2SO_4 (1.0 %) recorded the lowest yield (1006.13 kg ha^{-1}). Among growth regulators, maximum seed yield (1100.13 kg ha^{-1}) was in b_1 (GA_3 75 mg kg^{-1}) which was significantly superior to the BR and humic acid treatments. Seed yield was the lowest (934.02 kg ha^{-1}) in b_3 (HA 100 mg kg^{-1}). Interactions indicated significant variations with the maximum yield (1186.33 kg ha^{-1}) in the combination of 0.5 % KNO_3 and GA_3 (a_4b_1) and was significantly superior. The lowest yield (930.10 kg ha^{-1}) was in a_4b_3. The treatment mean was significantly superior to control.

Haulm yield: Haulm yields followed similar trends of growth and seed yields. The highest haulm yield (4837.27 kg ha^{-1}) was in a_4 (0.5 % KNO_3) and the lowest (4140.25 kg ha^{-1}) in a_3 (0.25 % KNO_3). The effect of growth regulators was also significant, the highest haulm yield (4780.82 kg ha^{-1}) was recorded in b_1 ($GA_3$75 mg kg^{-1}) but statistically comparable to that in b_2. Among the treatment combinations, a_4b_1 recorded the highest haulm yield (5815.05 kg ha^{-1}) in line with the individual effects and was significantly superior to other treatment combinations. The lowest haulm yield (3562.19 kg ha^{-1}) was recorded in a_3b_3. The significant difference between treatments means and control was also evident.

The indeterminate growth habit of red gram ensues a continuous competition for available assimilates between vegetative and reproductive sinks throughout the growth period. In pulses, yield is in general highly constrained by the lowered translocation of assimilates to the growing reproductive sinks. Insufficient partitioning of assimilates, poor pod setting due to flower abscission and lack of nutrients during critical stages of crop growth are crucial. In the present study, potassium nutrition was found to favourably influence the sink efficiency in red gram. Foliar application of KNO_3 at 0.5 per cent concentration was found to be superior. The results accords the reports on efficient utilisation of nutrients thereby reducing flower shedding and enhancing yields (Sathishkumar et al 2020, Singh et al 2021). The increased leaf area indicated higher source strength, increased photosynthesis and hence, higher photo assimilate production. Foliar application of potassium enhanced the rapid availability of the nutrient; redistribution of carbohydrates and translocation of assimilates to the economically important parts, the sink. In addition, potassium aids in acceleration of the physiological processes within, resulting in improved plant growth and yield attributes, and these were manifested in the seed yields. It is deciphered that the supply of potassium and nitrogen to supplement the soil contribution was effective in enhancing the production by virtue of the increased translocation of assimilates to the sinks, and a higher pod set, nearly 20 per cent greater than the lowest (24.18%) among potassium treatments. The impacts on the leaf area, number and weight of pods would have attenuated the higher yields.

Growth regulators had significant influence on average pod weight, seed and haulm yields and the values were superior in GA application which could be attributed to the significant role in stimulating physiological responses and altering the source–sink metabolism through their effect on photosynthesis and sink formation. Gibberellic acid is closely related to cell division and enlargement during fruit development (Zhang et al 2007) and the exogenous application increased seed weights. Application at 30 DAS and at pod formation stage might have improved the vegetative and reproductive development of red gram crop and supported efficient translocation of photosynthates from source to sink, as illustrated by Kumar and Sharma (2021). The increase in sink strength, number of pods, might be due to increased leaf area which leads to better utilization of sunlight and the plants remaining physiologically more active to build up sufficient food material for developing more number of pods. The enhanced sink potential and capacity through efficient translocation of photosynthates from source to sink with GA_3 application would also have complimented the higher yields. The results of the experiment are in line with the reports of Giri et al (2018) Kumar et al (2018) and Bhanu et al (2024).

CONCLUSION

The foliar application of KNO_3 and GA_3 significantly enhanced growth and seed yields in red gram. Growth attributes that represent the source strength, and seed yields, the sink capacity, were significantly superior with KNO_3 @ 0.5 % and GA_3 application. The individual effects were reflected in the interaction effects of KNO_3 (0.5 %) x GA_3 also. Therefore, source- sink regulation through the foliar applications of KNO_3 (0.5 %) at flower bud and pod formation stages and GA_3 (75 mg kg^{-1}), 30 DAS and at flower bud stage, proved superior and can be recommended for cultivation of short duration red gram in the warm humid tropics of Kerala.

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Impact of Intercropping with Black Gram on Incidence of Stem Fly, *Melanagromyza sojae* (Zehntner) during the *Kharif* Season in Gujarat

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Abstract: Investigation on impact of intercropping with black gram on incidence of stem fly, *Melanagromyza sojae* (Zehntner) were carried out at Anand Agricultural University, Anand during *kharif* season (2017 and 2021). Black gram intercropped with either maize or sorghum (3:2) proved superior over rest of intercropping systems with lower infestation (22.20 %), tunnelling (8.00 %), larval population (0.14 /plant) and pupal population (0.19 /plant) of stem fly, *M. sojae*. Higher black gram equivalent seed yield was registered in all the treatments of intercropping systems *i.e.*, black gram + maize (3:2 and 5:1 ratio) and black gram + sorghum (3:2 and 5:1 ratio) in comparison to black gram as sole crop.

Keywords: Black gram, Maize, Sorghum, Intercropping and stem fly

Pulse crops are hugely important in India since they help with crop diversity, revenue production, food security, sustainable agriculture, resilience to climate change, and export potential. One of the main pulse crops farmed in India is black gram. In India, the total production of black gram is 30,59,990 tons with 546 kg/ha productivity from an area of 56,02,470 ha in 2018-19 (Anonymous 2019). On an average, 2.5 to 3.0 million tonnes of pulses are lost annually due to pest problems (Rabindra *et al* 2004). In India, 60 insect species are known to attack black gram at different stages of crop growth. Yield loss due to stem fly varies between locations and according to the plant growth stage. Gaur et al (2015) reported 100% infestation and 33.84% stem tunnelling caused by *M. sojae* in soybean at Pant Nagar in Uttarakhand. Pathan et al (2023a) from Anand, Gujarat reported that *Melanagromyza sojae* (Zehntner) severely damages black gram at the seedling stage and exhibited a highly significant positive association with bright sunshine hours and maximum temperature. The black gram crop sown during the fourth week of August demonstrated the highest level of infestation (53.68%) and tunnelling (15.44%) followed by the crop sown during the third week of August (Pathan et al 2023c). The crop sown late i.e. 1st week of April showed significantly higher infestation (64.28%) of stem fly (Pathan et al 2022b). In the Gujarat region, the dipteran insect species *M. sojae* (Diptera: Agromyzidae) has emerged as a novel pest affecting black gram crop. Stem fly infestation exhibited a highly significant positive association (r = 0.519** and 0.655*) with bright sunshine hours (BSS) and maximum temperature (MaxT), respectively in *kharif* (Pathan et al 2023b) while minimum temperature (r = 0.769**) and evening during summer respectively in summer (Pathan et al 2022a). SKNU-11-11 proved to be susceptible genotype against *M. sojae* (Pathan and Sisodiya 2023, Pathan et al 2023d). Presently, there exists a deficiency of effective pest management strategies beyond the application of chemical insecticides. Given this scenario, it becomes imperative to explore and implement eco-friendly sustainable alternatives for insect pest control such as adopting cultural practices like intercropping. The comprehensive investigations were conducted to assess the influence of intercropping involving black gram on the incidence of the stem fly, *M. sojae* during the *kharif* season.

MATERIAL AND METHODS

In order to study the effect of intercropping on the incidence of stem fly, maize and sorghum was used as an intercrop with black gram. The experiment was conducted during *kharif*, 2017 and 2021. The variety of maize *i.e.* GAWMH-2 and for sorghum GNJ-1 (Gujarat Navsari Jowar 1) were used as an intercrop. There were four intercropping combinations *viz*, black gram + maize (5:1), black gram + maize (3:2), black gram + sorghum (5:1), black gram + sorghum (3:2) and sole black gram. The experiment was laid out in a randomized block design with four replication at Anand Agricultural University, Anand. Blackgram (Gujarat

Urad 1) were sown with the spacing of 45 x 10 cm with the plot size of 2.70 × 5.00 m.

For stem fly infestation, ten randomly selected seedlings were uprooted from each plot and brought to the departmental laboratory. The roots were gently washed in tap water to remove adhering soil. Stem of each plant was dissected and observations on the length of the stem, length of the tunnel and the number of larva (e) and pupae (e) present in the stem were recorded. The number of stem fly infested plants in each sample was also recorded at weekly interval starting from one week after germination.

Statistical analysis: The data were analysed by following standard statistical technique (Steel and Torrie 1980). Crop equivalent yield tunnelling and infestation per cent were calculated (Laxmigudi et al 2014). The software GWBASIC command prompt was used.

RESULTS AND DISCUSSION

Pest infestation (%): The impact of intercropping on pest infestation was significant as the treatments differed significantly (Table 1). The black gram crop intercropped either with maize or sorghum (3:2) registered 22.10 and 23.43% infestation of stem fly in black gram crop, respectively. Intercropping of black gram either maize or sorghum (5:1) exhibited 36.55 to 38.04% infestation of *M. sojae* but was at par. The black gram crop sown alone showed significantly higher infestation of the pest (51.33%).

Tunnelling (%): The black gram intercropped with maize (3:2 ratio) and sorghum (3:2) registered 7.63 and 7.95% tunnelling, respectively. These cropping systems proved best in significant reduction of tunnelling (%) due to stem fly in black gram. The intercropping systems of black gram with either maize or sorghum (5:1) also proved moderately effective but found significantly better than black gram crop grown alone. Significantly highest tunnelling was in sole black gram crop over the rest of the treatments (16.02%).

Number of larva: The black gram intercropped with maize or sorghum (3: 2) exhibited significantly low larval population (0.14 to 0.16 larva/ plant) over other treatments. Larval numbers were also suppressed moderately where black gram was intercropped with either maize or sorghum (5:1), but it was significantly better over black gram grown as sole crop.

Number of pupa: The pupal population of stem fly, *M. sojae* in black gram reduced significantly when it was intercropped either with maize (3:2) or sorghum (3:2). Promising effect of these intercropping systems also observed when it was evaluated as 5:1 ratio. Black gram crop grown as sole crop exhibited significantly highest (0.87 pupa/plant) pupal count over rest of the treatments of intercropping systems.

Yield: The maximum seed yield was harvested in black gram + maize (3:2) treatments (562 kg/ha) followed by black gram + sorghum (3:2), black gram + maize (5:1) and black gram + sorghum (5:1). All these treatments were at par and registered significantly higher yield in comparison to black gram as sole crop (460 kg/ha). The black gram intercropped either with maize or sorghum in 3:2 ratio yielded significantly

Table 1. Effect of intercropping on incidence of stem fly, *M. sojae* infesting black gram (Pooled: 2017 and 2021)

Treatments	Infestation (%)	Tunneling (%)	Larva (e)/plant	Pupa (e)/plant
Black gram + Maize (5:1)	37.20 (36.55)	20.22 (11.95)	0.94 (0.38)	0.99 (0.48)
Black gram + Maize (3:2)	28.04 (22.10)	16.43 (8.00)	0.80 (0.14)	0.83 (0.19)
Black gram + Sorghum (5:1)	38.08 (38.04)	20.66 (12.45)	0.97 (0.44)	1.02 (0.54)
Black gram + Sorghum (3:2)	28.95 (23.43)	16.79 (8.34)	0.81 (0.16)	0.84 (0.21)
Black gram as sole crop	45.76 (51.33)	23.59 (16.02)	1.10 (0.71)	1.17 (0.87)
CD (p=0.05) T	1.17	0.52	0.03	0.03
P	1.81	0.80	0.03	0.03
Y	0.74	0.32	0.02	0.02
T x P	NS	NS	NS	NS
T x Y	NS	NS	NS	NS
P x Y	NS	NS	NS	NS
T x P x Y	NS	NS	NS	NS
C.V. (%)	13.83	11.18	8.30	8.52

Figures in parentheses are retransformed values and those outside are arc sine transformed values, NS = Not Significant

Table 2. Yield of maize and sorghum intercropped with black gram (Pooled: 2017 and 2021)

Treatments	Yield (kg/ha)							
	Black gram		Maize		Sorghum		Equivalent yield	
	Seed	Haulm	Seed	Dry fodder	Seed	Dry fodder	Seed	Haulm
Black gram + Maize (5:1)	490	638	164	225	-	-	540	936
Black gram + Maize (3:2)	465	548	319	392	-	-	562	1070
Black gram + Sorghum (5:1)	496	624	-	-	126	159	534	834
Black gram + Sorghum (3:2)	470	570	-	-	275	332	553	1013
Sole black gram	461	682	-	-	-	-	460	681
CD (p=0.05) T	-	-	-	-	-	-	34.74	75.45
Y	-	-	-	-	-	-	NS	NS
T x Y	-	-	-	-	-	-	NS	NS

Price

Black gram = ₹63 /kg; Maize grain = ₹19 /Kg; Sorghum grain = ₹ 27 /Kg;
Black gram haulm = ₹ 1.5 /Kg; Maize fodder = ₹ 2 /kg; Sorghum fodder = ₹ 2/kg

Table 3. Economics of different intercropping systems evaluated in black gram (Pooled: *Kharif* 2017 and 2021)

Treatments	Yield (kg/ha)						Cost of treatment (₹/ha)	Income (₹/ha)	Gross income (₹/ha)	Net profit (₹/ha)	ICBR
	Black gram		Maize		Sorghum						
	Seeds	Haulm	Grain	Fodder	Grain	Fodder					
Black gram + Maize (5:1)	490	638	164	225	-	-	2847	35393	5327	2480	1:1.87
Black gram + Maize (3:2)	465	548	319	392	-	-	2865	36962	6896	4031	1:2.41
Black gram + Sorghum (5:1)	496	624	-	-	126	159	2229	35904	5838	3609	1:2.62
Black gram + Sorghum (3:2)	470	570	-	-	275	332	1629	38554	8488	6859	1:5.21
Sole black gram	461	682	-	-	-	-	2829	30066	-	-	-

See Table 2 for details

higher haulm yield than rest of the treatments. Black gram + maize and black gram + sorghum (5:1) produced 936 and 834 kg/ha haulm yield, respectively.

Economics: The maximum (₹ 6859 /ha) net profit was in black gram + sorghum (3:2) followed by black gram + maize (5:1). The black gram + sorghum (3:2) registered highest ICBR (1:5.27) followed by the treatment of black gram + sorghum (5:1) wherein it was 1:2.62 ICBR (Table 3).

The black gram crop intercropped either with maize or sorghum (3:2 ratio) registered low infestation of stem fly, *M. sojae* in black gram. Similarly, intercropping system of black gram with either maize or sorghum at 5:1 ratio was also promising in suppressing the infestation of stem fly. This finding is strongly supported by the report of Prodhan et al (2000) and Pathan et al (2024) where black gram crop intercropped with maize significantly reduced larval and pupal population, stem tunnelling, infested plants and produced higher yield over sole black gram crop. Peter et al (2009) observed that the population of *Ophiomia* spp. was higher in pure stands of common beans in Tanzania than in the intercrop with maize. Low counts of larvae and pupae were recorded in intercropping system.

CONCLUSION

The black gram crop intercrop with maize (3:2) proved superior over rest of the other treatments followed by black gram + sorghum (3:2) intercropping system by recording less number of larvae, pupae as well as lower percent infestation and tunnelling. Intercropping black gram with either maize or sorghum (5:1) suppressed the pest at moderate level. Black gram crop grown alone exhibited maximum infestation. Relatively higher black gram equivalent seed yield was registered in all the treatments of intercropping in comparison to seed yield recorded from black gram sown as sole crop.

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Effect of Date of Sowing and Varieties on Performance of Summer Fodder Pearlmillet (*Pennisetum glaucum* L.) under North Gujarat Condition

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Abstract: Field experiment was conducted on loamy sand soil at S. D. Agricultural University, Sardarkrushinagar, Gujarat during summer season of 2021. The experiment was laid out in split plot design with fifteen treatment combinations replicated thrice comprised of three dates of sowing in main plots *viz.* 25th February, 12th March and 27th March and five varieties in sub plots *viz.* Gujarat Fodder *Bajra* 4, Gujarat Fodder *Bajra* 1, BAIF *Bajra* 1, TSFB 15-8 and Moti *Bajra.* Crop sown on 12th March recorded significantly higher total green fodder and dry fodder yield *i.e.*, 589.8 and 139.2 q/ha, respectively. The 25th February sown crop was statistically at par with the crop sown on 12th March. Among the varieties, Gujarat Fodder Bajra 4 recorded significantly higher total green fodder yield (625.6 q/ha) and dry fodder yield (148.5 q/ha). TSFB 15-8 was statistically at par with Gujarat Fodder *Bajra* 4. The maximum B: C ratio *i.e.*, 2.25 was obtained under 12th March sown crop as compared to other dates of sowing. In case of varieties, maximum B: C ratio *i.e.* 2.39 was obtained in Gujarat Fodder *Bajra* 4.

Keywords: Date of sowing, Economics, Pearlmillet, Quality, Varieties, Yield

Livestock is becoming agriculture's most economically important sub sector and contributes 25% to the total agricultural income. One of the major reasons for low animal productivity in India is the shortage as well as poor quality of fodder. In Gujarat, total animal population is about 18.4 million and their optimum fodder requirement is 42.2 million tonnes, whereas, the availability is of only 20.0 million tonnes of forage during normal year (Pareek et al 2015). Cereals have major role to play in the fodder supply. Four major cereals *viz.* maize, barley, sorghum and pearlmillet account for approximately 44% of total cereals fodder production. Pearlmillet (*Pennisetum glaucum* L.) is an annual crop belongs to the family Poaceae (Gramineae), which is grown for food as well as fodder. It is a fast growing and short duration crop which has high biomass production potential. Pearlmillet as a fodder crop has some additional advantages over sorghum and maize because of high crude protein content (9.9 to 14%) and absence of hydrocyanic acid which makes feeding of green fodder of any crop stage safer to the cattle. It is nutritious, palatable and can be fed as green, dry or conserved in the form of silage or hay.

Date of sowing is an important non-monetary input affecting the fodder yield of summer pearlmillet. The weather parameters like rainfall, temperature and day length greatly influence the crop yield through their effect on phenological development of the crop. Late sowing coincides with high temperature, high wind velocity and early monsoon showers at reproductive stage adversely affect crop growth and yield, whereas, early sowing faces problems of low temperature during the initial stage of growth in North Gujarat. Moreover, late sowing does not leave enough time to prepare the land for *kharif* crop which resulted in delayed sowing of *kharif* crops. The sowing date is reported to have a significant impact on crop growth and development (Abd El-Lattief 2011), which is then reflected in yield and quality. Accurate decision-making with regard to the sowing date is not only important to achieve the higher crop yield and better quality fodder but also for minimizing the risk of crop failure. Santos et al (2017) reported that timely sowing decreases overall farming costs by eliminating labour and re-sowing costs. Therefore, it was of prime importance to find out the optimum date of sowing of fodder pearlmillet.

Feed shortage is a major challenge in livestock production enhancement. There are many options to cover the gap between forage demand and supply, one of them is adoption of high yielding crop varieties (Hassan et al 2014, Babiker et al 2015). Adoption of high yielding short duration varieties play an important role in the maximization of pearlmillet productivity. Screening of varieties which are appropriate to that particular climatic condition can help in boosting the production of pearlmillet. The identification of suitable variety to enhance productivity and quality is crucial to mitigate the present shortage of fodder requirement in summer season. Keeping in mind these facts, experiment was planned and conducted.

MATERIAL AND METHODS

Field experiment was conducted during summer season of 2021 at S.D. Agricultural University, Sardarkrushinagar. The standard week-wise meteorological data for the period of this investigation recorded at the Agricultural Meteorological Observatory (Fig. 1). The soil of the experimental field was loamy sand in texture with slightly alkaline in reaction. The details of the soil physical and chemical properties of the experimental plot are given in the Table 1. The experiment was laid out in split plot design with three replications. There were fifteen treatment combinations comprised of three dates of sowing in main plots *viz.* 25th February (D_1), 12th March (D_2) and 27th March (D_3) and five varieties in sub plots *viz.* Gujarat Fodder *Bajra* 4 (V_1), Gujarat Fodder *Bajra* 1 (V_2), BAIF *Bajra* 1 (V_3), TSFB 15-8 (V_4) and Moti *Bajra* (V_5). The crop was sown using recommended agronomic practices.

The biometric observations were recorded from randomly selected five plants in each net plot. Actual numbers of plants per metre row length were counted before harvesting of each cut without considering the tillers per plants. The plant height was measured from base to the tip of the plant at each cut. The number of leaves per plant was recorded at each cut. The average of five plants was calculated and presented as number of leaves/plant. The length of five leaves was measured from the base of the stem to the tip of the leaf to calculate average leaf length (cm). Similarly, the width of five leaves of the plant measured from the middle of the leaf to calculate the average leaf width (cm). Leaf: stem ratio was calculated during each cut at the time of harvest. The leaves were separated from the stem and fresh weight of both leaves and stem were recorded separately and leaf stem ratio is computed by dividing the leaves weight by stem weight and expressed in ratio. Average stem girth was calculated using the girth of five stem of the plant measured from the base, middle and tip of the stem. Two cuts were taken for green forage. The first cut was taken at 55 DAS, whereas, the second cut was taken 35 days after first cut (90 DAS). The ring area of each plot was first harvested and removed. The plants from the net plot were harvested keeping 5 cm stubble height from ground level and the fresh weight of harvested produce was recorded for each treatment separately at each cut and converted into quintal per hectare. After calculating green forage yield, one kg of green plant sample was weighed randomly from each net plot and kept in a brown paper bag. Thereafter, samples were first sun-dried then oven dried at 65°C. After oven drying, the dry forage yield in quintal per hectare was calculated on the basis of dry weight of sample for each treatment at each cut.

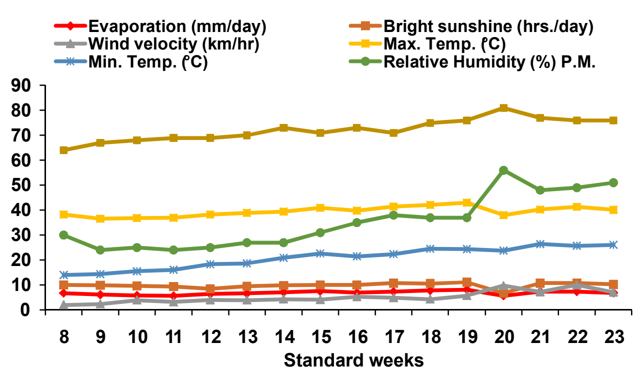

Fig. 1. Mean weekly weather parameters recorded during crop growth period of summer-2021

Total nitrogen content was determined by modified Kjeldahl method. Crude protein content of fodder was estimated by multiplying nitrogen percentage with 6.25 (Tsen and Martin 1971). The previously grinded and powdered samples were used to estimate the crude fibre (Mahadevan (1965). The residue left after ether extract was first boiled in 1.25 N H_2SO_4 followed by boiling in 1.25 N NaOH. The respective residue was washed with hot water, dried in oven and weighed. Thereafter, it was ashed in muffle furnace and per cent crude fiber was calculated using the formula given below.

$$\text{Crude fibre content (\%)} = \frac{\text{Weight of silica crucible with oven dry residues} - \text{Weight of silica crucible with ash}}{\text{Weight of oven dry sample}} \times 100$$

To evaluate the most effective and remunerative treatment, the relative economics of each treatment was worked out in terms of gross, net realization and benefit: cost ratio. The gross realization in term of ₹/ha was calculated from the income received from dry matter of each treatment with the prevailing market price. The cost of cultivation was worked out considering the cost of all the operations and inputs right from the preparation of land to harvesting of the crop. The net realization was worked out by deducting the total cost of cultivation from the gross realization per hectare for each treatment and recorded accordingly. The benefit: cost ratio (BCR) was calculated.

$$\text{Benefit: Cost Ratio} = \frac{\text{Gross realization (₹/ha)}}{\text{Total cost of cultivation (₹/ha)}}$$

Statistical analysis: Analysis and interpretation of data was done using MS excel programme.

RESULTS AND DISCUSSION

Growth and yield attributes: The plant height, number of leaves per plant, leaf length, leaf: stem ratio and stem girth were influenced significantly by different dates of sowing (Table 2). Crop sown on 12th March (D_2) produced significantly higher plant height, number of leaves per plant, leaf length), leaf: stem ratio and stem girth at 1st and 2nd cut, and was at par with 25th February sowing. The leaf width of fodder pearlmillet recorded at 1st and 2nd cut was non-significant due to different dates of sowing. This might be due to the sowing of pearlmillet at appropriate time which provided favourable climatic conditions in terms of temperature, humidity and bright sunshine hour during crop growth period, that had resulted in more cell division and enlargement which ultimately leads to more growth of crop. The present findings are in accordance with earlier observations (Abd El-Lattief 2011, Reiad et al 2014, Chaudhary et al 2020). Pearlmillet varieties significantly influenced plant height, number of leaves per plant, leaf length, leaf: stem ratio and stem girth except leaf width. Gujarat Fodder *Bajra* 4 recorded significantly higher plant height, number of leaves per plant, leaf length, leaf: stem ratio and stem girth and was at par with TSFB 15-8. This might be due to difference in genetic constitution among the varieties (Manjanagouda 2015, Bramhaiah 2016, Chaudhary 2021).

Fodder yield: Green fodder and dry fodder yields were influenced significantly by different dates of sowing (Table 3).

Table 1. Physico-chemical properties of the experimental soil

Properties	Soil depth (0-15 cm)	Methods of analysis
Mechanical composition		
Sand (%)	83.50	International pipette method (Piper 1966)
Silt (%)	7.55	
Clay (%)	7.10	
Textural classes	Loamy sand	
Chemical parameters		
Soil pH (1:2.5, Soil: Water ratio)	7.60	Potentiometric method (Jackson 1973)
Electrical conductivity (dS/m) 1:2.5, Soil: Water ratio at 25°C)	0.17	Schofield method (Jackson 1973)
Organic carbon (%)	0.16	Walkley and Black's rapid titration method (Walkley and Black 1934)
Available N (kg/ha)	160.20	Alkaline potassium permanganate method (Subbiah and Asijia 1956)
Available P_2O_5 (kg/ha)	32.47	Olsen's method (Olsen et al 1954)
Available K_2O (kg/ha)	282.00	Flame photometric method (Jackson 1973)

Table 2. Effect of date of sowing and varieties on growth of fodder pearlmillet

Treatment	Plant height (cm)		No. of leaves/plant		Leaf length (cm)		Leaf width (cm)		L:S ratio		Stem girth (mm)	
	1st cut	2nd cut	1st cut	2nd cut	1st cut	2nd cut	1st cut	2nd cut	1st cut	2nd cut	1st cut	2nd cut
Main plot: Date of sowing (D)												
D_1: 25th February	166.4	145.2	9.29	7.90	65.01	60.92	1.86	1.76	0.49	0.45	30.49	28.51
D_2: 12th March	181.5	158.0	9.65	8.26	67.74	64.18	1.88	1.79	0.51	0.47	31.82	29.84
D_3: 27th March	146.9	124.4	8.57	7.13	59.21	55.85	1.81	1.72	0.44	0.40	28.24	26.12
CD (p-0.05)	15.57	14.16	0.81	0.64	5.99	6.08	NS	NS	0.05	0.04	2.66	2.60
Sub plot: Varieties (V)												
V_1: Gujarat Fodder *Bajra* 4	177.6	155.4	10.41	8.80	69.94	67.24	1.91	1.83	0.55	0.51	31.63	29.63
V_2: Gujarat Fodder *Bajra* 1	157.5	135.1	8.40	7.15	60.76	56.07	1.82	1.71	0.43	0.40	29.24	27.19
V_3: BAIF *Bajra* 1	154.9	133.3	7.63	6.56	57.64	52.36	1.79	1.68	0.39	0.35	28.65	26.55
V_4: TSFB 15-8	172.4	149.7	10.08	8.49	67.30	64.84	1.88	1.81	0.53	0.49	31.17	29.17
V_5: Moti *Bajra*	162.1	139.4	9.32	7.82	64.29	61.06	1.85	1.76	0.48	0.45	30.22	28.24
CD (p-0.05)	12.77	10.35	0.68	0.52	4.87	4.74	NS	NS	0.04	0.03	2.08	2.08
Interaction (D × V)												
CD (p-0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Crop sown on 12th March produced significantly higher total green fodder yield (589.8 q/ha) and dry fodder yield (139.2 q/ha). The 25th February sown crop was statistically at par with the crop sown on 12th March. The increase in yields with normal sowing might be attributed due to favourable effect on growth attributes *viz.* plant height, number of leaves per plant, leaf length, leaf: stem ratio and stem girth. This might have ultimately resulted in higher photosynthetic activities and also in production of more photosynthates(Chandrika et al 2012, Salama et al 2020, Kaur and Oberoi 2021).

Pearlmillet varieties significantly influenced the green fodder and dry fodder yield. Gujarat Fodder *Bajra* 4 recorded significantly higher total green fodder yield (625.6 q/ha) and dry fodder yield (148.5 q/ha). TSFB 15-8 was statistically at par with Gujarat Fodder *Bajra* 4 with respect to green and dry fodder yield. Fodder yield was significantly higher under Gujarat Fodder *Bajra* 4 which might be due to the superiority of the genotype to produce better growth characters like plant height, number of leaves per plant, leaf length, leaf: stem ratio and stem girth. In earlier studies also similar trend was

Table 3. Effect of date of sowing and varieties on yield of fodder pearlmillet

Treatment	Green fodder yield (q/ha)			Dry fodder yield (q/ha)		
	1st cut	2nd cut	Total	1st cut	2nd cut	Total
Main plot: Date of sowing (D)						
D_1: 25th February	314.0	244.5	558.5	76.66	55.06	131.7
D_2: 12th March	332.0	257.8	589.8	81.16	58.06	139.2
D_3: 27th March	290.2	216.3	506.5	70.72	48.70	119.4
CD (p-0.05)	30.04	24.48	47.92	7.30	5.46	11.19
Sub plot: Varieties (V)						
V_1: Gujarat Fodder *Bajra* 4	347.1	278.5	625.6	85.80	62.66	148.5
V_2: Gujarat Fodder *Bajra* 1	296.1	217.0	513.1	71.87	49.48	121.4
V_3: BAIF *Bajra* 1	273.6	198.1	471.7	66.21	45.15	111.4
V_4: TSFB 15-8	329.0	263.5	592.5	80.58	58.77	139.4
V_5: Moti *Bajra*	314.5	240.5	555.0	76.43	53.63	130.1
CD (p-0.05)	28.28	18.76	38.88	7.02	4.18	9.34
Interaction (D × V)						
CD (p-0.05)	NS	NS	NS	NS	NS	NS

Table 4. Effect of date of sowing and varieties on quality of fodder pearlmillet

Treatment	Crude protein content (%)		Crude fibre content (%)	
	1st cut	2nd cut	1st cut	2nd cut
Main plot: Date of sowing (D)				
D_1: 25th February	7.85	7.62	27.33	23.30
D_2: 12th March	8.00	7.78	27.61	23.47
D_3: 27th March	7.73	7.51	26.98	23.08
CD (p-0.05)	NS	NS	NS	NS
Sub plot: Varieties (V)				
V_1: Gujarat Fodder *Bajra* 4	8.19	7.98	28.57	24.23
V_2: Gujarat Fodder *Bajra* 1	7.69	7.47	26.39	22.32
V_3: BAIF *Bajra* 1	7.59	7.37	26.24	22.16
V_4: TSFB 15-8	7.99	7.77	28.02	24.01
V_5: Moti *Bajra*	7.84	7.61	27.31	23.69
C. D. at 5%	NS	NS	NS	NS
Interaction (D × V)				
CD (p-0.05)	NS	NS	NS	NS

Table 5. Correlation and regression equations for various dependent and independent parameters of fodder pearlmillet as influenced by date of sowing and varieties

Independent variable (x)	Dependent variable (y)	Correlation coefficient (r)	Regression equation	R^2
First cut				
Plant height (cm)	Green fodder yield (q/ha)	0.873**	y =45.20+1.62x	0.763
No. of leaves/plant		0.958**	y = 67.68+26.65x	0.917
Leaf length (cm)		0.976**	y = -32.77+5.39x	0.953
Leaf width (cm)		0.970**	y = -722.33+559.33x	0.942
Stem girth (mm)		0.924**	y = -157.74+15.56x	0.854
Green fodder yield (q/ha)	Dry fodder yield (q/ha)	0.999**	y = -4.85+0.26x	0.998
Second cut				
Plant height (cm)	Green fodder yield (q/ha)	0.859**	y =-13.62+1.78x	0.737
No. of leaves/plant		0.996**	y = -36.90+35.60x	0.992
Leaf length (cm)		0.995**	y = 76.59+5.24x	0.990
Leaf width (cm)		0.993**	y = -714.20+542.78x	0.987
Stem girth (mm)		0.922**	y = -219.80+16.31x	0.850
Green fodder yield (q/ha)	Dry fodder yield (q/ha)	0.998**	y = 2.16+0.22x	0.997

** = Significant at 1%
The variable x refers to the independent parameters listed in the column, variable y refers to the dependent parameters listed in the column

Table 6. Effect of date of sowing and varieties on economics of fodder pearlmillet

Treatment	Gross returns (₹/ha)	Cost of cultivation (₹/ha)	Net returns (₹/ha)	BCR
Main plot: Date of sowing (D)				
D_1: 25th February	111700	52384	59316	2.13
D_2: 12th March	117960	52384	65576	2.25
D_3: 27th March	101300	52384	48916	1.93
CD (p-0.05)	-	-	-	-
Sub plot: Varieties (V)				
V_1: Gujarat Fodder *Bajra* 4	125120	52384	72736	2.39
V_2: Gujarat Fodder *Bajra* 1	102620	52384	50236	1.96
V_3: BAIF *Bajra* 1	94340	52384	41956	1.80
V_4: TSFB 15-8	118500	52384	66116	2.26
V_5: Moti *Bajra*	111000	52384	58616	2.12
CD (p-0.05)	-	-	-	-
Interaction (D × V)				
CD (p-0.05)	-	-	-	-

observed (Shroff and Patel 2017, Kaur and Goyal 2019, Chaudhary 2021).

Interaction effect between date of sowing and varieties: The interaction between date of sowing and varieties was non-significant for growth parameters, green and dry fodder yields as well as quality parameters.

Quality parameters: The crude protein content at 1st as well as 2nd cut of fodder pearlmillet crop did not differ significantly due to different date of sowing and varieties (Table 4). However, 12th March sown crop and Gujarat Fodder *Bajra* 4 variety had numerically high crude protein and crude fibre content values.

Correlation and regression analysis: There was significant and positive relationship found between plant height, number of leaves/plant, leaf length, leaf width, stem girth with the green fodder yield of fodder pearlmillet during 1st cut and 2nd cut, as evident from correlation coefficient (r) analysis (Table 5). This indicates that the enhancement in all the independent variable will increase the green fodder yield (dependent variable). There was significant positive relationship between green fodder yield and dry fodder yield indicating direct positive relationship between both parameters. Regression equations also revealed that increase in plant height by 1 cm, 1 leaf/plant, 1 cm leaf length, 1 cm leaf width, 1 mm stem girth shall increase the green fodder yield of 1st cut by 1.62 q/ha, 26.65 q/ha, 5.39 q/ha, 559.33 q/ha and 15.56 q/ha, respectively. Similarly, the increase in plant height by 1 cm, 1 leaf/plant, 1 cm leaf length, 1 cm leaf width, 1 mm stems girth shall increase the green fodder yield of 2nd cut by 1.78 q/ha, 35.60 q/ha, 5.24 q/ha, 542.78 q/ha and 16.31 q/ha, respectively. Increase in green fodder yield by 1 q/ha in 1st and 2nd cut shall increase the dry fodder yield of 0.26 and 0.22 q/ha, respectively.

Economics: Crop sown on 12th March gave the highest gross returns (₹ 117960/ha), net returns (₹ 65576/ha) with maximum B: C ratio (2.25) as compared to other dates of sowing. In varieties, Gujarat Fodder *Bajra* 4 recorded the highest gross returns (₹ 125120/ha), net returns (₹ 72736/ha) with maximum B: C ratio (2.39) followed by TSFB 15-8. Among the pearlmillet varieties and date of sowing, Gujarat Fodder *Bajra* 4 and 12th March, respectively adjudged best on the basis of economics.

CONCLUSIONS

The fodder pearlmillet variety Gujarat Fodder *Bajra* 4 or TSFB 15-8 should be sown on 25th February or 12th March to obtain higher fodder yield under North Gujarat condition.

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Optimizing Planting Geometry and Nutrient Management for Enhanced Growth and Yield of Teff (*Eragrostis tef* (Zucc.) Trotter) in Eastern Dry Zone of Karnataka

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Abstract: Teff (*Eragrostis tef (Zucc.)* Trotter is an introduced minor millet therefore, among prime areas of research is developing standard agro-techniques for higher productivity. Field experiment was conducted on optimizing planting geometry and nutrient management for enhanced growth and yield of teff during *kharif*-2021 at UAS, GKVK, Bangaluru in factorial randomized block design with ten treatment combinations consisting two planting geometry (30 cm × 10 cm and 45 cm × 10 cm) and five nutrient management (50, 75, 100 and 125 % recommended dose of fertilizers, (RDF) and absolute control). As per UAS, Bengaluru package of practices, RDF is 20 N: 20 P_2O_5: 20 K_2O and FYM @ 6 t ha^{-1}. Growth and yield parameters significantly varied with the treatments. Maintaining 30 cm × 10 cm spacing recorded significantly higher plant height (74.79 cm, 93.57 cm at 60 DAP and at harvest respectively), lodging (56.39%), grain yield (2.37 q ha^{-1}) and straw yield (3.65 q ha^{-1}). Application of 125 % RDF resulted in significantly higher plant height (80.05 and 99.33 cm) and number of tillers (16.45 and 23.07 per plant^{-1}) at 60 DAP and harvest respectively. However, significantly higher grain yield (2.73 q ha^{-1}) was at 100 % recommended dose of fertilizers

Keywords: *Eragrostis tef (Zucc.) Trotter,* Teff, Nutrient management, Planting geometry

Minor/small millets are the best examples of underutilized crops gaining more importance in recent days due to climatic smartness, nutritional richness, health benefits, low risk in production and lower production cost. Karnataka is majorly known for millet cultivation in India, primarily with respect to finger millet and foxtail millet among the other states. Nowadays farmers are much concerned in commercial agriculture and are replacing sustainable crops with cash crops, hence, the area under millets is declining day by day (Durgad et al 2019). Teff (*Eragrostis tef (Zucc.)* Trotter is an introduced minor millet originated and diversified in Ethiopia and cultivated on an area of 3.01 m ha, with an annual production of 5.01 m t and productivity of 1.664 t ha^{-1} in Ethiopia (Lee, 2018). Simultaneously, interests in teff cultivation are spreading to other parts of the world *viz.*, Australia, Canada, Cameroon, China, India, South Africa, The Netherlands, UK, Uganda, and the USA. Though teff grass is a boon to Indian farmers, little is known about its cultivation, production, and value addition. The limitations comprise lack of improved varieties, lodging of the crop at later stages of crop growth, lack of mechanization, lack of awareness, and the standard package of practice (agro-techniques). Premier areas of research are need of the hour to promote this crop at the global level. The standard agro techniques *viz.*, planting method, plant geometry, nutrient management, weed management, pest management, and reduction in post-harvest losses must be intended at reducing the loss in the output. Among these agro techniques, planting geometry and nutrient management play a vital role in increasing yield levels of teff crop as they ensure optimum plant population and ensures an adequate supply of nutrition to the plants. Row spacing is the key component in maximizing crop yield through optimizing plant population, improving light availability, and reducing weed competition. Therefore, it is of principal importance to develop and recommend suitable row spacing for maximizing teff production (Mihretie et al 2020). Dryland soils are 'not only thirsty but hungry too' and will make it mandatory to supply nutrients through external sources *viz.*, organic and inorganic fertilizers, these nutrients are to be applied wisely to achieve maximum yield potentiality of the crop with the least losses. The modern agronomic practices and technologies have the potential to substantially enhance teff productivity to ensure food security. The experiment was conducted with the objectives to study the effect of two levels of rows spacing, five levels of fertilizer rates and their interaction on growth parameters, yield components and yield.

MATERIAL AND METHODS

Field experiment was conducted during *Kharif* season of

2021 at Zonal Agricultural Research Station (ZARS), Gandhi Krishi Vignana Kendra, University of Agricultural Sciences, Bengaluru which comes under Eastern Dry Zone (Zone-5) of Karnataka. The geographical reference point of the experimental site was 13º 05' North latitude and 77º 34' East longitude and at an altitude of 924 m above mean sea level. The soil was red sandy loam in texture consisting of 53.6 per cent coarse sand, 14.7 per cent fine sand, 14.9 per cent silt and 14.8 per cent clay. The soil was acidic (6.85 pH) in reaction with an electrical conductivity of 0.40 dS m^{-1}, low organic carbon (0.42 %) and medium in available nitrogen (315.2 kg ha^{-1}), phosphorous (28.1 kg ha^{-1}) and potassium (281.3 kg ha^{-1}). During the crop season from August to November, a total of 881.2 mm of rainfall was recorded. The experiment was laid out in factorial randomized block design with ten treatment combinations and replicated three times. Treatments consisting of two factors planting geometry (S_1: 30 cm × 10 cm and S_2: 45 cm × 10 cm) and five nutrient management N_1: 50 % recommended dose of fertilizers (RDF), N_2: 75 %, N_3: 100 %, N_4: 125 % RDF and N_5 (absolute control). Farm yard manure was applied @ 6 t ha^{-1} commonly to all the treatments except absolute control. In this experiment, as per the UAS, Bengaluru package of practices, RDF of little millet (20 N: 20 P_2O_5: 20 K_2O and FYM @ 6 t ha^{-1}) was taken as base for determining fertilizer application rates in teff as teff morphology is much more similar to that of little millet compared to other millets. Brown seeded type teff was used for sowing. The gross plot size was 4.5 m × 3.0 m and net plot size was 3.9 m × 2.8 m (30 cm × 10 cm), 2.6 m × 2.8 m (45 cm × 10 cm) and treatments were allocated randomly in the plots within the blocks. Recommended dose of fertilizers and farm yard manure were applied at the time of sowing. Periodical observations were taken on growth parameters at 30, 60 DAP and at harvest where, five plants were selected randomly from each net plot and tagged with a label for recording various biometric observations on growth and yield parameters. Crop was harvested at 110 DAS, threshed and yield of the individual plots recorded separately and expressed in terms of per hectare. Lodging percentage was calculated by using formula:

$$\text{Lodging (\%)} = \frac{\text{Number of lodged effective tillers}}{\text{Total number of effective tillers}} \times 100$$

Statistical analysis: The data recorded on growth and yield parameters were subjected to Fisher's method analysis of variance using FRBD in MS excel.

RESULTS AND DISCUSSION

Growth Attributes

Plant height and number of tillers: Plant height was superior under 30 cm × 10 cm (74.79 and 93.57 cm, respectively) at 60 days after planting and at harvest. It could be attributed to the fact that higher plant population would certainly reduce the amount of light availability to the individual plant, particularly to lower leaves due to greater shading. As the mutual shading increases at higher plant densities, the plant tends to grow taller. Due to the elongation of internodes in narrow spacing leads to increase in plant height. Similar findings were reported by Hulihalli and Shantveerayya (2018) in buckwheat genotypes. Significantly higher plant height at 60 DAP (80.05 cm) at harvest (99.33 cm) was under application of 125 per cent RDF due to increased availability of soil nitrogen which leads to improved meristematic activity in terms of increased cell enlargement and elongation. Greater cell elongation resulted in increased plant height. Comparable findings were also described by Prakasha et al (2018). The number of tillers increased with age of the plant, at slower rate during early stages and at rapid rate up to 60 DAP and very few tillers were produced at later stage of plant growth. Wider spacing of teff produced significantly greater number of tillers per plant (14.76 and 20.34 $plant^{-1}$) at 60 DAP and at harvest respectively, as the individual plants could have effectively utilized the available resources such as space, foraging area for root system, light utilization etc. and thus enhanced the tiller production at wider spaced treatment. Similarly increased number of tillers plant under wider spacing was documented by Kumari et al (2015). Application of 125 per cent RDF resulted in significantly more tillers per plant at 60 and 90 DAP (16.45 and 23.07, respectively) among all the nutrient levels. This indicates that fertilization encouraged tiller formation in the crop due to increased uptake of available form of major nutrients present in the soil under increased fertilizer application. Parallel findings were reported by Kumari et al (2015).

Leaf area and Dry matter production: The wider spacing of 45 cm × 10 cm resulted in larger leaf area at 60 days after planting and at harvest (5.93 and 6.10 cm^2 $plant^{-1}$ respectively) encouraging better nutrient availability and reducing competition for growth promoting factors (Table 1). Wider spacing also favoured higher dry matter production (4.17 and 29.46 g $plant^{-1}$) at 60 DAP and harvest, attributed to increased tillers and better assimilating area (LAI). Improvement of LAI might have increased the radiation use efficiency and photosynthetic efficiency of crop and have induced to produce more DMP per plant under wider spacing. Application of 125 RDF significantly increased leaf area (6.85 and 7.12 cm^2 $plant^{-1}$) and dry matter (4.95 and 35.46 g $plant^{-1}$) at 60 DAP and harvest, respectively. This higher RDF provided more available nitrogen, phosphorus and potassium leading to rapid cell division and leaf expansion, reflected in terms of increased leaf area is similar to the findings in finger millet by Veeresh and Ramachandrappa (2016) and Hebbal et al (2018). Also, the adequate nutrient supply enhanced root development, photosynthetic rate, and carbohydrate utilization for more dry matter accumulation as reported by Charate et al (2018).

Lodging: Significantly higher lodging (56.39 %) was observed under narrow spacing of 30 cm × 10 cm (Table 2) which was due to competition for light under narrow spacing to utilize more incoming solar radiation which made the stem lean and when the plant grows taller, the nodes near the ground are unable to keep higher above ground biomass which resulted in greater lodging of teff. Similarly, with increased nitrogen application, the plant height was increased linearly and lean stems became more succulent and were unable to keep the plant in upright position. Due to this, lodging per cent was significantly higher under application of 125 per cent RDF than other lower nitrogen treatments. In contrary, under absolute control plants were short and stems were strong due to lack of sufficient nitrogen availability. Hence lodging per cent was least (39.89) in absolute control at harvest. Similar trend was observed by Mahantesh (2020).

Yield Attributes and Teff Yield

Number of productive tillers: Narrow spacing (30 cm × 10 cm) resulted in significantly a greater number of effective tillers (428.16 m^{-2}) compared to wider spacing of 45 cm × 10 cm (383.07 m^{-2}), Under wider spacing in spite of higher number of the tillers per plant, the number of productive tillers per unit area were less due to lower plant density. Significantly greater number of effective tillers were under

Table 1. Effect of planting geometry and nutrient management on growth parameters of teff

Treatments	Plant height (cm)		Number of tillers $plant^{-1}$		Leaf area (cm^2 $plant^{-1}$)		Dry matter (g $plant^{-1}$)	
	60 DAP	At harvest	60 DAP	At harvest	60 DAP	At harvest	60 DAP	At harvest
Factor 1: Planting geometry (S)								
S_1: 30 cm × 10 cm	74.79	93.57	12.95	18.13	5.45	5.62	3.92	27.61
S_2: 45 cm × 10 cm	63.92	86.20	14.76	20.34	5.93	6.10	4.17	29.46
CD (p = 0.05)	10.86	7.24	0.51	0.47	0.18	0.11	0.15	0.70
Factor 2: Nutrient levels (N)								
N_1: 50 % RDF (10:10:10)	66.98	86.75	12.74	17.91	5.10	5.16	3.53	26.10
N_2: 75 % RDF (15:15:15)	67.65	88.00	14.02	19.33	5.70	5.89	4.06	28.28
N_3: 100 % RDF (20:20:20)	78.23	95.33	15.65	21.03	6.23	6.61	4.38	32.02
N_4: 125 % RDF (25:25:25)	80.05	99.33	16.45	23.07	6.85	7.12	4.95	35.46
N_5: Absolute control	53.87	80.00	10.40	14.83	4.57	4.54	3.33	20.83
CD (p = 0.05)	17.17	11.44	0.81	0.74	0.28	0.17	0.23	1.11

Table 2. Effect of planting geometry and nutrient management on Lodging, yield parameters and yield of teff

Treatments	Lodging (%)	Productive tillers (m^{-2})	Grain weight (g ear^{-1})	Grain yield (q ha^{-1})	Straw yield (q ha^{-1})
Factor 1: Planting geometry (S)					
S_1: 30 cm × 10 cm	56.39	428.16	0.287	2.37	3.65
S_2: 45 cm × 10 cm	52.97	383.07	0.296	2.04	3.34
CD (p = 0.05)	2.55	44.74	0.007	0.30	0.11
Factor 2: Nutrient levels (N)					
N_1: 50 % RDF (10:10:10)	44.84	385.50	0.277	1.90	2.88
N_2: 75 % RDF (15:15:15)	55.37	423.17	0.290	2.23	3.47
N_3: 100 % RDF (20:20:20)	62.60	485.41	0.314	2.73	4.08
N_4: 125 % RDF (25:25:25)	70.69	425.00	0.305	2.45	4.36
N_5: Absolute control	39.89	309.00	0.270	1.74	2.66
CD (p = 0.05)	4.03	70.74	0.012	0.48	0.18

application of 100 per cent RDF (485.41 m^{-2}), however, it was on par with application of 125 and 75 per cent RDF due to higher number of tillers per plant that were erect enough to produce harvestable panicles. On the contrary, with increased nitrogen application the plants were much prone to lodging prior to panicle initiation itself, resulting in higher number of non-panicle bearing tillers.

Grain weight per ear: Wider spacing resulted in significantly higher grain weight per ear (0.296 g) compared to narrow spacing (0.287 g) which is mainly attributed to greater efficiency of the plants through nutrient absorption, photosynthetic activity and photosynthates translocation within the plants under leisure availability of growth resources in a wide spaced environment. Significantly higher grain weight per ear was observed under application of 100 per cent RDF (0.314 g) and was on par with application 125 per cent RDF (0.305 g). This is mainly attributed to the poor panicle initiation at higher nutrient application due to lodging of crop. There was poor photosynthate formation and supply to economic parts under lower nutrient supply levels and under absolute control. Balappa (2021) also observed similar trend.

Grain yield and straw yield: Among different planting geometry, significantly higher (2.37 q ha^{-1}) grain yield was attained under the narrow spacing of 30 cm × 10 cm compared to wider spacing (2.04 q ha^{-1}) of 45 cm × 10 cm. The higher grain yield in narrow spacing might be due to enhanced yield attributes, thus forming larger sink size coupled with efficient translocation of photosynthates to the sink. Simultaneously, due to higher plant population under closer spacing at 30 cm × 10 cm might have contributed to maximum dry matter production per unit area which ultimately enhanced the straw yield. Similar trend was observed by Thakur *et al* (2019). Grain yield was significantly higher under application of 100 per cent RDF (2.73 q ha^{-1}) as lodging was observed before grain filling stage under 125 per cent RDF causing severe yield reduction in teff. However, under application of 100 per cent RDF it was observed immediately after grain filling stage which has reduced impact on development of panicles. Unlike grain yield, the treatment supplied with highest fertilizers *i.e,* 125 per cent RDF resulted in statistically higher straw yield (4.36 q ha^{-1}) due to a more effective photosynthetic structure that allowed for more photosynthates to be synthesized, accumulated, partitioned and translocated to different regions of the plant. The crop was able to grow and develop more effectively reflecting in higher straw yield. Shankar (2017) and Ambresha (2017) also found similar results in little and foxtail millet respectively. However, the influence was non-significant with respect to interaction of different planting geometry and nutrient management.

CONCLUSION

Maintaining narrow spacing of 30 cm × 10 cm allows efficient utilization of growth factors ultimately leading to improved growth and development of teff crop than wider spacing. Among varied nutrient levels, supply of 100 % RDF (20 N: 20 P_2O_5: 20 K_2O) along with farm yard manure @ 6 t ha^{-1} results in statistically higher yield of teff crop. Further, increase in fertilizer levels is not recommended as it leads to greater lodging of the crop because of lean and long nature of the stem which cannot support the higher shoot biomass.

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Assessment of Heavy Metal Pollution in Soil of Different Land Uses of in Semi-Arid Region of Jaipur, Rajasthan

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Abstract: Due to extensive farming, urbanization and rapid growth, heavy metal contamination in soil has now a major issue in India. The semi-arid Jaipur region of Rajasthan underwent an environmental geochemistry assessment to ascertain the impact of pollution in the study area seasonally in the 2022. Soil samples collected from agriculture, industrial and forest area (as a control) in Jaipur were examined for soil physicochemical characteristics and heavy metal content, i.e., Cr, Pb, Ni, Cd, Zn, Cu, Mn and Fe by using the APHA method through an atomic absorption spectrophotometer. The determined mean metal concentration is in the order of Zn > Fe > Mn > Ni > Pb > Cr > Cu > Cd. Heavy metal contamination is also assessed using pollution indices like contamination factor , contamination degree, geoaccumulation index, enrichment factor and potential ecological risk index. Conclusively, the concentration of heavy metals in the soil samples is within permissible limits according to prescribed standards.

Keywords: Heavy metals, Pollution indices, Seasonal variation, Semiarid

Soil on the earth's surface is formed naturally, carries specific chemical, physical, mineralogical and biological characteristics, and varies from the earth's surface to its depths (Thakre et al 2012). In urban ecosystems, changes in land use have significantly impact soil properties. The origin of metals in soils could be geological (weathering and erosion) or anthropogenic (Sahu et al 2024), which could be differentiated as point sources (domestic, mining, refining, industrial and manufacturing) and non-point sources (fertilization, surface runoff, irrigation and agriculture). In semi-arid areas, where the supply of fresh water for irrigation continues to decline, the use of sewage water for cultivation is now a common practice, resulting in increased levels of heavy metals (trace elements) such as nickel (Ni), mercury (Hg), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), lead (Pb), chromium (Cr), arsenic (As), and cadmium (Cd), which have toxicity and extreme persistence, causing serious harm to humans and the environment (Kurniawan et al 2006, Singh et al 2020). In recent studies, various indices have been used to measure the level of metal contamination and understand its sources, distribution and allocation in soil including the geo-accumulation index (Igeo), enrichment factor (EF) and others like contamination factor, potential ecological risk index.

Jaipur, the state's capital city, has seen significant economic growth in the past two decades due to various industries such as textile, printing, dyeing, gems, jewellery, ready-made garments and marbles. However, the city poses a serious environmental risk because of the large amounts of water, chemicals and dyes required for production and commercial use (Chavan 2001). Dyes, bleaching chemicals, salts, acids and heavy metals like Cr, Cu, Pb, Zn and Fe are dumped constantly into Amanishah Nalla without treatment, mainly originating from the textile and dyes industries located in the Sanganer area of Jaipur (Marwari et al 2012). The present study aims to estimate the spatial and seasonal soil concentrations of eight heavy metals, viz. chromium, lead, nickel, cadmium, zinc, iron, manganese and copper and to assess the contamination level in soil using geochemical indices.

MATERIAL AND METHODS

Jaipur extends from 26°47'0.21" to 27°1'36.84" N and 75°41'15.19" to 75°54'36.27" and has hot summers with temperatures ranging from 20–32° C, low rainfall and low relative humidity. The minimum recorded temperature is 5°C in January and the maximum is 46°C in May and the average rainfall was 74.81 mm during the study period (IMD 2022). The Nahargarh forest range of Jaipur, which covers 52.40 km^2, is mostly dominated by Dhok (*Anogeissus pendula,* which covers 80% of the total vegetation). The other associated tree species are *Jatropha curcas, Maytenus emarginata, Adina cordifolia, Prosopis cineraria, Balanites aegyptiaca, Acacia nilotica, Acacia senegal, and Tecomella unduleta.* For the present study, seven sampling sites were selected based on land use activities, level of contamination and water use for irrigation (Table 1).

Soil sampling and analysis: Soil samples were collected for three seasons, i.e., pre-monsoon (March to May), monsoon (June to September) and post-monsoon (October to February) during 2022. Permanent 10×10 quadrats were used to gather soil samples from five different sites at a depth of 0 to 10 cm in each land use to make composites. To sample stainless-steel trowels were used to prevent metal contamination. Soil samples were manually cleaned, combined, and stored in zipper polythene bags. Therefore, three locations were selected for each land use at some distance, for a total of 20 samples, and each sample was tested in a triplicate manner. Soil samples were air dry, grounded and sieved to evaluate the physicochemical parameter and trace elements as per the recommended procedures (Table 2).

Environmental pollution indices: In study predicted heavy metal contamination risks using soil trace element concentrations and Shale's trace element values as baseline data: Cr=90, Pb=20, Ni=68, Cd=0.30, Zn=95, Fe=47,200, Mn=850 and Cu=45 (Turekian and Wedepohl 1961).

Geoaccumulation index: Muller (1969) devised the geoaccumulation index (Igeo) to analyse the heavy metal pollution in soil. Compare trace element amounts with background values to see contamination.

$$\mathrm{Igeo} = \log 2 \frac{\mathrm{Cn}}{1.5\mathrm{Bn}}$$

Where Bn is the average upper crust's (Turekian and Wedepohl 1961) trace element concentration, and Cn is the concentration in soil samples. The constant 1.5 accounts for environmental changes and human impact.

Enrichment factor (EF): The enrichment factor (EF) is used to measure the impact of human activity on soil composition. Sinex and Helz's (1981) equation was used to calculate EF by comparing the concentration of the element being studied (Cn) to the concentration of a reference element (CRef) in the

Table 1. Sampling sites description

Site name	Latitude	Longitude	Elevation (mm)	Vegetation	Site description
Sitapura	N26º47'32.04"	E75º49'39.36"	314	*Azadirachta indica, Acacia nilotica, Nerium oleander*	Industrial area
Bagru	N26º49'14.17"	E75º32'39.25"	308	Rabi: *Sinapis alba* L. (Sarso) Kharif: *Cenchrus americanus* L. Morrone (Bajra)	Industrial area, rainfed
Muhana	N26º47'36.52"	E75º45'4.59"	321	Rabi: *Coriandrum sativum* L. (Dhaniya), *Medicago sativa* L. (Ranjaka) Kharif: *Spinacia oleracea* L. (Palak), *Abelmoschus esculentus* (L.) Moench (Bhindi)	Agriculture field irrigated with nala's water
Vidhani	N26º46'7.40"	E75º52'4.73"	292	Rabi: *Solanum melongena* L. (Bengan), *Sinapis alba* L. (Sarso), *Triticum aestivum* L. (Wheat) Kharif: *Cenchrus americanus* L. Morrone (Bajra), *Sorghum bicolor* L. (Jwar)	Agriculture field irrigated with nala's water
Begas	N26º52'26.69"	E75º33'8.04"	344	Rabi: *Triticum aestivum* L. (Wheat), *Allium cepa* L. (Pyaj), *Medicago sativa* L. (Ranjaka), *Lathyrus oleraceus Lam. (1779)* (Pea) Kharif: *Arachis hypogaea* L. (Peanut), *Cenchrus americanus* L. Morrone (Bajra)	Agriculture field irrigated with tank's water
Chomu	N27º10'24.31"	E75º40'55.02"	405	Rabi: *Triticum aestivum* L. (Wheat), *Allium cepa* L. (Pyaj), *Medicago sativa* L. (Ranjaka) Kharif: *Praecitrullus fistulosus* (Tinda), *Cenchrus americanus* L. Morrone (Bajra)	Agriculture field irrigated with tank's water
Nahargarh	N26º58'56.0"	E75º48'01.0"	490	*Anogeissus* dominated	Forest area

Table 2. Procedure for soil parameter analysis

Parameter	Method used	References
Trace elements	AAS (Analytikjena ZEEnit 700 P)	(APHA 2005)
SM	Gravimetric (Oven dry)	
pH (1:2)	Potentiometry (Eutech model 510)	(Jackson 1973)
EC (1:2)	Conductometry (EI model 602)	(Jackson 1973)
SOC	Rapid titration method	(Walkley and Black 1934)
SN	Micro-kjeldhal method (Kelplus classic dxvatse)	(Subbiah and Asija 1956)
SP	Spectrophotometry (Systronics 1203)	(Olsen et al 1954)
Soil texture	Sieve analysis	(Gee and Bauder 1979)

SM soil moisture, EC electrical conductivity, SOC soil organic carbon, SN soil nitrogen, SP soil phosphorus, AAS atomic absorption spectrophotometer soil. Common reference elements used are Al (Islam et al 2015) and Fe (Parvez et al 2023), and Mn (Fabretti et al 2009, Sakata et al 2011). In this study, Mn was used to calculate enrichment.

$$\mathrm{EF} = \frac{\left(\frac{\mathrm{Cn}}{\mathrm{CRef}}\right)\text{sample}}{\left(\frac{\mathrm{Cn}}{\mathrm{CRef}}\right)\text{Background}}$$

Contamination factor and degree of contamination: Soil pollution is evaluated using two measures (Hakanson 1980): the contamination factor (CF) and the contamination degree (CD). The CF measures the concentration of a heavy metal in a soil sample compared to the normal level of that same metal in the environment. The CD determines the overall contamination level by adding up the values of all the contaminants present in the sample.

$$\mathrm{F} = \frac{(\text{Sample concentration})\ \text{sample}}{(\text{Sample concentration})\ \text{background}}$$

Potential ecological risk index: This index reflects the toxicity of soil heavy metals, and the response of the environment is computed (Hakanson 1980):

$$\mathrm{RI} = \sum_{i}^{n} E_r^i$$

$$E_r^i = T_r^i * C_r^i$$

Where Er is the potential ecological risk factor for heavy metals, Tr is the biological toxic metal response factor, and CF is the single element CF of the metal. The toxic response factors for Pb, Cd, Cu, Zn, Fe, Ni and Cr are 5, 30, 5, 1, 1, 1, 5 and 2, respectively (Gbadamosi et al 2018) and for Mn, 1 (Sinex and Helz 1981). Table 3 shows the categorization of pollution indices.

Statistical analysis: MS Excel was used to compile the data, and XLSTAT ver. 2023 was used to do Pearson's correlation matrix between intermetal and physicochemical parameters.

RESULT AND DISCUSSION

Physicochemical properties of soils: Soil pH ranges from slightly alkaline to moderately alkaline (Table 4). The electrical conductivity varies from 0.08 to 0.24 ms/m. The soil moisture was higher in agriculture land (S4) where sewage water was used for irrigation as compared to other land uses. The mean soil organic carbon concentration was higher in industrial soil (S1) and sewage-irrigated agricultural land (S4). The soil nitrogen was highest in forest soil (S7). The soil phosphorus ranged from 14.57 to 44.81 kg/ha in all land use. The soil texture varies from sandy loam to clay.

Seasonal and spatial variations of heavy metals in soil: The spatial and seasonal mean metal concentration in the soil follows the order as Zn > Fe > Mn > Ni > Pb > Cr > Cu > Cd, respectively (Fig. 1, A-H).

The average seasonal concentrations of most of the metals were maximum during the post-monsoon for Cr, Pb, Ni, Cd and Zn (1.58, 1.60, 5.21, 0.35 and 31.40 mg/kg, respectively), and Fe, Mn and Cu (3.72, 2.65 and 0.48 mg/kg, respectively) was maximum during the monsoon (Fig. 1). During post-monsoon, the nonpoint sources mainly fertilization, surface runoff, irrigation, and agriculture after the rainy period could have added the metal load in the soils which eventually settled to the bottom (Hossain et al 2020). The spatial variations showed that the average maximum metal concentrations for Cr, Ni and Zn, i.e., 1.85, 3.54 and 17.52 mg/kg at the industrial site (S1). In agriculture soils, the highest concentrations were obtained for Cd and Pb (S3:

Table 3. Soil quality classification for multiple indices to assess heavy metals

Enrichment factor (EF)[1]		Geoaccumulation index (Igeo)[2]			Contamination factor (CF)[3]		Potential ecological risk index (PERI)[4]	
EF classes	Sediment quality	Igeo value	Igeo class	Sediment quality	CF Value	Pollution level	PERI	Indication
EF < 1	No enrichment	0-0	0	Unpolluted	CF < 1	Low	PER < 50	Low risk
EF < 3	Minor enrichment	0-1	1	Unpolluted to moderately polluted	1 ≤ CF ≥ 3	Moderate	50 < PER> 100	Moderate risk
EF 3-5	Moderate enrichment	1-2	2	Moderately polluted	3 ≤ CF ≥ 6	Considerable	100 < PER > 150	High risk
EF 5-10	Moderate severe enrichment	2-3	3	Moderately to highly polluted	CF > 6	Very high	150 < PER > 200	Very high risk
EF 10-25	Severe enrichment	3-4	4	Highly polluted			PER > 200	Extreme risk
EF 25-50	Extremely severe enrichment	4-5	5	Highly polluted to very highly polluted				
		5-6	> 5	Very highly polluted				

[1 and 2] Birch and Olmos 2008, [3] Hakanson 1980, [4] Guan et al 2014

1.26; 3.72 mg/kg), and Cu and Mn (S6: 0.55; 2.75 mg/kg), respectively. However, at forest was highest for Fe (4.33mg/kg).

During the pre-monsoon, the maximum concentrations of most of the metals (Cr, Cd, Cu: S3; Pb, Ni: S5) were in agricultural land uses. However, in monsoon season a higher concentration of Cr, Cd, Mn and Fe was reported from forest soils. In post-monsoon season also, an increased metal concentrations were observed from agriculture land uses. This increased levels of heavy metals in agriculture soil could be explained by the overuse of fertilisers, and proximity to textile industries adding the Cd load in the soils of sewage-

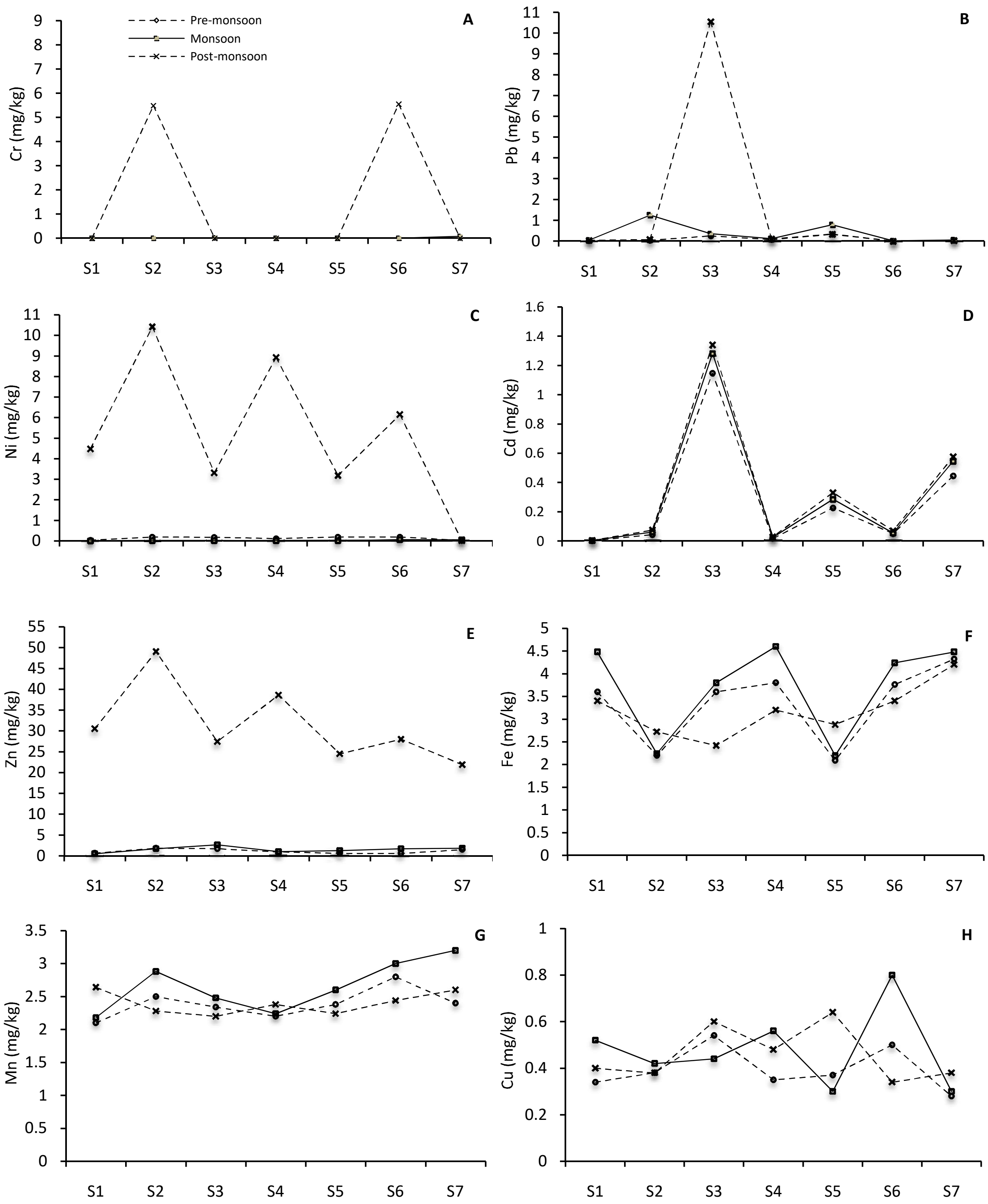

Fig. 1. (A-H) Seasonal and spatial variation in heavy metal concentration in the soil sample

irrigated agriculture lands (Bhuiyan et al 2011, Edogbo et al 2020). The higher values of Mn, Fe and Cu in Chomu agriculture site of Jaipur were also observed by Sharma (2023). The concentrations of Cd, Ni, Pb at industrial sites were in the range as reported by peri-urban soils of Bengaluru (Altaf and Subbarayappa 2022). The high Zn, Ni, and Mn content near Bagru industrial sites may be due to the wastewater generated by textile organizations (Pajot et al 2011).

The concentration recorded in this study was below the allowable limits, concerning the Indian (Awashthi 2000) and European (EU 2002) standard values. This could be explained by then the rejuvenation of the Dravyavati River (August 2016–August 2018), the ban on wastewater and garbage dumping and, five sewage treatment plants (STP) and cleaning the water of river. The limited anthropogenic and industrial activity during the COVID-19 pandemic could have resulted in reducing water and soil pollution sources, and diminish transfer of metal from water (river) to agriculture soil (sewage water irrigated).

Pollution Indices

Enrichment factor (EF): The mean enrichment (EF) factor for metals in the soil followed the order of Fe < Mn < Cr < Cu < Ni < Pb < Zn < Cd. The EF values indicated extremely severe enrichment of Cd and Zn (EF >25), severe enrichment of Pb (10-25), moderately severe enrichment for Ni (5-10), moderate enrichment of Cu (3-5), slightly Cr enrichment (EF < 3), Mn and Fe with no enrichment (EF < 1) (Table 3).

Geoaccumulation index (Igeo): The Igeo values indicated no contamination for Cr, Pb, Ni, Zn, Fe, Mn and Cu (≤ 0), while moderate contamination for Cd (0-2) in all seasons for forest land use (S7) and sewage irrigated agriculture land (S3) (Table 3). The mean Igeo values for heavy metals followed an order: Cr > Cd > Zn > Cu > Pb > Mn > Ni > Fe. The average value of Cf< 1 indicated no pollution in the studied soils across various land uses. However, the Cf for Cd ≥ 3 showed moderate contamination in soils.

Contamination factor (Cd): The average contamination factor (Cd) value for most of the metals, i.e., Cr, Pb, Ni, Zn, Fe, Mn, and Cu, was < 6, indicating a low degree of contamination, whereas the Cd values of cadmium lie between 6-12, indicating a moderate degree of contamination.

Potential ecological risk: The samples have a low potential ecological risk for Cr, Pb, Ni, Zn, Fe, Mn and Cu interpretd by the RI (risk index) value of less than 50 for these metals for all land uses in all seasons. However, the potential ecological RI of Cd lies between 190 and 380 (219), showing low to moderate pollution (Table 3).

During the monsoon season, metal levels decrease due to rainwater. The deposit of metals in the soil causes maximum enrichment during the post-monsoon. Distinct land use patterns, anthropogenic interruptions, past pollution record and its sources impact the soil pollution in various degree (Lee et al 2006). Previous study reports on increased EF values in urban soils are mostly due to industrial and road traffic emissions (Loska et al 2004, Ali and Malik 2010). The low metal background value (0.3 mg/kg) suggests an anthropogenic origin for the increased Cd concentration in the soil sample (Wedepohl 1991).

Intermetal correlation analysis: The inter-metal correlation analysis determined a significant positive correlation of Cr with Ni, Zn and Mn. In addition, a strong positive correlation was found between Cd, Pb, Ni, and Zn (R^2> 0.8). However, there is a weak positive correlation between Pb and Cu (Table 5). The SOC shows a positive correlation with microelements (Fe, Zn and Cu) similar to the agriculture land of N.T.R district in Andhra Pradesh (Prasad et al 2023). A significant correaltion of Fe with SOC indicated pedogenic origin of Fe. The positive correlations between Cd, Pb, Ni and Zn indicate these metals come from similar anthropogenic sources, which could be the nearby industries, automobiles, Pb-Ni-based batteries, fertilizers etc. which might have contributed to the presence of these metals in the soil (Pajot et al 2011, Marwari et al 2012). The discharge of untreated wastewater into nearby land and water systems,

Table 4. Physicochemical characteristics of soil in semiarid region of Jaipur

Site code	Site name	pH	EC (ms/m)	SM (%)	SOC (kg/ha)	SN (kg/ha)	SP (kg/ha)	Soil texture
S1	Sitapura	8.20±0.02	0.24±0	4.12±0.16	65.83±1.81	172.36±4.74	25.82±0.4	Clay
S2	Bagru	7.52±0.01	0.08±0	6.03±0.15	50.77±1.97	170.50±4.40	15.28±0.29	Clay
S3	Muhana	8.20±0.02	0.19±0	11.29±0.14	51.08±1.80	181.19±6.64	24.99±0.39	Clay loam
S4	Vidhani	7.53±0.03	0.20±0	11.46±0.23	65.52±2.25	183.51±4.06	44.81±0.39	Sandy loam
S5	Begas	7.79±0.04	0.16±0	5.91±0.16	50.66±1.91	165.85±5.46	32.93±0.33	Clay
S6	Chomu	8.24±0.02	0.16±0	8.53±0.12	56.38±1.59	175.15±4.99	26.26±0.42	Clay loam
S7	Nahargarh	7.64±0.02	0.08±0	10.12±0.11	43.75±1.74	194.43±5.20	14.57±0.31	Sandy loam

Values are in means ± standard error; EC electrical conductivity; SM soil moisture, SOC soil organic carbon, SN soil nitrogen, SP soil phosphorus

Table 5. Intermetal correlation with soil parameters

	pH	E.C	SM	SOC	SN	SP	Cr	Pb	Ni	Cd	Zn	Fe	Mn	Cu
pH	1	-0.02	-0.46	-0.01	-0.51	-0.52	0.67[a]	0.25	0.36[b]	0.00	0.43[b]	-0.41	0.14	0.29
E.C		1	-0.08	0.79	-0.26	0.64	-0.43	0.20	0.02	-0.00	-0.21	0.17	-0.74	0.55[a]
SM			1	-0.16	0.75	0.24	-0.21	0.40[b]	-0.11	0.52[a]	-0.10	0.43[b]	0.05	0.25
SOC				1	-0.25	0.67[a]	-0.11	-0.25	0.47[b]	-0.51	0.21	0.23	-0.60	0.36[b]
SN					1	-0.15	-0.32	0.07	-0.41	0.36[b]	-0.25	0.77[a]	0.27	-0.30
SP						1	-0.37	-0.06	0.27	-0.22	-0.04	0.04	-0.63	0.45
Cr							1	-0.23	0.58[a]	-0.37	0.52[a]	-0.27	0.59[a]	0.22
Pb								1	-0.18	0.90[a]	-0.04	-0.22	-0.33	0.44[b]
Ni									1	-0.52	0.89[a]	-0.37	-0.20	0.26
Cd										1	-0.32	-0.00	-0.09	0.19
Zn											1	-0.42	-0.16	-0.03
Fe												1	0.20	-0.07
Mn													1	-0.20
Cu														1

EC electrical conductivity; SM soil moisture, SOC soil organic carbon, SN soil nitrogen, SP soil phosphorus. [a]Correlation is significant at 0.01 level, [b]Correlation is significant at 0.05 level

contaminates the soils and poses a threat to human health and the environment.

CONCLUSION

The present study evaluated the spatial and seasonal concentrations of heavy metals (Cr, Pb, Ni, Cd, Zn, Fe, Mn and Cu) in the various land uses, i.e., industrial, agriculture and forests in the semiarid region of Jaipur. Pearson's correlation suggests a common source for metals Cd, Pb, Ni and Zn, could be anthropogenic, whereas for Fe is paedogenic. The geochemical approaches indicated a low degree of contamination for most of the metals except for Cd showing moderate pollution. The study suggests that wastewater containing domestic and industrial waste must be monitored periodically by various pollution control agencies. The untreated or partially treated waste from industrial effluents should be treated properly and efficiently by sewage treatment plants to maintain the metal concentrations at prescribed standards.

AUTHORS CONTRIBUTION

Sonali Tiwari: conducted field sampling, laboratory analysis, and manuscript preparation, Naveen Kumar: collected the data and edited the manuscript, Priyanka Jatav: reviewed and interpreted the result, Archana Meena: analyzed and supervised the data.

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Diversity and Phosphate Solubilization Potential of Rhizospheric Fungi from different Land-use of Mokokchung district, Nagaland, India

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***Abstract*:** This study investigates the rhizospheric fungal communities in soil samples from Mokokchung, Nagaland, India, collected from five land-use types: natural forest (NF), tree plantation (TP), bamboo plantation (BP), jhum fallow (JF), and shifting cultivation (SC). Various soil parameters, including temperature, pH, organic carbon, moisture, available nitrogen, phosphorus, and potassium, were analyzed. Soil fungal species were isolated in rose Bengal agar (RBA) and potato dextrose agar (PDA), and the diversity, richness, evenness, and abundance were estimated using diversity indices such as Shannon, Simpson, Berger-Parker, and Pielou's evenness. Results depict significant variations in soil properties influencing fungal populations across the different land-use types. NF exhibited the highest fungal diversity, taxa, and richness, while SC had the lowest, as reflected by the diversity indices. *Aspergillus* and *Penicillium* were the predominant genera. Additionally, eight fungal isolates demonstrated the ability to solubilize phosphate, with *Penicillium* emerging as a particularly promising candidate for further evaluation due to its high solubilization potential. This study highlights the impact of land-use on fungal diversity and the potential of phosphate-solubilizing fungi for sustainable agriculture.

***Keywords*:** Land-use, Fungal diversity, Phosphate solubilizing fungi, Diversity indices, North East India

The plant root system influences the soil rhizosphere and micro-organisms present in the soil are subsequently influenced by the plant-root metabolites (Sharma and Shrivastava 2017). Therefore, depending on the land-use, different fungal flora is present. The fungal population regulates the ecosystem, stabilizes habitat, and controls various soil processes (Frąc et al 2015). However, reports on the loss of biodiversity globally, which ultimately lowers ecosystem functionality, extinctions, and even ecosystem collapse in extreme situations are reported (Dunne and Williams 2009). The primary driver of this rapid loss of fungal biodiversity is converting forest land to agricultural systems and land-uses characterized by regular anthropogenic disturbances (Temjen et al 2021). Therefore, inventory is a valuable resource and ensures natural resource efficiency and sustainable utilization to prevent further biodiversity loss. The main instrument for ensuring ecological monitoring and addressing the biodiversity crisis is the use of diversity indices, which enable measurement of the two essential aspects of an ecosystem, i.e., richness and evenness (Stirling and Wilsey 2001, Morris et al 2014).

Phosphorus constitutes about 0.2% of the plant's dry weight and is essential for plant growth and metabolism (Widawati and Suliasih 2006). However, plants can only utilize a trace amount of the chemical P and a substantial amount is immobilized and left inaccessible to plants (El Attar et al 2022). The economically and environmentally beneficial solution would be a microbial inoculant capable of dissolving sparingly soluble inorganic soil P (Alori et al 2017). Phosphate solubilizing fungi (PSF) can solubilize insoluble phosphate in the soil. Fungi, in particular, have a more remarkable ability to solubilize insoluble phosphate than bacteria (Zhang et al 2018). Mokokchung district is a hilly region in Nagaland state, North-East India. The ever-increasing population in the state has amplified the pressure on the land. There is a trend of rapid conversion of natural forests into different land-use systems, which negatively affects the fungal community (Miah et al 2010, Temjen et al 2021). Therefore, the present work aims to study the diverse rhizospheric fungal populations from various land-use sites in Mokokchung district, Nagaland, India and estimate those fungi with the capacity to solubilize P for sustainable agriculture.

MATERIAL AND METHODS

Site selection: Five land-use sites under Mokokchung district, Nagaland, India, were selected (Table 1). The major type of soil in the region have alluvial soil, non-laterite red soil, and forest soil, with an average temperature of 27°C and 2500 mm of rainfall annually (Temjen et al 2022).

Soil sample: Composite soil layers at 0-30 cm were collected from the rhizospheric region of each site during spring 2023. Soil temperature and pH were recorded on-site, soil organic carbon (SOC) was estimated using air-dried sieved soil samples (Walkley and Black 1934), and soil moisture was measured via the gravimetric method. The available nitrogen (N) was estimated as per the Kjeldahl method (1883), the available phosphorus (P) as per Bray's no. 1 extract method (Bray and Kurtz 1945), and exchangeable potassium (K) as per Trivedy and Goel (1986). All tests were performed in triplicates. Soil fungal species were isolated in rose bengal agar (RBA) and potato dextrose agar (PDA) plates supplemented with streptomycin sulphate (0.03g/L) and prepared following the serial dilution method (Selman and Waksman 1921). PDA and RBA plates were incubated at 25±1°C for 5-7 days. The fungi were identified with the help of standard literature (Gillman 1957, Nagmani et al 2006, Webster and Weber 2007), and the colony-forming unit was expressed as CFU/g^{-1} (Johnson and Case 2006).

Phosphate solubilizing fungi (PSF): Pikovskaya (PVK) agar (Himedia) was utilized to screen their ability for phosphate solubilization. PVK agar was autoclaved at 121°C, and the subsequently sterilized PVK agar was transferred to fixed Petri plates. Fungal isolates from the pure culture were transferred to the PVK agar in three replicates. The mean values of the clearing zone diameter/halo formed around the PSF colony were recorded on the 5^{th}, 10^{th} and 15^{th} days of incubation. The phosphate solubilization index (SI) was recorded by measuring the area of the clearing zone/halo area (Premono et al 1996).

Statistical analysis: Data were analysed using SPSS version 26.0 to perform the Duncan's multiple range test (DMRT). PAST 4.03 was utilized to calculate the number of taxa (S), individuals (N), dominance (D), Simpson (1-D), Shannon (H), Pielou's evenness (J), and Berger-Parker indices to determine the diversity, richness, evenness, and abundance of the fungal population.

RESULTS AND DISCUSSION

Soil properties: Soil temperature varied significantly among the sites, with the highest at JF, followed by SC (Table 2). This increased temperature at JF and SC may be attributed to the loss of vegetation cover at both sites and the resultant exposure of the soil layer to the sun. The highest pH was observed at SC, while the lowest was reported at NF and TP, respectively. The increased pH level at SC is attributed to the burning of the soil, which has been reported to raise pH (Temjen et al 2021). In contrast, the decreased pH levels at NF and TP may be attributed to the increased organic matter input from aboveground biomass at the sites. There was an also significant variation in soil moisture. Site NF possessed the highest moisture content. This is attributed to the increased vegetation and water-holding capacity of the site. The decreased soil moisture at SC may be due to the heating of the soil by slash and burning activities. SOC was found to be highest in BP and NF, while the lowest was reported under

Table 1. Description of study sites

Site	Vegetation	Period	Disturbances
Natural Forest (NF) 26.31203°N, 94.49328°E	*Ageratum conyzoides, Amaranthus* sp, *Angiopteris* sp, *Artemisia vulgaris, Azadirachta indica, Eupatorium* sp, *Sonchus wightianus, Macaranga denticulate, Mikania cordata, Pueraria* sp, *Terminalia myriocarpa* and *Thysanolaena maxima*	12^{th} year of fallow	No anthropogenic disturbance
Tree plantation (TP) 26.3123°N, 94.4942° E	*Duabanga grandiflora*	5^{th} year of plantation	Little or no anthropogenic disturbance
Bamboo plantation (BP) 26.3130°N, 94.4949°E	*Dendrocalamus* sp	5^{th} year of plantation	Little or no anthropogenic disturbance
Jhum fallow (JF) 26.3130°N, 94.4959° E	*Ageratum conyzoides, Eupatorium* sp, *Amaranthus* sp	1^{st} year of fallow	Little or no anthropogenic disturbance
Shifting cultivation site (SC) 26.31065°N, 94.49405°E	*Manihot esculenta*	4^{th} cycle of cultivation	High anthropogenic disturbance

Table 2. Soil parameters across the during study sites

Site	Temperature (^{0}C)	pH	Moisture (%)	SOC (%)	N (Kg ha^{-1})	P (Kg ha^{-1})	K (Kg ha^{-1})
NF	22^a	5.4^{ab}	24^d	3.42^c	478^d	190^c	31^c
TP	23^b	5.1^a	19^c	3.01^b	316^c	170^b	23^c
BP	21^a	5.5^{ab}	17^b	3.37^d	303^c	169^b	24^{bc}
JF	24^a	5.6^b	18^b	2.64^a	240^b	116^{ab}	21^b
SC	24^b	5.7^b	16^a	2.47^a	114^a	98^a	19^a

*Values in the same column with different superscripts are significantly different at the 5% level by DMRT

SC. This increased SOC at BP and NF may be attributed to the increased build-up of organic matter from both root and aboveground biomass at the respective sites. Bamboos, in particular, have high carbon sequestration capacity owing to their large biomass density and fast growth rate (Devi and Singh 2021). Meanwhile, lower SOC under SC and JF may be due to high rates of continuous cultivation for an extended period without a sufficient fallow phase, reducing the amount of organic material available in the soil (Yimer et al 2007). Similar trend was reported for the macronutrients in the study, i.e., N, P, and K. We report higher values under NF, TP, and BP as compared to JF and SC. This may be attributed to the increased mineralization process under the soils of the undisturbed sites as compared to the disturbed sites, i.e., SC and JF (Temjen et al 2021).

Fungal diversity and diversity indices: Thirty-one fungal species were isolated from the various land-use sites (Table 3), and the CFU is depicted in Table 4. *Aspergillus* and *Penicillium* were the most dominant genera, while *Absidia* sp. and *Fusarium* sp. were the least occurring genera. The

Table 3. Fungal diversity of the different land-use sites

Fungal species	Land-use				
	NF	TP	BP	JF	SC
1. *Absidia* sp.*				+	
2. Acremonium murorum ***	+	+	+		
3. A. strictum *			+		
4. A candidus *	+				
5. A. flavus ****	+		+	+	+
6. A. fumigatus ***	+	+	+		
7. A. versicolor *	+				
8. *A,* ***	+	+			+
9. *Aspergillu*s sp. 1 **	+	+			
10. *Aspergillus* sp. 2	+		+		+
11.Chladosporium chaldosporiodes *****	+	+	+	+	+
12. Eupenicillium javanicum ****	+	+	+		+
13. *Fusarium* sp. *				+	+
*14. Geotrichum candidum****	+	+	+		
15. *Humicola* sp. **			+	+	
16. *Mortierella* sp. *****	+	+	+	+	+
17. *Mucor circinelloides*	+			+	+
18. M.hiemalis ****	+	+	+		
*19. Paecilomyces carneus****		+	+	+	
20. P. farinosus ****	+	+	+		+
21. Penicillium brevicompactum ***	+		+	+	
22. P.citrinum ***		+	+	+	
23. P. digitatum *	+	+			
24. *Penicillium* sp. 1 ***	+			+	+
25. *Penicillium* sp. 2 ***	+	+	+		
26. *Penicillium* sp. 3 ****	+	+	+		
27. *Penicillium* sp. 4 ***	+	+		+	
28. *Rhizopus* sp. ***	+		+	+	
29. *Scopulariopsis* sp. *	+				
30.Trichoderma viridie ***	+	+	+		
31.Trychophyton sp. ***		+	+	+	

Species distribution is categorized based on their presence across the land-use sites: ***** = very broad (present in all five sites); **** = broad (present in four sites); *** = moderate (present in three sites); ** = narrow (present in two sites); * = very narrow (present in one site) distribution of the fungi in the present study may be attributed to a combination of their host-specificity and suitable environmental conditions that enable their establishment. Further, there are observations that fungal colonies with better sporulation features dominate and colonize the culture plates better, resulting in more spores (Jena et al 2015). NF had the highest fungal taxa, followed by BP, TP, JF, and SC (Table 5). The dominance value, indicating the evenness of taxa distribution, was highest at SC and lowest at NF. The Simpson index of diversity was highest at NF, suggesting greater species dominance, while SC had the lowest. The Shannon index, reflecting species richness and evenness, was also highest in NF. Pielou's evenness index showed the highest evenness at JF and the lowest at SC. The Berger-Parker dominance index indicated that the most abundant species were more dominant at SC compared to other sites. The most fungi live in symbiotic association with their respective host, a change in land-use is expected to change the fungal community. Overall, NF exhibited the highest fungal diversity, likely due to its undisturbed nature and diverse vegetation. In contrast, SC had the lowest diversity, potentially due to anthropogenic activities like slash-and-burn practices, which lead to lower soil moisture and reduced fungal evenness. Miah et al (2010) also reported lower fungal populations in disturbed sites than in forests. The dominance of certain species at SC highlights the impact of land-use changes on fungal communities and underscores the importance of understanding the entire fungal population for ecosystem sustainability (Dai et al 2013)

Phosphate solubilizing fungi (PSF): Eight isolates were identified from different land-use sites with the capacity for phosphate solubilization. The SI varied significantly among the isolates (Table 6). The largest halo zone was observed under *Penicillium* sp. 3, while the smallest was reported under *Aspergillus* sp. 1. *Aspergillus* and *Penicillium* genera were particularly notable for their phosphate solubilizing capabilities. Turan (2006) and Alori et al (2017) also reported that these genera significantly reduced pH during phosphate solubilization. The process is understood to occur due to organic acids lowering pH or by complexing cations bound to phosphates (Johan et al 2021). The NF site also had the highest concentration of PSF, while JF and SC had the lowest concentrations. The greater abundance of PSF in NF may be attributed to diverse vegetation and increased organic matter, while the reduced PSF population in SC is likely due to high anthropogenic disturbances and burning practices, making the environment less suitable for these fungi (Temjen et al 2021).

CONCLUSIONS

The present findings identified eight fungal species capable of solubilizing phosphate, with higher PSF recorded in the natural forest and lower in shifting cultivation and *jhum*

Table 4. Fungal colony forming unit of the different land-use sites

Site	Fungal CFU
NF	76 x10^4/g[a]
TP	40.5 x10^4/g[b]
BP	45 x10^4/g[b]
JF	26 x10^4/g[c]
SC	24.5 x10^4/g[c]

*Values with different superscripts are significantly different at the 5% level by DMRT

Table 6. Solubilization index of PSF

PSF	Phosphate solubilisation index (cm)		
	5th day	10th day	15th day
Acremonium murorum	2.56±0.12	2.78±0.02	2.84±0.23
Aspergillus sp. 1	1.02±0.23	1.42±0.13	1.53±0.22
Aspergillus sp. 2	1.05±0.53	1.65±0.02	1.71±0.31
Mucor hiemalis	1.56±0.11	1.72±0.13	1.81±0.09
Penicillium sp. 1	1.14±0.14	2.58±0.25	2.94±0.18
Penicillium sp. 2	1.81±0.13	2.22±0.36	2.52±0.17
Penicillium sp. 3	3.20±0.25	3.50±0.24	3.54±0.22
Rhizopus sp.	2.12±0.05	2.64±0.22	2.87±0.09

Table 5. Diversity indices of different land-use sites

Indices	NF	TP	BP	JF	SC
Taxa (S)	21	17	20	15	12
Individuals (N)	152	81	90	52	49
Dominance (D)	0.077	0.096	0.085	0.088	0.132
Simpson (1-D)	0.922	0.903	0.914	0.912	0.868
Shannon (H)	2.815	2.564	2.681	2.566	2.221
Pielou's evenness (J)	0.924	0.905	0.894	0.947	0.893
Berger-Parker	0.190	0.185	0.155	0.173	0.224

fallow sites. Among these, species from *Penicillium* sp. 3 demonstrated superior solubilization potential, making it a promising candidate for further evaluation. Given the rising costs and adverse effects of chemical fertilizers, PSF offers a sustainable alternative for agriculture. Developing high-quality inoculants and consistently monitoring biological resources is essential. Future research should focus on field trials and large-scale experiments to assess the viability of PSF.

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Studies on Four Species of Genus *Hypolampurus* Hampson (Lepidoptera: Thyrididae) from Western Ghats, India

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Abstract: The communications deals with the studies on the morphotaxonomy of four species i.e., *angulalis* Moore, *striatalis* Swinhoe, *langualis* sp. nov. and *neostriatalis* sp. nov. belonging to genus *Hypolampurus* Hampson under family Thyrididae of order Lepidoptera. The species i.e., *H. angulalis* Moore is recorded for the first time from India. The female genitalia of species *striatalis* Swinhoe have been studied for the first time which is the type-species of the genus *Hypolamprus* Hampson. Beside this, the details on the morphology of the adults, male and female genitalia, nomenclature of the wing venation, distribution and materials examined for all the species have been discussed and illustrated in full details. A dichotomous key for their interspecific discrimination is also provided.

Keywords: Morphotaxonomy, Lepidoptera, Thyrididae, *Hypolampurus* Hampson, Western Ghats

Lepidoptera are scaly winged insects (Moths, butterflies and skippers) in the class Insecta which are having 1,58,570 species on global basis which are approximately to 9% of total Animalia. About 15,000 species belonging to 84 families fall in this order out of which 13,359 species under 78 families are moths and remaining are butterflies from India (Chandra 2011). Under this order one of the Superfamily Thyridoidea, the family Thyrididae comprise the picture winged leaf moths which are sometime included in Superfamily Pyraloidea, but all these not supported by cladistic analysis.

The genus *Hypolampurus* Hampson is a genus of the family Thrididae under order Lepidoptera. This genus was proposed for its type-species i.e., *Microsca striatalis* Swinhoe (Hampson 1893). Hampson (1894) reported only seven species from the then limits of India including and only one species i.e., *striatalis* Swinhoe from Western Ghats of India. Eleven specimens belonging to four species of genus *Hypolampurus* Hampson were identified from the Lepidoptera collection of Western Ghats which are housed in different museums. Owing to characters such as position of labial palpi, type of antenna (which are minutely ciliated in male) and on the basis of wing maculation and venation, the phenon has been found to be identical to the genus *Hypolamprus* Hampson of family Thyrididae. Besides above, the materials were comparison with the reference collections housed in different national museums and consultation of relevant literature (Warren 1896, 1896a and Whalley 1971), the aforesaid phenon has been sorted out into four species *i.e., H. angulalis* Moore, *H. striatalis* Swinhoe, *H. langualis* sp. nov and *H. neostriatalis* sp. nov. A dichotomous key for their interspecific discrimination is also prepared.

MATERIAL AND METHODS

The adults of this genus were exclusively collected with the help of portable light trap (Plate 1) or fluorescent lights at night hours from different localities of Western Ghats of India (Plate 2) and put in the glass bottles charged with the ethyl acetate. The collected specimens were stretched and dried in stretching boxes and afterwards preserved well fumigated wooden boxes. The external morphological characters like antennae, proboscis, labial palpi, colour of frons and vertex, eyes, markings on patagia and tegula, wing venation and maculation, colour and markings of thorax, abdominal characters, position and number of tibial spurs were studied at first instance. To study wing venation, permanent slides of wings were made. For the preparation of permanent slides of fore and hindwings, the method proposed by Common (1970) and advocated by Zimmerman (1978) and to study the external male genitalia, methodology given by Robinson (1976) were followed. The photographs of genitalia were taken in stereo zoom binocular and wing venation drawn on graph papers. Multiple dissections of the studied species were made to examine the population variations. The terminology given by Klots (1970) was followed for the nomenclature purpose. All the collections were deposited in the Insect Museum, Department of Zoology & Environmental Sciences, Punjabi University, Patiala and National PAU Insect Museum, Department of Entomology, Punjab

Agricultural University, Ludhiana, Punjab. The geographical information of the localities in the states/district of Karnataka, Kerala, Maharashtra and Goa are provided below (Table1).

RESULTS AND DISCUSSION

HYPOLAMPRUS Hampson

Hypolamprus Hampson, 1893, *Fauna of British India (Moths)* 1: 364.

Type-species: *Hypolamprus striatalis* Swinhoe.

Labial palpus slight, upturned and reaching above vertex of head; antenna minutely ciliated in male; forewing with costa straight, convex near apex, apex slightly produced and acute, termen wavy or evenly curved, tornus rounded, anal margin nearly straight, R_3, R_4 stalked, M_1 from middle of discocellulars; hindwing with costa straight, apex rounded, termen wavy or evenly curved, tornus rounded, anal margin straight.

Key to the species of the genus *Hypolamprus* Hampson

1.	Abdomen brown, irrorated with pale red scales …	2
-	Abdomen not as above …………………………..	3
2.	Head with frons and vertex velvety red tinged with brown………..	*angulalis* Moore
-	Head with frons and vertex fuscous.……………..	*striatalis* Swinhoe
3.	Legs furnished with red brown scales …………..	*langualis* sp. nov.
-	Legs furnished with white scales …………..	*neostriatalis* sp. nov.

Hypolamprus angulalis Moore

Morova angulalis Moore, 1888, *Lepid, Atkin* : 214.

Hypolamprus angulalis (Moore) Hampson, 1892.

Male: Alar expanse: 24 mm (Plate 3). Vertex and frons velvety red tinged with brown; labial palpus slight, upturned and reaching above vertex of head; antenna minutely ciliated; forewing with costa straight, convex near apex, apex slightly produced and acute, termen wavy, tornus rounded, anal margin nearly straight, ground color dull coffee color, irregularly striated with light red; hindwing with costa straight, apex rounded, termen wavy, tornus rounded, anal margin rounded, anal margin straight, ground color dull coffee color, irregularly striated with light red; underside of both wings suffused with silvery scales; tarsi striped white and brown; abdomen brown, irrorated with pale red scales.

Wing Venation: Forewing with vein Sc ending beyond middle of costa, R_1 and R_2 from cell, $R_3$and R_4 stalked, R_5 from upper angle of cell, M_1 from middle of discocellulars, M_2 and M_3 from lower angel, Cu_1 very near to lower angle, Cu_2 from middle of cell, 1A present, 2A forked with 1A at base; hindwing with $Sc+R_1$ orignating from base of cell, anastomosing upper nervure at angle and separates to meet costa, Rs and M_1 from upper angle of cell, M_2 and M_3 from lower angle, Cu_1 very near to angel of cell, Cu_2 from middle of cell, 1A and 2A present.

Male genitalia: Male genitalia with uncus strongly built, sclerotized, broadens toward middle and again tapering towards distal end, tip ending to a small spine, gnathos absent; tegumen broad, vinculum very long, deep U- shaped; saccus present; valva simple, flap-like, without any projections, setosed with long setae, tip blunt; transtilla membranous; juxta small; aedeagus moderately long, much broad towards proximal end, cornuti absent, ductus ejaculatorious enters apically.

Plate 1. Portable light trap

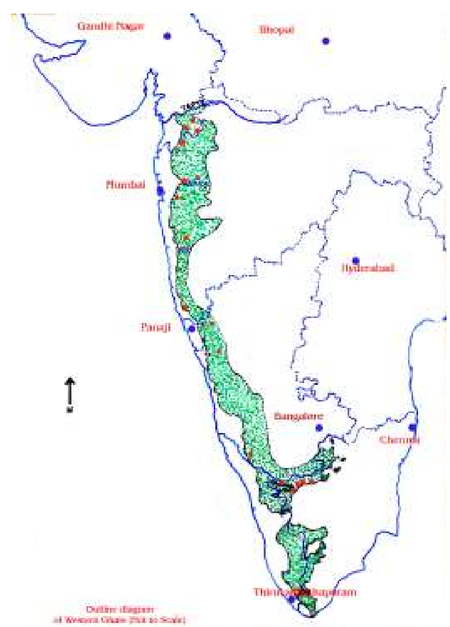


Plate 2. Area surveyed

Female genitalia: Not examined.

Material examined: India: Goa: Distt. Sanguem, Molem, 110mASL, 23.ii.2004, 2♂; Distt. Ponda, Ponda, 85mASL, 28.ii.2004, 1♂, coll. A. Katewa.

Old distribution: Rangoon (Hapmson 1892)

Remarks: The species *angulalis* Moore has earlier been reported from Rangoon by Hampson (1892). During the present studies, three specimens were collected from two different localities in the state Goa. In view of this, it is clear that the species is new record not only for the Western Ghats but the country, as well. The external male genitalia of this species is being studied for the first time.

***Hypolamprus striatalis* Swinhoe**

Microsa striatalis Swinhoe, 1886, *Procceding of theZoologicalSociety, London*. 1885: 875.

Hypolamprus striatalis (Swinhoe) Hampson, 1892

Male and Female: Alar expanse: 17mm (Plate 4).Vertex and frons fuscus; labial palpus slight, upturned and reaching above vertex of head; antenna minutely ciliated; forewing with costa straight, convex near apex, apex slightly produced and acute, termen evenly rounded, not wavy, tornus rounded, anal margin straight, ground color pale red brown, evenly striated with brown lines, a dull spot on upper angle of cell and one below cell; hindwing with costa straight, apex rounded, termen straight, tornus rounded, anal margin straight, ground color pale red brown, evenly striated with brown lines, medial band present; legs white; abdomen pale red brown.

Wing Venation: Forewing with vein Sc ending beyond middle of costa, R_1 and R_2 from cell, $R_3$and R_4 stalked, R_5 from upper angle of cell, M_1 from middle of discocellulars, M_2 and M_3 from lower angel, Cu_1 very near to lower angle, Cu_2 from middle of cell, 1A present, 2A forked with 1A at base; hindwing with $Sc+R_1$ orignating from base of cell, anastomosing upper nervure at angle and separates to meet costa, Rs and M_1 from upper angle of cell, M_2 and M_3 from lower angle, Cu_1 very near to angel of cell, Cu_2 from middle of cell, 1A and 2A present.

Male genitalia: Not studied.

Female genitalia: Female genitalia with corpus bursae rounded, weakly sclerotized; signum not distinct; ductus bursae long and narrow, sclerotized towards corpus bursae; ostium bursae marked with two sclerotized structures; apophyses small; papilla analis weakly sclerotized, setosed with fine setae.

Material examined: India: Maharashtra: Distt. Sindhudurg, Amboli, 850mASL, 11.x.2005, 3♀♀, coll.

Distribution: Dharamshala, Calcutta, Poona, Nilgiris, Ceylon (Hampson 1892)

Remarks: The species *striatalis* Swinhoe has earlier been reported from Poona (Maharashtra) near the Western Ghats by Hampson (1892). During the present collection tours, it has again been collected from a locality (Amboli) which is nearer to Poona, from the same state which is very close to Poona. The present distributional data is additional to the old one. It can be inferred that the species has restricted distribution. Also, the female genitalia of this species which is type-species of the genus *Hypolamprus* Hampson has been studied for the first time.

***Hypolamprus langualis* sp. nov.**

Male: Alar expanse: 19mm (Plate 5).Vertex and frons fuscus; labial palpus slight, upturned and reaching above vertex of head; antenna minutely ciliated; forewing with costa straight, convex near apex, apex slightly produced and acute, termen wavy, cilia white, tornus rounded, anal margin straight, ground color red-brown, evenly striated with red lines; hindwing with costa straight, apex rounded, termen wavy cilia white tornus rounded, anal margin straight, ground color rusty-red, striated with brown lines; legs furnished with red brown scales; abdomen fuscus.

Wing Venation: Forewing with vein Sc ending beyond middle of costa, R_1 and R_2 from cell, $R_3$and R_4 stalked, R_5 from upper angle of cell, M_1 from middle of discocellulars, M_2 and M_3 from lower angel, Cu_1 very near to lower angle, Cu_2 from middle of cell, 1A present, 2A forked with 1A at base; hindwing with $Sc+R_1$ orignating from base of cell, anastomosing upper nervure at angle and separates to meet costa, Rs and M_1 from upper angle of cell, M_2 and M_3 from lower angle, Cu_1 very near to angel of cell, Cu_2 from middle of cell, 1A and 2A present.

Table 1. Geographical information of the localities

State	District	Locality	Geographical coordinates	Altitude
Karnataka	Uttar Kannada	Ganeshgudi	15.2843° N, 74.5302° E	480mASL
Kerala	Palakkad	Mukkali	11.0587° N, 76.5402° E	560mASL
	Idukki	Vallakadavu	8.4750° N, 76.9195° E	780mASL
Maharashtra	Sindhudurg	Amboli	15.9647° N, 74.0036° E	850mASL
Goa	Sanguem	Molem	15.3758° N, 74.2269° E	110mASL
	Ponda	Ponda	15.4027° N, 74.0078° E	85mASL

Male genitalia: Male genitalia with uncus long and narrow, sickle-shaped, sparsely setosed, tip ending to a curved spine; tegumen broad; vinculum long, broad U- shaped; saccus present; valva simple, costa and succulus well differentiated, a pair of small projections present towards distal end, tip blunt without any bifurcation, setosed with long hairs; transtilla membranous; juxta present; aedeagus long and narrow, curved, cornuti absent, ductus ejaculatorious enters laterally.

Female genitalia: Not studied.

Material examined: India: Kerala: Dist. Palakkad, Mukkali, 560mASL, 22.ix.2004, 01♂; Karnataka: Dist. Uttar Kannada, Ganeshgudi, 480mASL, 16.x.2005, 02♂, coll.

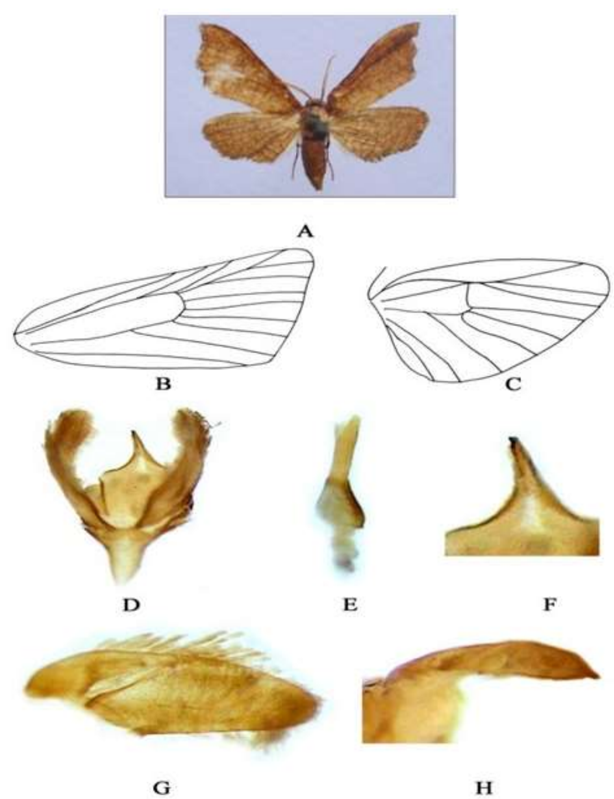
Etymology: The name of the species as *Hypolamprusl angualis* sp. nov.is proposed as an anagram of its closely allied species *i.e., Hypolamprus angulalis* Moore.

Remarks: *Hypolamprusl angualis* sp. nov. is allied to the species *i.e., striatalis* Swinhoe from which it can be easily differentiated on the basis of ground color which is red in the former species and grey in latter. The former species is smaller in size as compared to the latter.

***Hypolamprus neostriatalis* sp. nov.**

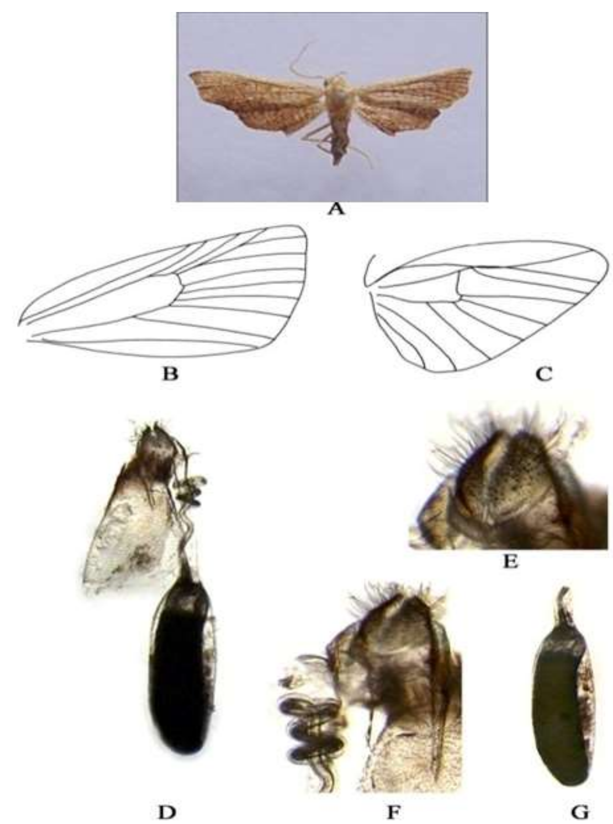
Male: Alar expanse: 13mm (Plate 6).Vertex and frons white; labial palpus slight, upturned and reaching above vertex of head; antenna minutely ciliated; forewing with costa straight, convex near apex, apex slightly produced and acute, termen wavy, cilia fuscus, tornus rounded, anal margin straight, ground color red-brown, striated with red lines; hindwing with costa straight, apex rounded, termen wavy, cilia fuscus, tornus rounded, anal margin nearly straight, ground color rusty-red, few ill-defined dark-red striae present; legs white; abdomen scaled with few shite scales.

Wing Venation: Forewing with vein Sc ending beyond middle of costa, R_1 and R_2 from cell, R_3 and R_4 stalked, R_5 from upper angle of cell, M_1 from middle of discocellulars, M_2 and M_3 from lower angel, Cu_1 very near to lower angle, Cu_2 from middle of cell, 1A present, 2A forked with 1A at base; hindwing with $Sc+R_1$ orignating from base of cell, anastomosing upper nervure at angle and separates to meet costa, Rs and M_1 from upper angle of cell, M_2 and M_3 from lower angle, Cu_1 very near to angel of cell, Cu_2 from middle of cell, 1A and 2A present.



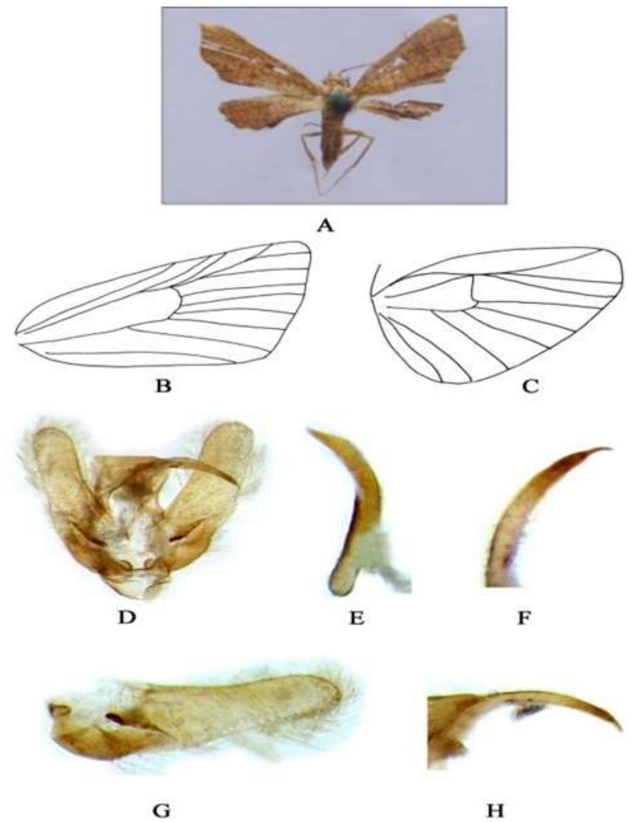
Figs. A=Adult, B=Forewing, C=Hindwing, D=Male external genitalia, E=Aedeagus, F=Uncus and Gnathos ventral view, G=Valva, H=Uncus and Gnathos ventral view

Plate 3. *Hypolamprus angulalis* Moore



Figs. A=Adult, B=Forewing, C=Hindwing, D=Female external genitalia, E=Ovipositor lobes, F=Ductus Bursae and Apophyses,, G=Corpus Bursae

Plate 4. *Hypolamprus striatalis* Swinhoe



Figs. A=Adult, B=Forewing, C=Hindwing, D=Male external genitalia, E=Aedeagus, F=Uncus and Gnathos ventral view, G=Valva, H=Uncus and Gnathos ventral view

Plate 5. *Hypolamprus langualis sp. nov.*

Male genitalia: Not studied.

Female genitalia: Female genitalia with corpus bursae elongated, bag-like, sclerotized; signum not distinct; ductusbursae very long and narrow, coiled towards ostium bursae; ostium bursae simple; apophyses long, almost of same length small; papilla analis semicircular, setosed with fine setae.

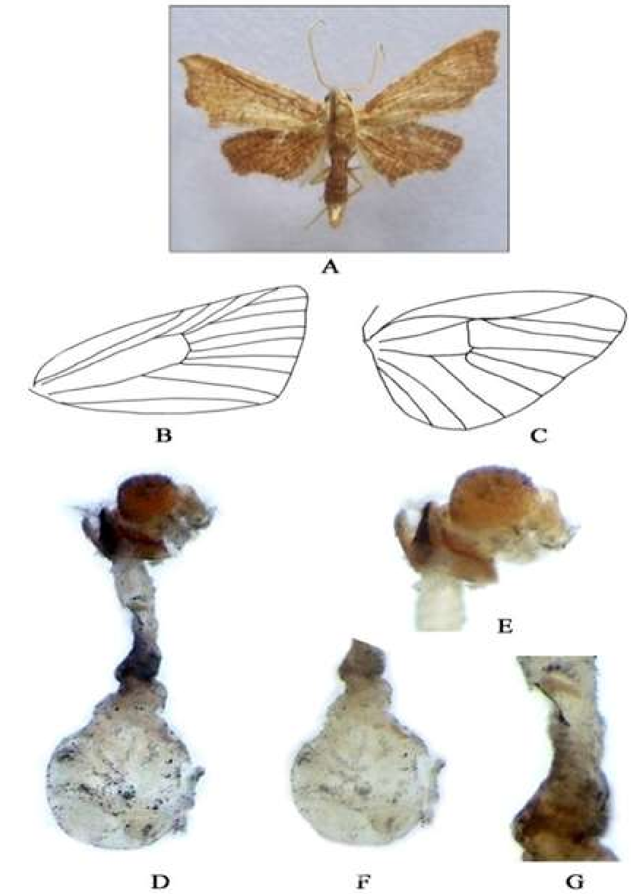
Material examined: India: Kerala: Dist. Idukki, Vallakadavu, 780mASL, 11.ix.2004, 01♀; Dist. Palakkad, Mukkali, 560mASL, 19.ix.2004, 01♀, coll..

Etymology: The specific name is derived as *Hypolamprus neostriatalis* sp. nov. being sibling to *Hypolamprus angulalis* Moore.

Remarks: *Hypolamprus neostriatalis* sp. nov.is allied to *Hypolamprus angulalis* Moore sp. nov. but either of them can be easily separated by their alar expanse and general maculation of the wings.

CONCLUSIONS

The present study has information on the taxonomy and distribution of four species of genus *Hypolampurus* Hampson



Figs. A=Adult, B=Forewing, C=Hindwing, D=Female external genitalia, E=Ovipositor lobes, F=Ductus Bursae and Apophyses, G=Corpus Bursae

Plate 6. *Hypolamprus neostraiatlis sp. nov.*

from Western ghats of India. Seven species from the then limits of India including and only species i.e., *striatalis* Swinhoe from Western Ghats of India was reported (Hampson, 1894). The collected materials have been sorted out into four species *i.e., angulalis* Moore (New record from India), *striatalis* Swinhoe and two new species i.e., *langualis* sp. nov and *neostriatalis* sp. nov. reported from the area under reference. A dichotomous key for their interspecific discrimination is also provided.

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Potential of Twin Key Management Practices: Higher Colony Strength and Lower Honey Extraction Frequency in Improving Honey Quality of *Apis mellifera*

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***Abstract*:** Present study signifies the benefits of scientific management practices which eventually will earn more returns to beekeepers in India. Colonies with initial 10 frames strength and two extractions in the seasons were observed to produce honey of good quality and most economical. In 5 frame colonies moisture remained well below (17.91%) the maximum standards (20%) set for "special" grade honey and was still lower (17.80%) in medium strength (10 frames) and the strongest (15 frames) colonies (17.43%). However, under regular honey extraction, the moisture content was maximum in colonies of lowest strength (20.02%) compared to in 10 and 15 frame colonies. Other quality parameters like F: G ratio, sucrose, hydroxy methyl furfural (HMF) was observed above standards in 10 frame and two extraction colonies. Total reducing sugars was highest (82.23 %) in 15 frame single extraction colonies and 80.24 % in 10 frame colonies with similar extraction frequencies. Present findings clearly support the role of extraction frequencies in improving honey quality as we decrease frequency quality improves remarkable even in low strength colony. Strength is also a very important factor in deciding honey quality.

Keywords: Honey quality, Extraction, Quality Parameters, Moisture, Honey sugars

Beekeepers desire to make beekeeping more and more profitable and keep on extracting honey at regular intervals during honey flow season. Scientific knowledge of beekeeping to beekeepers is a major constraint and they follow either traditional or own developed non-scientific practices which degrades quality of honey. Regular extraction of honey at fixed interval of 7-10 days and extraction of un-ripened honey from brood chamber and reluctant to use supers for honey production are some causes of quality degradation. In India winter is the major honey flow season from mustard crop followed by few minor seasons up to early summer (December to May) followed by a long dearth from summer through rainy season till November (Chaudhary 2005). The Bureau of Indian Standards (BIS) standard (No. IS: 4941-1974), now Food Standard and Safety Authority of India (FSSAI 2010) through its regulation (No. 5.7.4) also recommends extracting honey from ripe and sealed honey combs and by default present Indian honey does not confirm to these standards. Besides poor quality, such practices are the root cause of low colony productivity. The production of honey and growth of colony is dependent over colony strength & honey extraction frequency. Right colony strength and extraction frequency gives better economical returns in beekeeping enterprise (Bhusal 2011, Saini et al 2018b, 2022). Honey quality parameters contain moisture content, ash content, total soluble solids (TSS), acidity, reducing & non-reducing, fructose: glucose ratio and HMF content (Codex 2001). Beekeeping now days facing four major problems *viz*. low colony productivity, colony debilitation / mortality, extremely poor honey quality and ever increasing cost of production (labor and migration) resulting in non-stability of the beekeeping enterprise. Present study on colony strength and honey extraction frequencies was conducted to formalize some practices for beekeeping that improves colony health and honey quality.

MATERIAL AND METHODS

Present investigations were carried out on western honey bee, *A. mellifera* L. colonies at beekeeper's apiary during major honey flow season of mustard crop. Initial colony strength (ICS) and for equalization of colonies standard protocol were followed Delaplane et al (2013) and Saini et al (2022). After equalization colonies were migrated to the experimental site at RDS Farm of CCS Haryana Agricultural University, Hisar on the mustard crop which was about to flowering. Each colony with specified frame strength was labeled and placed in diamond orientation at 10 feet row and 5 feet colony distance. Bee colony with 5, 10 and 15 frames strength were the treatments, these colonies were then extracted at different frequencies (once, twice and regular) considering single colony as one replication and four replications were kept in each treatment, total 36 colonies were under experiment (12 in each colony strength)

Honey extraction frequencies: To determine the effect of honey extraction frequencies on honey quality four colonies in each colony strength of 5, 10 and 15 frame were extracted once for honey in the season, four were extracted twice and remaining four in each strength were extracted regularly or following beekeeper's practice. During the experiment, 36 colonies (Colony strength and honey extraction frequencies) were used.

Collection of sample: Samples of honey for each treatment were collected in wide mouth food grade plastic bottles (Cello) on the day of honey extraction in the field, specific number were given to each sample and stored in a closed big plastic box at home under favorable temperature condition so that any change in property could be avoided before going for physio-chemical analysis. All precautions were taken care to keep the quality unaltered during storage.

Preparation of sample before processing: Samples for quality testing, were placed in hot water bath at 40^{0}C for liquefaction, strained through muslin cloth and stored in clean containers. Three honey sub samples from each treatment were drawn, then mixed together and a composite sub sample of 50 g was made for further processing. Honey left in the containers after making composite sample was again sealed in air tight jars. Three sets (replications) were made from the composite sample and subjected to testing for different honey quality parameters.

Physio-chemical characteristics of honey: The sub samples (in triplicate) were prepared from different treatments were analyzed as per standard procedures prescribed by the Bureau of Indian standard (IS4941:1994) unless specified in text. Standard procedures specified in FAO Manuals of Food Quality Control (FAO 1984), ISI Hand book of Food Analysis (Part II), and in testing manual of food safety and security authority of India (FSSAI 2010) were followed for honey quality testing.

RESULTS AND DISCUSSION

Honey quality in different colony strengths under different honey extraction regimes: In regular honey extraction, the moisture content was maximum in colonies of lowest strength (19.33%) compared to in 10 and 15 frame colonies where values were significantly lower but at par with each other (Table 1). The honey from lowest colony strength had least specific gravity (1.407) compared to the stronger colonies with similar values (1.409). On the contrary total reducing sugars was minimum in the lowest strength colonies 78.48 percent and increased progressively with increase in colony strength (79.22 and 79.43%). Colony

Table 1. Comparison of honey quality parameters in colonies with varied frame strength under different honey extraction regime

Quality parameters	Regular extraction in colony strengths (frames/colony)				2 extractions in colony strengths (frames/colony)				1 extraction in colony strengths (frames/colony)			
	5	10	15	CD (p=0.05)	5	10	15	CD (p=0.05)	5	10	15	CD (p=0.05)
Moisture (%)	19.33	19.05	19.05	0.06	19.10	18.80	19.00	0.06	18.60	18.40	17.40	0.07
Total reducing sugar (%)	78.48	79.22	79.43	0.20	78.96	79.65	79.78	0.05	79.87	80.24	82.23	0.05
Fructose (%)	40.06	41.18	40.85	0.07	40.60	40.80	41.07	0.02	40.66	41.15	41.89	0.04
Glucose (%)	38.42	38.04	38.59	0.16	38.36	38.85	38.71	0.06	39.21	39.09	40.34	0.08
Sucrose (%)	2.56	2.23	2.00	0.06	2.57	2.25	2.23	0.03	2.00	1.87	1.40	0.07
Acidity (%)	0.076	0.066	0.075	0.004	0.077	0.084	0.084	0.002	0.070	0.086	0.080	0.012
Ash (%)	0.091	0.082	0.093	0.005	0.088	0.095	0.094	0.003	0.086	0.095	0.090	NS
F/G ratio	1.042	1.082	1.059	0.005	1.058	1.051	1.061	0.002	1.036	1.053	1.038	0.003
H.M.F.	6.91	7.00	7.00	NS	7.103	7.038	7.000	0.048	7.107	7.190	7.190	NS
Specific gravity	1.407	1.409	1.409	0.000	1.408	1.410	1.409	0.001	1.410	1.411	1.414	0.001

strength under regular honey extraction had no effect on HMF content in the honeys. The moisture content was lowest in 10 frame colonies (18.80%) followed by 15 frames (19.00%). The increase in TRS was significant with increase in colony strength (78.96, 79.65 and 79.78%) from 5, 10 and 15 frame strengths, respectively. Fructose content also increased with colony strength while the glucose content was least in 5 frame colonies (38.36%) and maximum in 10 frame colonies (38.85%). The acidity and ash content was lowest in the weakest colonies (0.077 and 0.088%) that increased significantly in higher strength colonies.

Honey quality in different colonies strengths under different honey extraction regimes: In 15 frame colonies lowest moisture content 17.43%, signifying the highest honey quality in 15 frame colonies in the single honey extraction regime (Table 2). The specific gravity also had an increasing trend with increase in colony strength. TRS content increased from 80.38 percent in 5 frame colonies to 81.89% in 10 frame colonies and was the maximum in the strongest colonies (82.04%). The fructose content also exhibited similar increase from 40.90 to 41.71% while the glucose content was minimum in 5 frame (39.48%) to become maximum (40.57%) in 10 frame colonies. The sucrose exhibited reverse trend with colony strength being maximum in 5 frame (1.88%) and reducing in 10 (1.81) to become the least (1.26%) in strongest colonies. Acidity observed high in 5 frame colony (0.173) which decreases with increase in colony strength became minimum in 15 frame (0.076) and ash content where maximum in 15 frame colonies (0.093%) then 10 and 5 frame colonies (0.085 and 0.081, respectively).

Under twice honey extraction regimes, sucrose content was higher in 5 frame colonies which indicate un-ripened honey or nectar. F:G ratio showed pattern that was highest in the strongest colonies and lowest in weakest colony. Under regular honey extraction, the moisture content was maximum in colonies of lowest strength (20.02%) compared to in 10 and 15 frame colonies where values were significantly lower and varies significantly with each other. The honey from lowest colony strength had least specific gravity (1.405) compared to the stronger colonies which had value higher (1.409) than this. The total reducing sugars was minimum in the lowest strength colonies 78.54 percent and increased progressively with increase in colony strength (79.01 and 79.38%). Sucrose content was least in the strongest colonies (1.699%), increased to 2.01 % in 10 and 2.44 percent in 5 frame colonies. Ash content in honey was observed maximum in strongest colony (0.094%) which decreases significantly in 10 frame (0.089) and minimum in 5 frame colonies (0.082). The results for all the honey quality

Table 2. Comparison of honey quality parameters in colonies with varied frame strength under different honey extraction regime

Quality parameters	Regular extraction in colony strengths (Frames/colony)				2 extractions in colony strengths (Frames/colony)				1 extraction in colony strengths (Frames/colony)			
	5	10	15	CD (p=0.05)	5	10	15	CD (p=0.05)	5	10	15	CD (p=0.05)
Moisture (%)	20.022	19.809	19.652	0.016	19.860	19.697	19.345	0.021	17.907	17.807	17.433	0.115
Total reducing sugar (%)	78.542	79.011	79.384	0.049	78.433	79.385	79.597	0.019	80.387	81.897	82.047	0.025
Fructose (%)	40.051	40.931	41.241	0.034	40.183	40.713	40.879	0.021	40.900	41.390	41.713	0.060
Glucose (%)	38.492	38.080	38.144	0.037	38.248	38.675	38.718	0.028	39.487	40.573	40.333	0.146
Sucrose (%)	2.447	2.019	1.699	0.015	2.363	1.692	1.505	0.023	1.887	1.810	1.267	0.045
Acidity (%)	0.109	0.112	0.097	0.002	0.109	0.085	0.082	0.004	0.173	0.083	0.076	0.006
Ash (%)	0.082	0.089	0.094	0.002	0.079	0.085	0.079	0.002	0.081	0.085	0.093	0.004
F/G ratio	1.040	1.075	1.082	0.002	1.051	1.053	1.056	0.001	1.035	1.020	1.034	0.005
Hydroxy methyl furfural (mg/kg)	6.888	6.872	6.663	0.018	7.222	7.175	7.055	0.020	7.073	6.937	6.990	0.049
Specific gravity	1.405	1.408	1.409	0.001	1.399	1.404	1.410	0.001	1.412	1.413	1.415	0.001

Annexure 1. Various honey standards by agencies

Characteristics	P.F.A	BIS (4941-1994)			AGMARK (2008)			CODEX (2001)
		Special	"A"	Standard	Special	"A"	Standard	
Specific gravity at 27 C (Min)	-	1.37	1.37	1.37	1.40	1.37	1.35	--
Moisture % (Max)	25	20	22	25	20	22	25	21
Reducing sugars % (Min)	65	70	65	65	70	65	65	65
Sucrose % (Max)	5	5	5	5	5	5	5	5
Ratio L/D (Min)	0.95	1	1	1	1	0.95	0.95	--
Ash% (Max)	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.6
Acidity as formic acid % (Max)	0.20	0.20	0.20	0.20	0.20	0.20	0.20	40
Fiehe 's test			Negative			Negative		
Aniline Chloride test	-	-	-	-		Negative		
Total pollen count and plant elements / g A Apiary honey (Max)	-	50,000	50,000	50,000	50,000 50,000	50,000 50,000	50,000 50,000	-
H.M.F. mg / Kg (Max)	-	80	80	80	80	80	80	40
Optical density % (Max)	-	0.3	0.3	0.3	0.3	0.3	0.3	-
Diastase (Min)	-	-	-	-	3	3	3	3
Water insoluble matters % (Max) for pressed honeys	-	- -	- -	- -	0.50 0.10	0.50 0.10	0.50 0.10	0.1 0.5

BIS -If Fiesh's test is Positive and HMF content is more than 80 mg/kg then L/D ratio should be more than1.00
Agmark:
1.If the pollen count is higher than 50,000/gm. Then honey may be categorized as squeezed honey.
2.If the Fiehe's test is positive but Hydroxyl Methyl Furfural (HMF) content is below 80ppm then honey may be accepted.
If granulated, it should be warmed at 60 till the crystals have dissolved completely

parameters were remarkable under single and two honey extractions over regular extractions regime. Similar high quality of honey was recorded in strongest (15) and 10 frame colonies over the weakest 5 frame colonies. The moisture content which is major quality criteria even in 5 frame colonies (17.91%) remained well below the maximum standards (20%) set for "special" grade honey and was still lower in medium (17.80%) and the strongest colonies (17.43%). The specific gravity, total reducing sugars, fructose, glucose, ash content (0.081 to also increased with increase in colony strength. The acidity and HMF content were least in these honeys and confirm to best quality honey. Reports of Szabo et al (1992) and Szabo & Lefkovitch (1990) about the effects of the frequency of honey extraction (4, 2 and 1 times) quantity and quality of honey on A. mellifera colonies indicating higher moisture content in colonies with applications of 5 supers and 4 honey removals (19.0%) and the lowest with 2 honey removals and 12 supers (16.7%), highest diastase (amylase) numbers for honey removed once (28.6) followed by that removed twice (26.5) and 4 times (23.2) amply support the present findings.

There is significant role of extraction frequencies in improving honey quality as we decrease frequency quality improves remarkable even in low strength colony. Strength is also a very important factor in deciding honey quality. In spite improving honey quality less number of honey extractions increases economic returns to the farmers (Saini et al 2022). The results for all the honey quality parameters were remarkable under single and two honey extractions over regular extractions. Colonies with initial 10 frames strength and two extractions in the seasons were observed to produce honey of good quality and most economical as per findings of the study. The moisture content which is major quality criteria even in 5 frame colonies (17.91%) remained well below the maximum standards (20%) set for "special" grade honey and was still lower in medium (17.80%) and the strongest colonies (17.43%). However, under regular honey extraction, the moisture content was maximum in colonies of lowest strength (20.02%) compared to in 10 and 15 frame colonies. If beekeepers in India want to improve honey quality and to earn more returns from this enterprise honey extraction should be limit to one or two in the season leaving enough food stores for bee to survive dearth period.

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Morphological and Molecular Confirmation of *Thrips palmi*, Karny 1925 (Thripidae) and *Haplothrips tenuipennis* Bagnall, 1918 (Phlaeothripidae) of Order Thysanoptera in Muthalamada Mangoes of Kerala, India

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Abstract: Periodic incidence of sucking pests in Muthalamada mangoes, Palakkad, Kerala has caused severe setback to mango growers. Symptoms of damage include malformation of mango panicles and bronzing of mango fruits which resulted in the reduced marketability of the produce. A random survey was conducted in mango orchards of these regions during the flushing, flowering, and fruit setting stage of crop during September 2022 to May 2023. Collected thrips specimens were subjected to morphological identification done with permanent slide technique of taxonomic key characteristics. Because *T. palmi* Karny and *Haplothrips tenuipennis* Bagnall has close physical resemblance to other thrips species, we used the mitochondrial cytochrome oxidase 1 (mtCO1) gene as a molecular marker. BLAST analysis of this sequence allowed us to identify the collected specimen as *T. palmi* and *H. tenuipennis.*

Keywords: Muthalamada, Mango city, Mitochondrial COI, *Thrips palmi, Haplothrips tenuipennis*

Palakkad district of Kerala is the mango hub ('mango city') with have maximum production of 55120 MT and area of 10068 ha (Ecostatkerala 2020). Kerala is also a hotspot for climate change and variability particularly Muthalamada experiences a lot of climatic variabilities which causes fluctuations in the population of insect pests mainly thrips. Thrips causes scars on the surface of fruit and foliage in addition to feeding and reproduction on inflorescences (Kumar et al 2012). *T. palmi* Karny and *H. tenuipennis* Bagnall was reported on mango inflorescence from India (Tandon and Verghese 1987 and Ramasubbarao and Thammiraju 1994). Krishnamoorthy and Visalakshi (2012) reported that of the several sucking pests infesting mango inflorescence, *T. palmi* and *H. tenuipennis* caused considerable loss. The unique properties of thrips make morphological key identification a laborious process that requires accuracy and speed (Asokan et al 2007). Nuclear markers such as ribosomal ITS have been utilized for molecular identification (Farris et al 2010). Nevertheless, it has been found that the best method for molecular identification within the genus Thrips is mitochondrial COI (DNA barcoding). The objective of paper is to confirm the presence of *T. palmi* and *H. tenuipennis* through morphological key characters and molecular DNA barcoding (Asokan et al 2007) and NJ (neighbour joining) or maximum likelihood analyses help for phylogeny study of such species.

MATERIAL AND METHODS

Sampling and morphological identification: Random survey was conducted in five orchards (Table 1) of Muthalamada panchayat, Palakkad, Kerala during the year 2023 provided a sample, which thrips were collected from five randomly chosen trees in each orchard by adopting CO_2 method (Aliakbarpour and Che Salmah 2010). The samples were subsequently stored in 70% alcohol, and a stereomicroscope was used to sort each individual thrips. Adult thrips were mounted using procedure of permanent slide technique (Mound 2005). The specimens were divided into suborders, Terebrantia and Tubulifera and placed in vials containing 70% alcohol before being transmitted to the NBAIR and ZSI for species confirmation.

DNA Barcoding using Universal Primers of COI

Genomic DNA isolation: Using the NucleoSpin® Tissue Kit (Macherey-Nagel) and the manufacturer's instructions, genomic DNA was extracted from the tissues. The extracted DNA stored at – 20º C. PCR was carried out with universal primer forward primer (LCO1490) 5'-GGTCAACAAATCATAAAGATATTGG-3' and reverse primer (HCO2198) 5'-TAAACTTCAGGGTGACCAAAAAATCA-3' (Vrijenhoek 1994), to amplify a 478 bp and 483 bp fragment of COI gene for *T. palmi* and *H.tenuipennis*. PCR amplification was carried out by following Thermo Scientific Phire Plant Direct PCR Master Mix product's instruction (http://assets.fishersci.com/TFS-Assets/LSG/manuals/F-=160_QR_TS_5.PDF). Purification of amplified product checked by 1.2 % agarose gel with ethidium bromide (Buckman *et al*. 2013 and Kumar *et al*. 2014). The products that were amplified were sent to the Rajiv Gandhi Centre for Biotechnology (RGCB) in Trivandrum, Kerala, for sequencing (India).

The National Center for Biotechnology Information (NCBI) database's Basic Local Alignment Search Tool (BLAST) was used to run a similarity search to determine the identity of the genomic DNA. The sequences were then compared with an existing database to confirm the species. Furthermore, additional sequences were obtained from GenBank and a multiple alignment was done using ClustalX version 2.1 (Thompson et al 1997). In addition, extra sequences were dragged from GenBank, and ClustalX version 2.1 (Tamura et al 2021) was used to perform a multiple alignment. Using the Jukes-Cantor distance model and the Maximum Likelihood approach with a bootstrap test of 1000 replications, the phylogenetic tree was studied using MEGA version 11.0. (Jukes and Contar 1969).

RESULTS AND DISCUSSION

Morphological Confirmation

Phylum: Arthropoda

Class: Insecta

Order: Thysanoptera

Family: Thripidae

Sub family: Thripinae

Genus: *Thrips*

Species: ***T. palmi* (Karny) 1925:** The following characteristics distinguish *T. palmi* from other known species of the genus Thrips during the morphological key characterisation process, which was carried out using created permanent slides of thrips (Fig. 1a-g). Head is broader than long; Ocellar seta III faces lateral on anterior ocellus (Fig. 1g); antenna 7- segmented, I-II yellowish, III – V basally yellowish and distally brown, VI-VII brown (Fig 1b); Pronotum with 2 pair of long posteroangular setae (Fig 1d); Metanotum with two companiform sensilla (Fig 1e); Forewing yellow with three (sometimes two or four) setae on distal half of first anterior vein, Second vein with row of 15 setae approximately (Fig 1f). Abdomen tergite II with four lateral setae and microtrichia lacking on lateral thirds of tergites IV–VI; Tergite V –VII with paired ctenidia laterally; Tergite VII Posteromarginal comb complete, microtrichia long and slender (Fig 1c); Discal setae absent.

Phylum: Arthropoda

Class: Insecta

Order: Thysanoptera

Family: Phlaeothripidae

Sub Family: PhlaeothripinaGenus: *Haplothrips*

***Species*: *H. tenuipennis* Bagnall**, 1918: 210: *Haplothrips ceylonicus var. mangiferae* Priesner, 1933: 359 syn.n. All members of the genus Haplothrips have four sense cones (rarely three) on segment IV of the antenna and one or two on segment III of the antenna. In *Haplothrips tenuipennis*, S1 setae in tergite not more than 0.75mm as long as tube. Antenna; the antennal segment III has a smaller sense cone and thinner. Sub basal S3 seta of forewing is acute (Mound 2019), which were confirmed the attack of mango inflorescence by *T. palmi* and *Haplothrips tenuipennis.* Zambrano et al (2021) first reported *T. palmi* on cotton in Ecuador by using the taxonomic key characters. Krishnamoorthy and Ganga Visalakshi (2009) reported *T. palmi* on flowers in his trail field to manage mango hoppers and thrips using entomopathogens. Additionally, *H. tenuipennis* was found in the same host from Andhra Pradesh, India by Ramasubbarao and Thammiraju 1994; Kannan and Rao 2006a, b). Earlier, *S. rubrocintus* has been

Table 1. Location of orchards covered during survey 2023

State	District	Panchayat	Locality	Latitude, Longitude	Host	Specimen	Date of collection	Name of collector	Material deposited
Kerala	Palakkad	Muthalamada	Adavumaram	10.5992614 76.7621706	Mango	*T. palmi* and *H. tenuipennis* (Adult thrips)	04/12/2023	Syed Mohamed Ibrahim	Insect museum, College of agriculture, Vellayani
			Vellaramkadavu	10.5740950 76.7725330			04/12/2023		
			Vellaramkadavu	10.5772010 76.7762450			08/12/2023		
			Anna nagar	10.5792830 76.7786070			08/12/2023		
			Chemmanapathy	10.57927 76.778582			13/12/2023		

observed in Kerala on inflorescence of mango (Ananathakrishnan and Muraleedharan 1974). But, till now no other thrips species was reported on mango in Kerala, India. Verghese et al (1988) and Krishnamoorthy and Visalakshi (2009) had previously reported on *T. palmi*'s attack on mango inflorescence in Tamil Nadu. On the other hand, Kerala is the first place where reports of these two species attacking mango inflorescences have been confirmed.

Molecular Characterisation

In the study, the NCBI database was used to BLAST sequences generated over incomplete mtCOI areas in order to obtain the accession numbers (OP963194 and OP957024) for *T. palmi* and *H. tenuipennis* from Muthalamada. With an E-value of 0 and a likelihood of 92.79% and 92.89% match, the Blast search using the NCBI BLAST connected the individuals to the *T. palmi* and *H. tenuipennis* sample from China and Pakistan, accession numbers MF686687 and KP871477. The sum of branch length of optimal maximum likelihood tree = 0.015689 and 0.015939 is displayed in Figure 2 & 3. Eight nucleotide sequences for *T. palmi* and *H. tenuipennis* were analyzed. First, second, third, and noncoding codon locations were covered. Every ambiguous location was removed for every sequence pair (pairwise deletion option). The completed dataset contained 478 and 483 positions in total. Evolutionary analyses of maximum likelihood tree and *T. palmi mtCOI* gene sequence (collected from GenBank) revealed that our samples were closest to the *T. Palmi* of China, Bangladesh and Indonesia formed as separate cluster. *mtCOI* sequence of *T. major* was taken as outgroup (Fig 2). Similarly, the maximum likelihood tree analyses for *H. tenuipennis* displayed that the sample from Kerala was close near to the Bangladesh which occupied in one clade and the sample from India and Pakistan of GenBank occupied on different clade. *Haplothrips ganglbaueri* as taken as outgroup (Fig. 3).

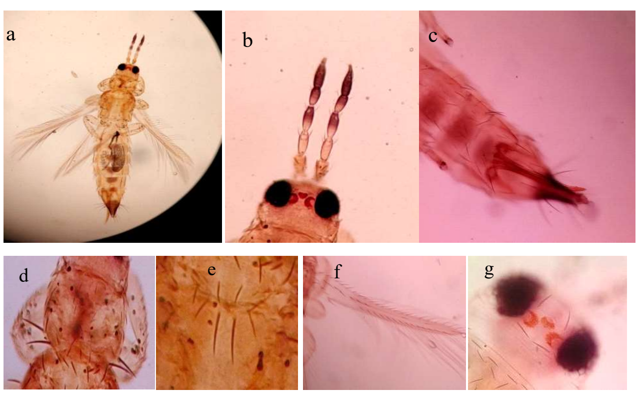

Fig. 1(a-g). *Thrips palmi*. **a**, Female; **b**, antenna; **c**, abdominal tergite; **d**, pronotum; **f**, meso and metanotum; **g**, forewing; **e**, ocelle setae

T. palmi morphologically resembles both *T. alatus* Bhatti and *T. fabus* Schrank. The location of the interocellar setae, which in *T. palmi* originate from outside the ocellar triangle but in *T. fabus,* originate from inside the ocellar triangle posterior to the anterior ocellus, supports differentiation (Mound 2009). Unlike *T. palmi,* where the metanotal sculpture is typically convergent on the posterior margin, *T. alatus* exhibits striate metanotal sculpture (Mound 2009). Likewise, female paratypes of *H. ceylonicus var. mangiferae* and syntypes of this species from northern India have been examined and compared. Mound (1968) established the first synonymy between these two species, whose females cannot be distinguished from one another. *H. tenuipennis* resembles members of the *H. anceps* group of species in general because it has dark pronotal major setae in common with them, but it differs from them in that it has a small, slender sense cone on the inner margin of antennal segment III that

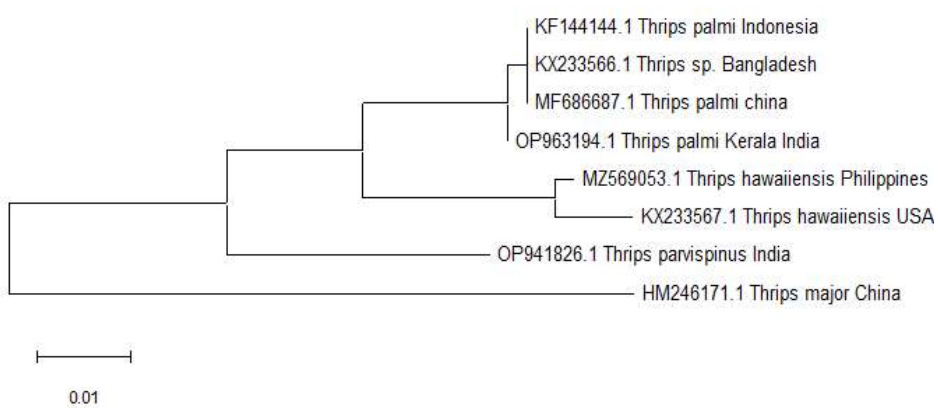

Fig. 2. Maximum likelihood tree of *T. palmi* samples from Muthalamada, Kerala, and other locations retrieved from GenBank

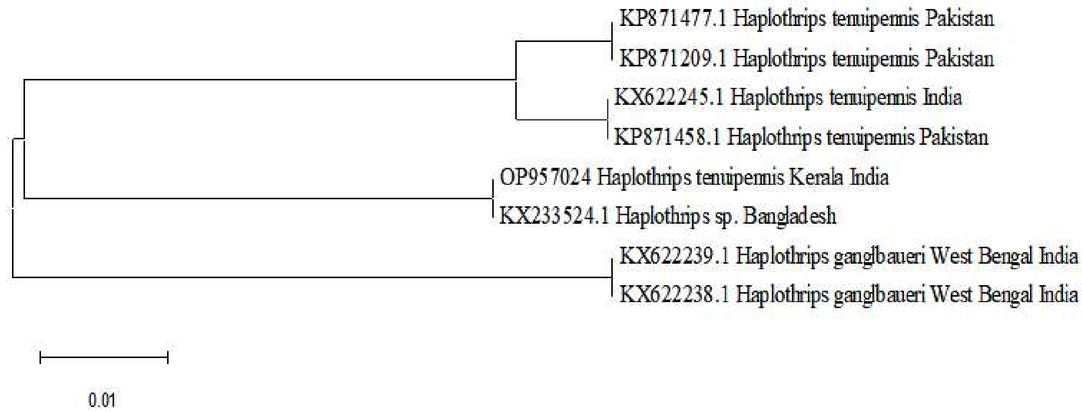

Fig. 3. Maximum likelihood tree of *H. tenuipennis* samples from Muthalamada, Kerala and others extracted from GenBank

neither of the other two species have developed. In order to prevent misunderstandings, specimens that had been recognized morphologically were next subjected to molecular identification using mtCO1 gene PCR amplification to confirm that they were as *T. palmi* and *H. tenuipennis* not any other thrips species (Riley et al 2011).

CONCLUSION

The specimens collected on mangos were confirmed to be *T. palmi* and *H. tenuipennis* by both morphological and molecular evidence. This is the first report of *T. palmi* and *H. tenuipennis* on mango inflorescence at Muthalamada panchayat in Palakad, Kerala, India. The southern states of India are ideally suited for thrips' occurrences on mango, Since *T. palmi* and *H. tenuipennis* are spreading their host range, their occurrences in various regions of India require rigorous monitoring and IPM measures.

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Life Table of Pod Borer, *Helicoverpa armigera* (Hubner) on Pigeonpea

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***Abstract*:** Life-table of *H. armigera* on pigeonpea was studied under laboratory condition. The output showed that out of total 100 eggs only the 89 eggs, 77 larvae and 70 pupae survived and finally emerged in to adults. The maximum durations of egg, larva, and pupa was 6, 20 and 8 days, respectively with pre-oviposition period varied from 33^{rd} to 35^{th} days of pivotal age. Female started laying eggs after 35^{th} days and ceased after 47^{th} days with lx (survival of female) values of 0.70 and 0.31 respectively. Females produced the maximum progenies (mx = 48.09) on the 38^{th} day of pivotal age. The net reproductive rate (Ro) was 142.07 times multiplication of population per generation. Adults contributed only 0.76 percent of the population of stable age whereas eggs, larvae, and pupae contributed 59.31, 37.68 and 2.26 per cent, respectively. The expectancy of further life was 4.76 days at the time of adult emergence which showed that life expectancy of *H. armigera* declined with the advancement of development.

***Keywords*:** *H. armigera,* Adults, Female, Eggs, Larvae, Pupae, Progenies, Legume, Life table

Pigeonpea [*Cajanus cajan* (Linnaeus) Millspaugh] is an important grain legume crop of the tropics and subtropics. Globally, pigeonpea is grown in an area of 6.03 million hectares with a production of 5.33 million tonnes and productivity of 883.40 kg/ha (FAO 2022). In India, it is grown on 5.05 million hectares with an annual production and productivity of 4.34 million tonnes and 859 kg/ha, respectively (Anonymous 2022). Among several insect pests infesting pigeonpea the lepidopteran pest *viz*., pod borer, *Helicoverpa armigera* (Hubner) is most serious. In India, the pod damage caused by *Melanogromyza obtusa*, *H. armigera* and *Maruca vitrata* was reported as 34.4 to 49.9, 9.4 to 18.1 and 5.7 to 12.4 per cent, respectively (Keval et al 2017). The maximum damage was recorded due to pod borer, *H. armigera* (34.90 %) followed by pod fly, *M. obtusa* spotted pod borer, *M. vitrata* and tur plume moth, *Exelastis atomosa* up to 23.64, 14.09 and 5.60 per cent, respectively (Muchhadiya et al 2024). Considering the above facts, the present investigation was carried out.

MATERIAL AND METHODS

To construct the life-table, the culture of *H. armigera* was maintained on pigeonpea tender plant for two consecutive generations at room temperature during October to March, 2021-22. The adults obtained from the culture were used for the further study. The freshly emerged male and female moth were kept for egg laying in wooden cages. The sides of the cage were covered with muslin cloth and the tender pigeonpea branches were provided for egg laying. In order to construct life table, freshly laid 100 eggs were collected from the cage with the help of wet camel hair brush and placed in ten petri plate (10.0 cm diameter × 1.5 cm height) in batches of 10 (ten) were observed closely for recording the hatching percentage. After hatching, the first instar larvae were transferred individually into plastic vials. Fresh food was provided daily in morning. Vials were kept clean by removing frasses. Took daily observations on larval development, formation of pupae, emergence of adult and fecundity were recorded. Age-specific mortality in several developmental stages such as egg, larva, pupa and adult were also documented. To establish age-specific fertility, the total number of adults that emerged on the same day were placed in a cage for oviposition. Pigeonpea branches with leaves, buds, and pods were placed in conical flasks with fresh water and kept in cages until oviposition. The twigs were replaced every day and the number of eggs laid on the twigs, buds, pods and muslin material inside the cage were noted. Observations on fecundity were recorded until the female died. Assuming a 1:1 sex ratio, the number of eggs collected per female was divided by two to get the number of female births (mx). The methodology for life table as proposed by Howe (1953) followed by Atwal and Bains (1974), Dabhi et al (2009a), Dabhi et al (2009b), Patel et al (2016), Singh et al (2022) and Chaudhari et al (2023) was adopted. The stable age distribution was determined by observing the population schedule of birth and death rates (mx and lx) when grown in a limited amount of time. The methodology for the construction of the life table proposed by Howe (1953) followed by Atwal and Bains (1974) was used in this study. The same is as under:

x = Pivotal age in days

lx = Survival of female at age 'x'

mx = Age schedule for female birth at age 'x'

Net reproductive rate (Ro): The values of 'x', 'lx', and 'mx' were calculated using the data provided in the life tables. The sum total of the products 'lxmx' is the net reproductive rate (Ro). The Ro is the rate of multiplication of population in generation measured in terms of females produced per generation. The formula used to compute the number of times a population would multiply per generation is as follows: $Ro = \Sigma\, lxmx$

Mean duration of generation (T): The approximate value of generation time (T) (the mean age of the mother in a cohort at the birth of female offspring) was calculated by using following formula (Atwal and Bains 1974)

$$T = \frac{\Sigma\, x\, lxmx}{Ro}$$

Innate capacity for increase in numbers (rm): At each age interval, the total number of survivors and the average number of females emerged were recorded. The arbitrary value of 'rm (rc)' was determined from these data using the following formula (Loughlin, 1965 and Atwal and Bains 1974)

$$rm = \frac{\log e^{Ro}}{T}$$

Where,

e = 2.71828

T = Mean generation time

The intrinsic rate increase (rm) was calculated subsequently from the arbitrary 'rm' by taking two trial values; arbitrary selected on either side of it, differing in the second decimal place by establishing the following relationship as suggested by Atwal and Bains (1974).

$$\Sigma\, e^{7-rmx}.\, lxmx = e^{7} = 1097.00$$

Where,

e = 2.71828

The precise generation time (T) was calculated by using the following formula:

$$T = \frac{\log e^{Ro}}{Rm}$$

Finite rate of natural increase (λ): The number of females per female per day *i.e.* finite rate of increase was determined as:

$\lambda = \text{anti} \log e^{rm}$

From this data the weekly multiplication of the population was calculated. Hypothetical F_2 females were also be worked out with the formula $(Ro)^2$.

Stable age distribution: The stable age distribution (per cent distribution of various age groups) of *H. armigera* on pigeonpea was calculated using the knowledge of 'rm' and age-specific mortality of the immature and mature stages. The stable age distribution table was created using the methods proposed by Andrewartha and Birch (1954) and Atwal and Bains (1974). The 'Lx' (life table age distribution) was calculated from the 'lx' table using the following formula:

$$Lx = \frac{lx + (lx + 1)}{2}$$

Per cent distribution of each age group (x) was calculated by multiplying the Lx with $e^{-rm(x+1)}$. By putting together, the percentage under each stage *viz*., egg, larval, pupal and adult stages, the expected per cent distribution were worked out.

RESULTS AND DISCUSSION

The study on the life table, age-specific distribution and life expectancy of *H. armigera* on pigeonpea were carried out at laboratory of Entomology from October to March during 2021-22 at Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar. The 89 per cent egg survived and 70 per cent reached the adult stage (Table 1). The longest durations of egg, larva, and pupa were 6, 20 and 8 days, respectively.

In the past, Deb and Bharpoda (2016) at Anand reported that total 92 eggs survived and 71 per cent reached adults. Basavaraj et al (2018) at Raichur (Karnataka) reported that 77 per cent survived from egg to adult emergence. The maximum duration of egg, larva and pupa was as 6, 28 and 9

Table 1. Survival of different life stages of *H. armigera* during development on pigeonpea (Based on 10 eggs)

Egg	Larva	Pupa
	Number survived	
9	7	6
8	7	6
9	8	6
10	8	7
8	7	7
9	7	7
8	7	6
9	8	8
10	9	8
9	9	9
89	77	70

days, respectively. Thus, the findings of the current study are more or less consistent with those of the previous researchers. The pre-oviposition period occurred between the 33rd and 35th days of pivotal age (Table 2). Female began depositing eggs after 35th days and ceased after 47th days with lx of 0.70 and 0.31 respectively. Females produced the most progenies (mx = 48.09) on the 38th day of pivotal age, which declined day by day, thereafter.

The net reproductive rate (Ro) was 142.07 with a mean length of generation (Tc) 38.35 days. The intrinsic rate of natural increase in number (rm) was 0.1292 females per female per day with finite rate of increase (γ) 1.14 females/female/day and the population was multiplied 2.48 times per week. The hypothetical F2 females were calculated to be 20183.8849 (Table 3).

Basavaraj et al (2018) reported that mean length of generation (T) was 41.40 days. The innate capacity (rm) and finite rate (λ) of the in number was 0.13 and 1.14 females per female per day, respectively. Fathipour et al (2020) reported

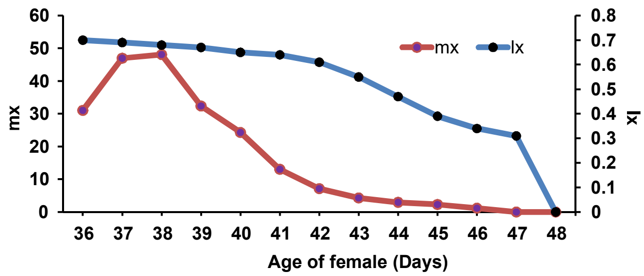

Fig. 1. Survivorship curve (lx) and age specific fecundity (mx) of *H. armigera* on pigeonpea

Table 2. Life table (Female) and age specific fecundity for *H. armigera*on pigeonpea

Pivotal age in days (x)	Survival of female at different age interval (lx)	Age schedule for female births (mx)	lxmx	xlxmx
0-33		Immature stages		
33-35		Pre-oviposition stages		
36	0.70	31.03	21.72	781.96
37	0.69	46.99	32.42	1199.65
38	0.68	48.09	32.70	1242.65
39	0.67	32.38	21.69	846.09
40	0.65	24.31	15.80	632.06
41	0.64	13.03	8.34	341.91
42	0.61	7.12	4.34	182.41
43	0.55	4.31	2.37	101.93
44	0.47	2.94	1.38	60.80
45	0.39	2.31	0.90	40.54
46	0.34	1.17	0.40	18.30
47	0.31	0.00	0.00	0.00
			lxmx = 142.07	xlxmx = 5448.30

Table 3. Mean length of generation, innate capacity for increase in numbers and finite rate of increase in numbers of *H. armigera*on pigeonpea

Population growth statistics	Formula	Calculated values
Net reproductive rate	Ro = lxmx	142.07
Mean length of generation (days)	Tc = xlxmx/Ro	38.3494
Innate capacity for increase in numbers (Females/female/day)	rm = $\log e^{Ro}$/Tc	0.1292
Arbitrary 'rm' (rc)	0.12 and 0.13	
Corrected 'rm' (Females/female/day)	$e^{7 - rmx.\ lxmx}$	0.1299
Corrected generation time (days)	T = $\log e^{Ro}$/rm	38.1342
Finite rate of increase in numbers (Females/female/day)	(λ) = antilog e^{rm}	1.1387
Weekly multiplication of population (times/week)	$(\lambda)^7$	2.4820
Hypothetical F_2 females	$(Ro)^2$	20183.8849

Table 4. Stable age specific distribution of *H. armigera*on pigeonpea (rm = 0.1299)

Pivotal age in days 'x'	Lx	$e^{-rm(x+1)}$	Lx. $e^{-rm(x+1)}$	Percentage distribution
0	1.00	0.8781	0.8781	13.3646
1	1.00	0.7711	0.7711	11.7357
2	1.00	0.6771	0.6771	10.3054
3	1.00	0.5946	0.5946	9.0494
4	1.00	0.5221	0.5221	7.9464
5	0.99	0.4585	0.4539	6.9082
Eggs				59.3097
6	0.89	0.4026	0.3583	5.4534
7	0.88	0.3535	0.3111	4.7350
8	0.82	0.3104	0.2546	3.8744
9	0.81	0.2726	0.2208	3.3607
10	0.81	0.2394	0.1939	2.9511
11	0.81	0.2102	0.1703	2.5914
12	0.80	0.1846	0.1477	2.2475
13	0.80	0.1621	0.1297	1.9736
14	0.79	0.1423	0.1124	1.7114
15	0.78	0.1250	0.0975	1.4838
16	0.78	0.1098	0.0856	1.3029
17	0.77	0.0964	0.0742	1.1295
18	0.77	0.0846	0.0652	0.9918
19	0.77	0.0743	0.0572	0.8709
20	0.77	0.0653	0.0502	0.7648
21	0.77	0.0573	0.0441	0.6716
22	0.77	0.0503	0.0387	0.5897
23	0.77	0.0442	0.0340	0.5178
24	0.77	0.0388	0.0299	0.4547
Larvae				37.6759
25	0.77	0.0341	0.0262	0.3993
26	0.77	0.0299	0.0230	0.3506
27	0.77	0.0263	0.0202	0.3079
28	0.77	0.0231	0.0178	0.2704
29	0.77	0.0203	0.0156	0.2374
30	0.77	0.0178	0.0137	0.2085
31	0.77	0.0156	0.0120	0.1831
32	0.77	0.0137	0.0106	0.1608
33	0.77	0.0120	0.0093	0.1412
Pupae				2.2591
34	0.75	0.0106	0.0079	0.1207
35	0.70	0.0093	0.0100	0.1522
36	0.70	0.0082	0.0057	0.0869
37	0.69	0.0072	0.0049	0.0752
38	0.68	0.0063	0.0043	0.0651
39	0.67	0.0055	0.0037	0.0563
40	0.65	0.0048	0.0032	0.0480
41	0.64	0.0043	0.0027	0.0415
42	0.61	0.0037	0.0023	0.0347
43	0.55	0.0033	0.0018	0.0275
44	0.47	0.0029	0.0014	0.0206
45	0.39	0.0025	0.0010	0.0150
46	0.34	0.0022	0.0008	0.0115
Adult				0.7553

Table 5. Life table for computing life expectancy of *H. armigera*on pigeonpea

Pivotal age (Days)	Number surviving to the beginning of age interval	Number dying during 'x'	Mortality rate per hundred alive at beginning of age interval [dx.100/lx]	Alive between age 'x' and 'x + 1' [lx + (lx+1)]/2	No. of the individual's life days beyond 'x'	Expectation of further life (Tx / lx) × 2
(x)	(lx)	(dx)	(100 qx)	(Lx)	(Tx)	(ex)
0-5	100	11	11.00	100.50	689.00	13.78
5-10	89	8	8.99	89.50	610.50	13.72
10-15	81	3	3.70	81.50	537.00	13.26
15-20	78	1	1.28	78.50	461.50	11.83
20-25	77	0	0.00	77.50	385.00	10.00
25-30	77	0	0.00	77.50	307.50	7.99
30-35	77	7	9.09	77.50	230.00	5.97
35-40	70	5	7.14	70.5	166.50	4.76
40-45	65	26	40.00	65.5	106.00	3.26
45-50	39	8	20.51	39.5	92.50	4.74
50-55	31	0	0.00	0.00	0.00	0.00

that the net reproductive rate (Ro) was 147.40 female offspring. The mean length of generation (T) was 37.90 days. The innate capacity (rm) and finite rate (λ) of the in number was 0.126 and 1.131 females per female per day, respectively. Maity et al (2020) reported that the net reproductive rate (Ro) was 133.83female offspring. The mean length of generation (T) was 43.7days. The innate capacity (rm) and finite rate (λ) of the in number was 0.112 and 1.118 females per female per day, respectively. In current findings are similar trend was observed. The impact of each developmental stage and the stable age distribution indicated that adults showed just 0.76 per cent of the population of stable age whereas eggs, larvae and pupae contributed 59.31, 37.68 and 2.26 per cent, respectively (Table 4).

The life expectancy demonstrated that *H. armigera* life expectancy decreased significantly as development progressed. The life expectancy of newly placed eggs was 13.78 days (Table 5). The expectancy of further life was 4.76 days at the time of adult emergence.

CONCLUSION

Females produced the maximum progenies (mx = 48.09) on the 38th day of pivotal age. The net reproductive rate (Ro) was 142.07 times multiplication of population per generation. Adults contributed only 0.76 per cent of the population of stable age, whereas, eggs, larvae, and pupae contributed 59.31, 37.68 and 2.26 per cent, respectively. The expectancy of further life was 4.76 days at the time of adult emergence which showed that life expectancy of *H. armigera* was declined with the advancement of development. It is important to increase the egg mortality and minimize the population of *H. armigera*.

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Phenology, Productivity and Profitability with Phosphate and Zinc Solubilizing Microbes in Lentil (*Lens culinaris* L.) under *tarai* region of Uttarakhand

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Abstract: The field experiment was conducted at G. B. Pant University of Agriculture and Technology, Pantnagar during *rabi* 2020 on phosphorus and zinc efficacy with phosphate and zinc solubilizing microbes in lentil (*Lens culinaris*L.) in *tarai* region. Twelve different doses of phosphorus and zinc with phosphate and zinc solubilizing microbes in combinations were evaluated. Growth parameters*viz*. plant height, number of branches per plant, number of compound leaves per plant and dry matter accumulation were highest with application of 50% RDP @ 24 kg ha^{-1} +12.5 kg ha^{-1} $ZnSO_4$ + Biophos @ 5 ml kg^{-1} seed + Biozinc @ 5 ml kg^{-1} seed (40.5 cm, 14 no. $plant^{-1}$, 207 no. $plant^{-1}$, 8.2 g $plant^{-1}$, respectively) with respect to control (32.9 cm, 10.5 no. $plant^{-1}$, 136 no. $plant^{-1}$, 4.1 g $plant^{-1}$, respectively). Grain yield, harvest index, net returns and B: C ratio were also highest with the application of 50% RDP @ 24 kg ha^{-1} +12.5 kg ha^{-1} $ZnSO_4$ + Biophos @ 5 ml kg^{-1} seed + Biozinc @ 5 ml kg^{-1} seed (1735 kg ha^{-1}, 0.53, 58460 ₹ ha^{-1}, 2.51, respectively) with respect to control (1318 kg ha^{-1}, 0.34, 40231 ₹ ha^{-1}, 1.82, respectively).

Keywords: Biophos, Biozinc, Harvest index, Nitrogen fixation, *Rhizobium*

Lentil (*Lens culinaris* L.) belongs to the family Fabaceae and about 5% of the total area under pulses is lentil of which Asia accounts for 65% in terms of production. In India, lentil is a significant pulse crop, grown on approximately 1.42 million hectares, yielding around 1.28 million tonnes (Sah et al 2022**)**. The lentil crop accounts for about 4.9% of the total pulse cultivation area and contributes 5.03% to the country's overall pulse production (2021–22).Phosphorus and zinc are essential elements for successful plant growth, particularly in pulse production (Siddiqui et al 2015). Lentils use *Rhizobium* bacteria to fix atmospheric nitrogen, reducing the need for nitrogenous fertilizers to about 25-30 kg N ha^{-1} (Singh and Singh 2016). Proper phosphorus application is essential for improving lentil yield and soil quality, although excess application can lead to fixation and unavailability in acidic or alkaline soils. Introducing phosphorus-solubilizing microbes (PSB) into the rhizosphere enhances phosphorus availability to plants through the release of organic acids and enzymes, potentially increasing crop yields by 10-30% and supplementing phosphorus needs. Zinc-solubilizing microorganisms use various mechanisms, such as acidification and chelation, to make zinc more available in the soil. Inoculating plants with beneficial bacteria like *Pseudomonas*, *Rhizobium strains*, *Bacillus* and *Azospirillum* has shown improvements in growth, phosphorus and zinc content (Sindhu et al 2019, Chetan Babu et al 2023). Overall, these micronutrients and microbial interventions are crucial for optimizing crop health and yield in pulse production. The information available on the effect of phosphorus and zinc solubilizing microbes in the *Tarai* region of Uttarakhand is sparse and inadequate. With respect to this objective, the present study was conducted on phenology, productivity and profitability with phosphate and zinc solubilizing microbes in lentil.

MATERIAL AND METHODS

Experimental site: The field experiment was carried out during the *rabi* season of 2020 at N.E. Borlaug Crop Research Centre of G. B. Pant University of Agriculture and Technology. The research center lies 30 km Southern end of foot hills of Shivalik Range of Himalayas at 29°N latitude and 79.3°E longitude and at an altitude of 243.83 m above the mean sea level in the *tarai* region of Uttarakhand.

Experiment details: The experiment was conducted with twelve treatments and three replications in randomized block design using lentil variety Pant L-8 with row to row spacing of 23cmand experimental area was about 812.16$m^2$with gross plot size of 13.8m^2 (2.76 m x 5 m) each. The nutrients like N and K were given to all treatments alike. But P, Zn and their solubilizing organisms were varied in different treatments. The other agronomic practices were followed as per the standard package of practices of lentil cultivation.

Growth and development parameters: At 30, 60, 90 days after sowing (DAS) and at harvest, the growth parameters were recorded. Height was measured from ground surface to the base of the apical leaf of five tagged plants from each plot. Total branch of branches of the five tagged plants were counted. The number of leaves form the five tagged plants were counted. Nodules collected from the five roots from of plants were dried in the oven at 70°C till the constant weight. Number of nodules were separated counted for the roots of five plants. The five plants were cut near the surface and dried in the hot air oven at 70°C till the constant weight.

Yield parameters: After threshing, the grain yield from each net plot was weighed and then multiplied with suitable conversion factor to get yield (kg ha^{-1}). Straw yield was calculated by deducting the grain yield from the biological yield. Total produce of each net plot (excluding the root biomass) was dried in the sun in the field after harvest and weighed. Yield ha^{-1} was computed by multiplying this with suitable conversion factor.

Harvest index = (grain yield /biological yield) x100

Grain: Straw ratio was calculated by dividing the grain yield by straw yield.

Economic evaluation: Selling price of grain and straw were multiplied to the grain and straw yield to obtain the gross returns**.** The cost was deducted from the gross returns to obtain the net returns. The net return was divided by the cost of cultivation to obtain benefit cost (B: C) ratio.

Statistical analysis: The experimental data were analyzed using OPSTAT for randomized block design which is programmed by HAU, Hisar, Haryana.

RESULTS AND DISCUSSION

Growth and Development

Plant height (cm): Plant height increased up to crop maturity (Table 1). The rate of increase of plant height for 30-60 DAS, 60-90 DAS and 90 DAS to maturity stage was 0.19, 0.72 and 0.31 cm day^{-1}. Maximum increase was observed between 60-90 DAS stage. The T_{10} produced tallest plants at 30, 60, 90 and maturity *i.e.* 6.4, 12.2, 32.9 and 40.5 cm, respectivelyand was significantly superior over the other treatments at 30, while at 60 DAS and 90 DAS, T_{10}, T_{11} and T_{12} were statistically on a par with each other, and significantly superior to other

Table 1. Plant height, number of branches and compound leaves at different stages of crop growth as influenced by phosphorous and zinc treatments

Treatments	Plant height (cm)				No. of branches $plant^{-1}$				No. of compound leaves $plant^{-1}$		
	30 DAS	60 DAS	90 DAS	Maturity	30 DAS	60 DAS	90 DAS	Maturity	30 DAS	60 DAS	90 DAS
T_1: Absolute Control (without P and Zn)	4.7	9.1	25.4	32.9	2.7	4.9	9.2	10.5	8.7	37	136
T_2: RDP (Control) @ 48 kg ha^{-1}	5.2	10.9	28.6	37.9	2.9	6.3	11.3	12.4	9.2	43	146
T_3: Soil application of $ZnSO_4$@ 25 kg ha^{-1}	5.1	10.5	28.0	37.3	2.9	5.6	10.4	11.7	9.0	40	142
T_4: Biophos @ 5ml kg^{-1} seed	5.0	10.4	27.8	37.0	2.8	5.5	10.1	11.1	9.0	39	142
T_5: Biozinc @ 5ml kg^{-1} seed	4.9	9.8	26.5	35.1	2.8	5.3	9.6	10.8	8.8	37	137
T_6: Biophos and Biozinc @ 5 ml each kg^{-1} seed	5.2	10.7	28.5	37.6	2.9	5.8	10.8	11.8	9.1	42	145
T_7:50% RDP@ 24 kg ha^{-1} + Biophos@ 5 ml kg^{-1} seed	5.2	11.1	29.1	38.1	3.0	6.4	11.6	12.4	9.8	43	158
T_8:12.5 kg ha^{-1} $ZnSO_4$ + Biozinc @ 5 ml kg^{-1} seed	5.0	10.1	27.7	36.4	2.8	5.5	9.6	11.1	8.9	39	139
T_9:50% RDP@ 24 kg ha^{-1}+ Biophos @ 5ml kg^{-1} seed + Biozinc @ 5 ml kg^{-1} seed	5.3	11.1	31.2	38.1	3.0	6.5	11.8	12.6	10.1	43	179
T_{10}:50% RDP@ 24 kg ha^{-1} + 12.5 kg ha^{-1} $ZnSO_4$ + Biophos @ 5 ml $seed^{-1}$ + Biozinc @ 5 ml kg^{-1} seed	6.4	12.2	33.9	40.5	3.4	7.0	13.6	14.0	13.4	47	207
T_{11}:RDP@ 48 kg ha^{-1} + Nutrient Mobilizer (LNm 43a) @ 20 g kg^{-1} seed	5.7	11.3	32.5	38.4	3.1	6.6	12.2	13.7	10.9	43	187
T_{12}:50% RDP@ 24 kg ha^{-1} + Soil application of 12.5 kg ha^{-1} $ZnSO_4$ + Nutrient Mobilizer @ 20g kg^{-1} seed	5.8	12.0	32.9	39.2	3.1	6.7	13.0	14.0	11.3	44	203
CD (p=0.05)	0.5	1.0	2.7	3.4	0.3	0.9	2.7	3.0	1.4	4	26

treatments (Table 1). At maturity too, T_{10}produced the tallest plants being significantly superior over that of the other nutrient formulations except T_{12}, T_{11}, T_9, T_7, T_6, T_2 and T_3 which produced statistically similar plants in terms of the plant height. This could be due to synergistic effect of various sources of nutrients known to have beneficial effects in lenti l(Singh et al 2017). Ganie et al (2009) in garden pea and Kant et al (2016) in blackgram observed same trend. Singh et al (2013) also reported variations in plant height of lentil crop due to different doses of phosphorus and zinc.

Number of branches: The number of branches increased steadily until maturity, with the growth rate slowing near maturity (Table 1). The highest growth rate occurred between 60 and 90 days. Treatment T_{10} consistently produced the most branches at all stages. The increased branch number was linked to higher nitrogen uptake during early vegetative stages, supported by phosphorus, which also enhanced root proliferation and the plant's nitrogen-fixing ability. Similar finding was also reported by Kalayu (2019) and Singh et al (2017). Singh et al (2013) also reported that the maximum number of productive branches plant^{-1} obtained in case of zinc (0.04%) and minimum in control (no application of zinc) in lentil. Thus, zinc and phosphorus both applied at optimum dose increased the number of branches by improving root as well as shoot growth.

Number of compound leaves: Leaf count per plant increased up to the 90 day stage, with the most significant rise between 60 and 90 days, averaging 5.3 leaves per day, compared to 1.12 leaves per day between 30 and 60 days after sowing (Table 1). Treatment T_{10} consistently produced significantly more leaves than other treatments, except at 60 and 90 days, where it was comparable to T_{12}. Nitrogen, being a key component of chlorophyll, played a crucial role in leaf development, while optimal phosphorus and zinc uptake enhanced apical branching, further increasing leaf numbers. Kasturikrishna et al(2000) observed that the application of 26.6 kg P_2O_5 ha^{-1} significantly increased the number of leaves as well as the area of the leaves.

Dry matter accumulation (g plant^{-1}): Dry matter accumulation increased with crop age and the rate of increase between 60 to 90 DAS was the highest at about 0.25 g day^{-1} (Table 2). The maximum dry matter accumulation at 30, 60 and 90 DAS stages *i.e.*0.08, 0.7 and 8.2 (g plant^{-1}), respectively, was associated with T_{10}. At 30 DAS and 60 DAS stage, T_{11} and T_{12}were statistically on a par with the T_{10} while at 90 days, T_{10} and T_{12} were statistically on a par. Pandey et al (2010) also drew similar conclusion in lentil crop that the plants grown in soil supplied with zinc produced maximum dry matter yield over no zinc application. Similarly, Singh et al (2013) also confirmed that total above ground biomass was influenced by application of zinc. Tagore et al (2013) and Meena et al (2015) came to similar conclusion that the dry matter yield plant^{-1} increased significantly with inoculation of phosphorus solubilizing microbes

Days taken to flowering: The effect on number of days taken to flowering due to various treatments was non-significant yet the T_1 took the least number of days (73days) to flowering while T_{10} took the more number of days (80 days) (Table 2). Days taken to flowering is initiated later when the vegetative growth is lusher and more prolonged due to higher uptake of nitrogen. The treatments lacking in nutrients yields flower sooner to mitigate the unfavorable conditions.

Days taken to maturity: Number of days taken to maturity due to different phosphorus and zinc treatments were non-

Table 2. Dry matter accumulation at different stages of crop growth and days taken to flowering and maturity as influenced by phosphorous and zinc treatments

Treatment	Dry matter (g plant^{-1})			Number of days taken to	
	30 DAS	60 DAS	90 DAS	Flowering	Maturity
T_1	0.041	0.34	4.1	73	131
T_2	0.052	0.51	5.7	76	134
T_3	0.046	0.47	5.1	75	133
T_4	0.046	0.46	4.3	75	133
T_5	0.045	0.34	4.1	74	132
T_6	0.050	0.51	5.3	75	134
T_7	0.064	0.53	5.9	76	135
T_8	0.045	0.43	4.1	75	132
T_9	0.064	0.54	6.2	77	135
T_{10}	0.076	0.66	8.2	80	139
T_{11}	0.068	0.58	7.1	78	136
T_{12}	0.072	0.62	7.7	78	137
CD (p=0.05)	0.012	0.09	1.0	NS	NS

See Table 1 for details

significant (Table 2). The crop took minimum (131 days) number of days for maturity under T_1 and maximum (138 days) days for maturity under T_{10}. Higher phosphorus application lengthened the period of crop maturity (Rasheed et al 2010).

Grain yield (kg ha^{-1}): Grain yield ha^{-1} differed significantly due to varying treatments of phosphorus and zinc (Table 3).Treatment T_{10} produced the maximum grain yield being significantly superior over all the other treatments. Combination of different organic and inorganic and timely availability of the nutrients owing to nutrient solubilizing microbes enhanced the plant growth and significantly increased the grain yieldover control (Singh et al 2017). Hussain and Ahmad (2015) reported similar results on effect of phosphorus and zinc on the grain yield.

Straw yield (kg ha^{-1}): Straw yield ha^{-1} was not influenced significantly due to varying treatments of phosphorus and zinc (Table 3). The highest yield was observed in T_{10}. Phosphorus aids in cell division and help in the development of new tissue and in energy transformation in plants. Enhanced plant growth due to proper availability of nutrients increased the straw yield too.The zinc helped the plant in chlorophyll production and directly contributed in plant growth. Meena et al (2017) observed that the application of phosphorus with zinc resulted in higher grain and straw yield.

Biological yield (kg ha^{-1}): The highest biological yield was obtained from T_{10} and was statistically superior to all the other treatments (Table 3). Application of phosphorus and zinc to plants increased grain and straw yield and thus, the biological yield. The applied nutrients improved the various parameters of growth and development like plant height, number of branches plant^{-1}, number of compound leaves plant^{-1}, dry matter accumulation plant^{-1}, the cumulative effect of which ultimately resulted in higher yields of both straw and biological parts. Singh et al (2008) found that the biological yield increased significantly up to 50 kg P_2O_5 ha^{-1}. Different organic and inorganic nutrients might have helped in providing nutrients to the plants and ultimately improving the productivity of lentil (Singh et al 2017).

Grain straw ratio:. The variations in grain to straw ratio owing to different treatments was non-significant (Table 3.) The highest ratio was found in treatment T_{10}, T_9 andT_7.

Harvest index: Harvest index varied non-significantly among the different treatment of phosphorus and zinc application (Table 3). The highest harvest index was in T_8 and T_7. Improved crop growth from adequate phosphorus and zinc likely regulated the starch/sucrose ratio in reproductive organs and leaves. Phosphorus enhanced fruiting and facilitated better translocation of essential metabolites to yield-contributing parts, boosting grain yield. Large variations in harvest index are not influenced by any of the given treatments and this might be due to character, highly associated with genetic makeup of the crop (Singh et al 2011). Each increment of phosphorus from (25 to 75 kg ha^{-1}) gave superior HI value of lentil (Fatima et al 2013).

Economic Studies

Gross returns (₹ ha^{-1}): The gross returns was highest in the case of T_{10} followed by theT_{12} (Table 3). These returns may be ascribed to the higher yield of the treatments due the balanced application of the nutrients. The higher growth parameters and yield attributes resulted in higher gross returns.

Table 3. Effect of different treatments of phosphorus and zinc on grain, straw, biological yield, grain straw ratio, harvest index, cost of cultivation, net returns and B:C ratio

Treatments	Yield (kg ha^{-1})			Grain straw ratio	Harvest index	Net returns (₹ ha^{-1})	Cost of cultivation (₹ ha^{-1})	B: C ratio
	Grain	Straw	Biological					
T_1	1318	2591	3909	0.52	0.34	40231	22058	1.82
T_2	1418	2894	4271	0.49	0.35	43906	23183	1.89
T_3	1381	2880	4198	0.52	0.33	42005	23308	1.80
T_4	1363	2731	4179	0.49	0.34	42091	22103	1.90
T_5	1322	2668	4049	0.49	0.35	40123	22103	1.82
T_6	1363	2816	4216	0.48	0.33	41791	22148	1.89
T_7	1522	2890	4298	0.53	0.31	49161	22666	2.17
T_8	1341	2708	4094	0.49	0.37	40410	22728	1.78
T_9	1531	2930	4475	0.53	0.33	49293	22711	2.17
T_{10}	1735	3424	5063	0.53	0.35	58460	23336	2.51
T_{11}	1544	2980	4502	0.52	0.32	53399	24183	2.21
T_{12}	1563	3333	4544	0.47	0.33	55101	24246	2.27
CD (p=0.05)	191	NS	383	NS	NS	-	-	-

See Table 1 for details

Net returns (₹ ha^{-1}): The highest net returns was obtained in T_{10} whereas the minimum net return was in T_1 (Table 3). Yadav et al (2017)observed that the application of phosphorus at 40 kg ha^{-1} gave significantly higher net returns.

B: C ratio: The highest B:C ratio was obtained in T_{10} followed by the T_{12} at 2.27 (Table 3). The minimum was in T_1. This indicates amount of money earned from investment of a unit amount of money. The higher B:C ratio may be ascribed to higher net returns rupee^{-1} of cost. The nutrients applied caused better output when both phosphorus and zinc were combined along with the solubilizing microbes and led to higher gross and net returns which also led to higher B:C ratio (Singh et al 2019).

CONCLUSION

The application of. 50% RDP @24 +12.5 kg $ZnSO_4$ + Biophos + Biozinc (5 ml kg^{-1} seed each) proved effective in significantly enhancing the plant height, number of branches plant^{-1}, number of compound leaves plant^{-1}, dry matter accumulation plant^{-1}, number of days taken to flowering and maturity and B: C ratio. The research demonstrates the significant impact of phosphate and zinc solubilizing microbes on growth and yield of lentil. The synergistic interactions between these beneficial microbes and phosphorus and zinc fertilizers not only enhances nutrient availability but also promotes sustainable agricultural practices.

AUTHORS CONTRIBUTION

Monica Yaying: Conceptualization and execution of field experiment and laboratory analysis, data analysis, writing; Anil Shukla: Conceptualization of research work, supervision; Supriya: Preparation of manuscript, editing; Sudarshan S: Data analysis and editing; Shobhana Singh: Editing; Gunashekhar H: Preparation, correction and revision of manuscript; Chandra Bhushan: Correction and revision

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Morphological and Chemical Profile of *Pulicaria undulata* L. (Compositae) in Iraq

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Abstract: The morphological features of *Pulicariaundulata* (L.) C.A. Mey. were observed. This species is a perennial plant, twiggy subshrub 30-120 cm high with a deep root system, leaves are lanceolate, semi-amplexicaul and decurrent on one side, Inflorescence in irregular cymes, peduncles 4-5 cm long, Involucre 5-7 × 3-4 mm, phyllaries numerous, linear, brown, hairy or glabrous. Kaempferol, kaempferol 3-methyl ether, 6-methoxykaempferol, quercetin, quercetin 3-methyl ether, quercetin 3,7-dimethyl were estimatedusing HPLC chromatography.

Keywords: Compositae, Chemical study, Iraq, Morphological study, *Pulicaria*

Pulicaria undulata (L.) C.A.Mey. (1831) (syn. *Francoeuria crispa* subsp. crispa, *F.crispa* var. *crispa*, *Pulicaria crispa* subsp. *crispa*, *P. crispa* var. *crispa*, *P. crispa* var. *gracillima* Maire, *P. undulata* var. *undulata*, belongs to the family compositae (asteraceae) (GBIF Secretariat, 2020). This is native in Iraq, Iran, Yemen, Afghanistan, Algeria, Benin, Chad, Djibouti, Egypt, Eritrea, Ethiopia, Gulf States, India (Dawar et al 2002).This species very important medicinal plant known as *Dethdath*, and used medicinal plants to make traditional medicines all over the world since ancient times. The branches and flowers are used to prepare powders for sneezing which works to repel insects, also in the tea of herbal (Khansaa et al 2017). This species is used for a traditional medicine which act as tonic, antispasmodic, antihypoglycemic drugs and ingredients of perfumes (Ghazanfar and Edmondson 2019) and is rich source forlarge number of bioactive compounds such as flavonoids which are thesecondary plant metabolitesandare compounds of low molecular weight. They are chemically polyphenolic and their nature offers a common structure, benzo-γ-pyrone (Ahmed and Ibrahim 2018). These flavonoids are used by the action of antioxidants, antimicrobials, photoreceptors, optical attracts (Khalid et al 2020). This study aimed to characterize the plant through morphologic characteristics and toevaluate the flavonoids present in it.

MATERIAL AND METHODS

Twelve plant were collected from Al-Zafaraniyah/ Baghdad- Iraq in 2020during the flowering period in Aprilat 3 geographical locations, the coordinate of these stations was 33°15'49.0"N 44°29'16.6"E, 33°15'44.4"N 44°29'13.1"E and 33°15'34.7"N 44°29'17.4"E.. The taxonomical key was used to identify the specimens of this species for precise identification (Ghazanfar and Edmondson 2019). After being air dried in nature, the aerial parts of this species were ground in a mortar and flavonoids were isolated from *Pulicaria undulata*in pure form. Five grams of plant material separated in 100 ml of methanol using maceration (48 h). Then removed in the vacuum with the temperature at 50ºC and the extracts were freeze-dried (Romanik et al 2007).

RESULTS AND DISCUSSION

Morphological study: *Pulicaria undulata*is perennial plant and twiggy subshrub were 30-120 cm high with adeep root. Plant branches from the base, white-floccose or light gray in color, densely glandular, and take the form of extensive cushions. Its branches are many and may intertwine. The leaves are very long at the bottom and shorter towards the top with shape as lanceolate, semi-amplexicaul and decurrent on one side. The margin of the leaves are very clearly undulating, 2-25×1-5mm,base almost auriculate (Fig. 1). Inflorescence is irregular cymes, peduncles 4-5 cm long, involucre 5-7 × 3-4 mm, phyllaries numerous, linear, brown, hairy or glabrous Ghazanfar and Edmondson (2019) also mentioned similar observation . Corolla yellow, 2.75-3 mm long, the ligule only 1 mm, and the disc florets 2.5-3.5 mm long, with glandular hairs. Cypsela 0.8 mm long, glabrous, brown, 5-ribbed, the bristles with a short narrow tuft of slightly longer hairs at the tip. Outer pappus is ring of scales and inner pappus of bristles (short stiff hair) joined at the base into a tube, each bristle with a narrow apical tuft of slightly longer hairs. The morphology gave as clear features of this species because assemblage for species and is very useful for the delimitation and identification. There were two types in trichomes that spread densely in its parts. The non-glandular and glandular which spread and concentrated in all parts organs: leaves, stems and flowers (Abid and Qaiser 2002) Trichome diversity were divided.

Non-glandular trichome: These are found in all plant parts and are simple non-glandular unicellular trichomes, different lengths ranging from short to very long about 10-860μm, curved all with acute apex (Fig. 2. A 1- A 3) (Krak and Mraz 2008).

Non-glandular multicellular trichomes: These are also found in all parts of plants, some trichome fragmented from ending with a thin flagellum, others have basal cell broader,3-7 cells long and the apical cell like a conical shape, others consists of two cells of different lengths, straight or curved and all with obtuse apex (Fig. 2. A 3- A7) (Al-dobaissi et al 2016).

Stellate trichomes: The sparse stellate hairs are on the involucral bracts (Fig. 2. A 8).

Glandular trichome: These were multicellular divided into head and stalk (Fig. 2. B1) (Valkama et al 2003, Ciccarelli et al 2007).

Chemical profile: Six different flavonoids were extracted and identified: Kaempferol, kaempferol 3-methyl ether, 6-methoxykaempferol, quercetin, quercetin 3-methyl ether, quercetin 3,7-dimethyl ether (Fig. 3). The peaks for target

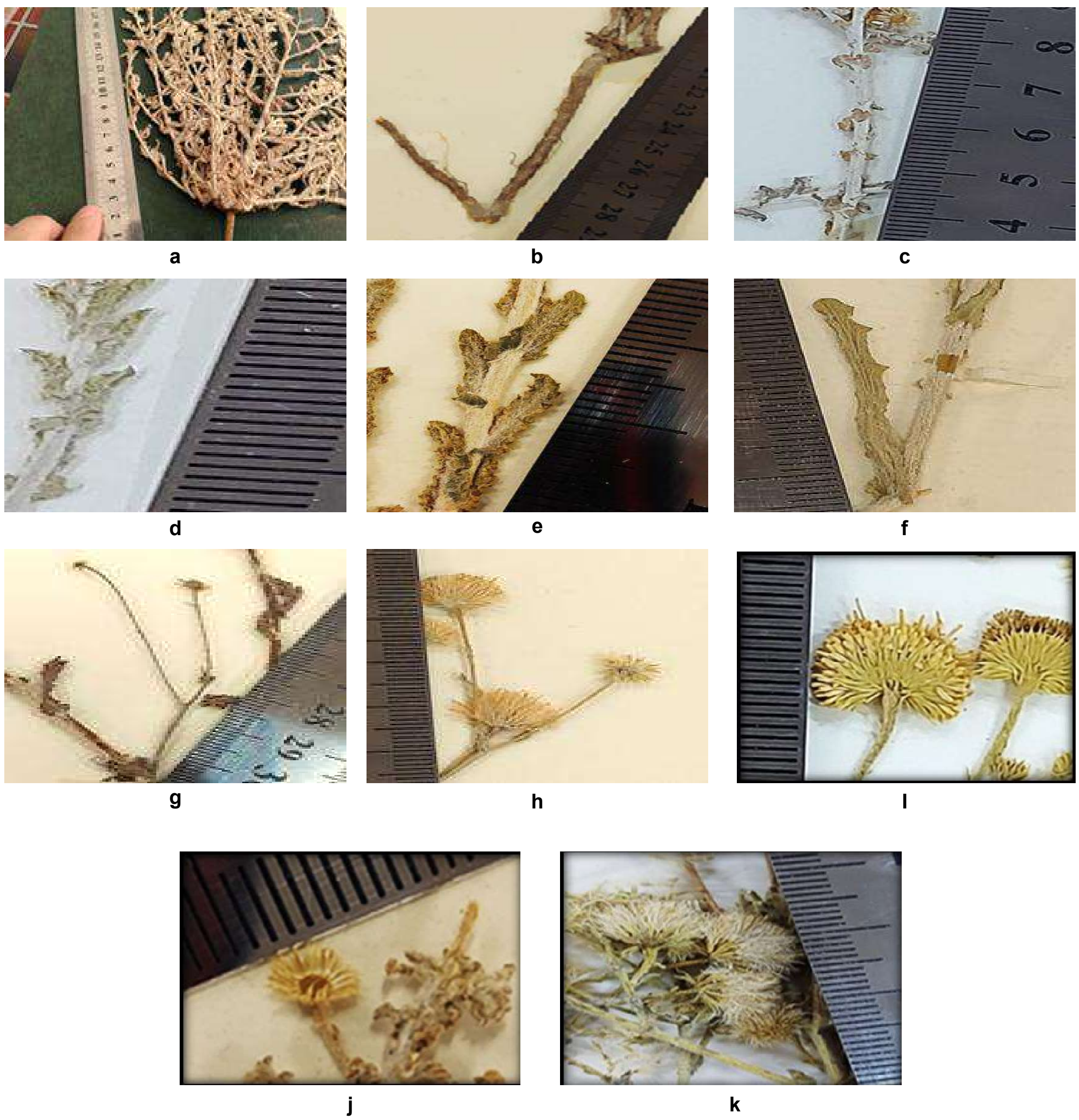


Fig. 1. Morphological characteristics of *Pulicaria undulata*a: Whole plant, b: Root, c: the stem, d1-3: Different lengths of leaves, e-i: Inflorescence, j: Pappus calyx

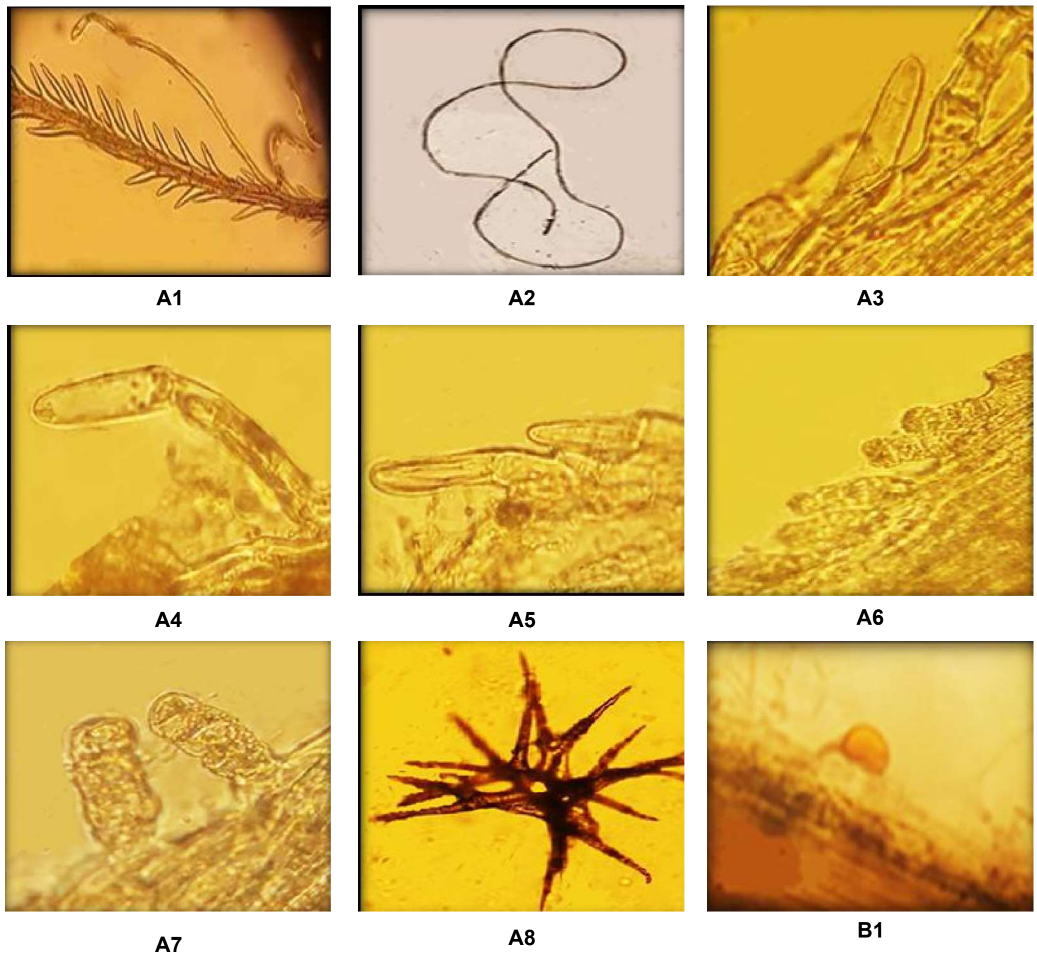


Fig. 2. Morphological characteristics for the trichomes of the species *Pulicaria undulata*A1-10:Non-glandular trichomes (300x), B1-5 Glandular trichomes(400x)

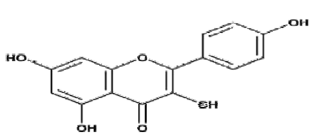
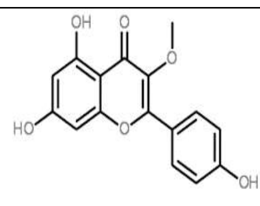
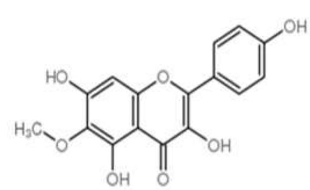
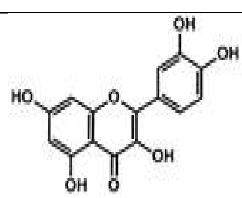
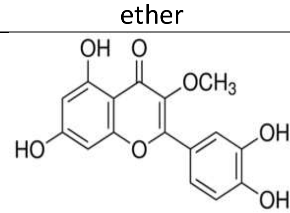
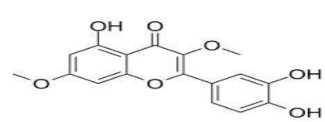
		
Kaempferol	Kaempferol 3-methyl ether	Methoxykaempferol-6
		
Quercetin	Quercetin 3-methyl ether	Quercetin 3,7-dimethyl ether

Fig. 3. Morphological form for the flavonoid compounds of the species *P. undulata*

Table 1. The flavonoids component with retention time and area of this species

Flavonoid compounds	Retention time (mints)	Area	Concentration (mg/mL)
Kaempferol	47.82	160.55	0.26
Kaempferol 3-methyl ether	52.38	50.32	0.11
6-Methoxykaempferol	44.71	40.13	0.05
Quercetin	34.41	36.66	0.04
Quercetin 3-methyl ether	83.22	90.71	0.15
Quercetin 3,7-dimethyl ether	40.32	110.53	0.20

flavonoidseluted at retention times 47.82, 52.38, 44.71, 34.41, 83.22 and 40.32 min, respectively, through the sample extract (Table 1). Fahmiet al (2019) also made similar observation.Kaempferol recorded the highest value of160.55 but quercetin recordedthe lowest value both in retention time and area which was 36.66 and 34.41, respectively. The highest concentration recorded for kaempferol was 0.26 mg/mL. Flavonoids protect plants against different biotic and abiotic stresses, and responsible for a very important role in resistance to frost, hardiness, drought resistance, also have a functional role for plant heat acclimation and freezing tolerance (Vieira et al 2003). Mierziak et al (2014) reported that the essential oil of the aerial parts for *P. gnaphalodes* has shown the presence of flavonoids, but studies on the concentrations of flavonoids are very rare in Iraq.

CONCLUSION

The study verified the morphological features of *Pulicaria undulate* (L.) C. A. Mey. (Asteraceae) which collected from Al-Zafaraniyah/ Baghdad- Iraq. Trichomes (hairs) weredivided into non-glandular and glandular. Various chemical kaempferol, kaempferol 3-methyl ether, 6-methoxykaempferol, quercetin, quercetin 3-methyl ether, quercetin 3, 7-dimethyl were estimated by HPLC chromatography. This will be helpful for medicinal use and further investigations.

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Impact of Western Disturbances on Stone Fruits in Mid Hill Zone of Himachal Pradesh

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Abstract: The study on impact of western disturbances on stone fruits grown in mid hill zone of Himachal Pradesh" was done at Dr. YS Parmar University of Horticulture and Forestry, Nauni.The western disturbances (WD) data was collected for the period 1984-2022. The arrival and withdrawal of WD indicated that during the period of 38 years the WD arrived during October and withdrawal during May in Solan district of Himachal Pradesh. The WD duration and amount of rainfall received was decreasing at 0.29 Julian days/year and 1.65 mm/year but, the number of WD was increasing at a rate of 0.12 JD/year which indicated that the frequency, distribution and intensity of WD was increasing over time in mid hills of Himachal Pradesh. The regression relationship was developed between the number of WD and productivity at development and maturity stages of plum and apricot crops. The results depicted positive relationship between number of western disturbance and productivity at developmental stages with coefficient of determination (R^2: 0.58 and R^2: 0.51) whereas showed negative relationship at maturity stage of selected crop.

Keywords: Frequency, Western disturbance, Monthly variation, Regression, Crop

Western disturbances (WD) are cyclonic circulation/ trough in the mid and lower tropospheric levels or as a low-pressure area occurs in mid-latitude westerlies and originates over the mediterranean Sea, Caspian Sea and Black Sea and moves eastwards across north India. These are the most fundamental level, synoptic-scale vortical perturbations embedded in the subtropical westerly jet stream (Dimri et al 2016) and are most common during December to March, bring rain to the Western Himalayas as well as to the surrounding areas of north India, Pakistan and the Tibetan Plateau and also associated with weather hazards such as heavy snowfall, hailstorms, fog, cloudbursts, avalanches, frost, and cold waves (Hunt et al, 2024). The erratic and increasing pattern of rainfall in Karnataka district may lead to the flash floods and at times drought situations (Bharath and Venkatesh 2022).

Agarwal et al (2021) also analysed that in early 1950s, winter and monsoon rainfall was showing decreasing trend whereas the summer and post-monsoon was showing an increasing trend resulting into a westward shift, more variable and declining rainfall over the country. Himachal Pradesh is situated in the western Himalayas and is divided by altitudinal ranges of 350 m to 6975 m above sea level due to a complex geographical feature which results in a variety of climatic patterns, from hot and humid tropical climates in the south to frigid, alpine, and glacial climates in the eastern and northern mountain ranges. According to the report of Himachal Pradesh State Action Plan on Climate Change (2012) projects states that during the last 25 years, there has been a 40% decrease in rainfall. Kumar et al (2019) highlights the vulnerability of stone fruit cultivation in the face of such climatic variability. The study underlines the importance of understanding the specific impacts of western disturbances on stone fruit crops to devise effective adaptations and mitigation strategies.

Western disturbances exert a notable influence on stone fruit cultivation in the mid-hill zone of Himachal Pradesh, necessitating a comprehensive understanding of their impacts and the implementation of suitable measures to ensure the sustainability of agricultural practices. The main objective of the study is to investigate how WD influences phenological stages (flowering, fruit set, ripening) of stone fruit crops in the mid-hill zone of Himachal Pradesh.

MATERIAL AND METHODS

Experimental site: The study was conducted at Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni-Solan (30°2240– 33°1240N and 75°4755-79°0420E) and 350 m to 6,816 m amsl during 2021-2023.

Data collection: The daily rainfall and rainy days data of 38 years (1984-2022) was collected from Agromet observatory, Department of Environmental Science, Nauni Solan whereas the data on area and production of stone fruit crops *viz*., Plum and Apricot for last 30 years (1990-2020) for Solan district was collected from the Department of Horticulture, Govt. of Himachal Pradesh.

Analysis of Western Disturbances

Duration and Frequency of western disturbances: The rainfall 2.5mm/day and more was considered as a WD spell. If the spell was continued for one day than WD spell is considered for 1 day. If the spell was continued for two days than WD spell is considered for 2 days and so on if the spell was continued for five days, than WD spell is considered for 5 days. The frequency of western disturbances was considered as the number of WD occurred during a month, season or year. Gill et al (2021) calculated the frequency of occurrence of WD duration for each month separately.

Frequency = Total rainfall / Total numbers of WD

Linear regression analysis: Linear regression analysis is a parametric model and one of the most commonly used methods to describe a trend in a data series and develops a relationship between two variables by fitting a linear equation to the observed data. The data is first checked whether there is relationship between the variables of interest or not. This can be done by using the scatter plot. The linear regression model is generally described by the following equation:

$Y = aX + b$

Y= dependent variable, X= independent variable, a= slope of line, b= intercept constant.

RESULTS AND DISCUSSION

Arrival, withdrawal and duration of western disturbances: The date of arrival of WD was decreasing (advancing) at a rate of 0.19 Julian days/year. Out of 37 years the arrival was below the normal for 21 years and above the normal during 16 years, it means that the WD arrival was early in 21 years and getting late during 16 years in the study area (Fig. 1) and the withdrawal date was increasing (delaying) at a rate of 0.11 Julian days/year (Fig. 2). Out of 37 years, 12 years showed the withdrawal below and remaining 25 years above the normal date of withdrawal of WD. The withdrawal of western disturbances was advanced in 12 years and delayed in 25 years in the study area. Dadial et al (2024) also studied the different behavioural characteristics of western disturbances (WD) like onset, withdrawal, durations and amount of rainfall in WD in Solan district of Himachal Pradesh. The annual duration of WD was decreasing at a rate of 0.29 Julian days/year, means decreasing at about 8 hours/year (Fig. 3).

Annual variation of number of WD and associated rainfall : The highest number of WD had been observed in one day duration (405) followed by two days duration (234) up to more than five days duration in the descending order whereas the associated rainfall was observed highest (4692.1 mm) for the WD of two days duration followed by one day duration and three days duration whereas lowest for the WD of more than five days duration. The frequency of WD spell (61.8 mm) was received highest in five days WD spell followed by four days WD spell (61.1mm). Deviation from mean value was highest for two days duration and lowest for more than five days duration whereas coefficient of variation was calculated highest for more than five days duration and lowest for one day duration. The positive slope and trend were observed increasing for the WD of one to four days duration whereas decreasing for five and more than five days duration (Table 1).

The variation in annual number of WD was increasing at a rate of 0.12JD/year (Fig. 4) whereas, annual rainfall received from WD was decreasing at a rate of 1.66 mm per year (Fig. 5). Similar results were obtained by Jaswal et al (2015) indicated that seasonal and annual trends in rainfall over Himachal Pradesh for 37 stations from 1951 to 2015 significantly decreasing by 4.58 mm/year. All the 37 stations in Himachal Pradesh were not showing an increasing trend in

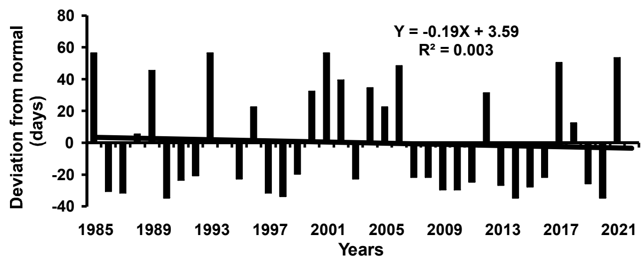

Fig. 1. Annual deviation (days) of WD from normal date of arrival

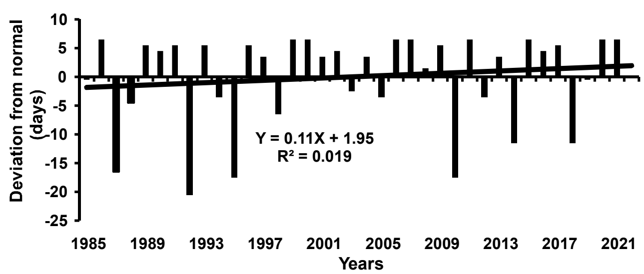

Fig. 2. Annual deviation (days) of WD from normal date of withdrawal

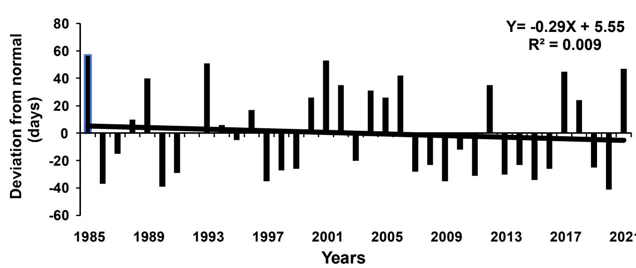

Fig. 3. Deviation in day from normal duration of western disturbances

Table 1. Annual variation in WD of different durations from 1984-2022

Durations (Days)	Number of WD	Rainfall (mm)	Mean	SD (σ)	CV (%)	Slope (Year)	Trend	Frequency
1	405	3321.5	44.8	81.01	55.3	0.11	↑	8.2
2	234	4692.1	67.7	114.44	59.1	0.06	↑	20.0
3	91	3309.2	71.9	80.71	89.1	0.16	↑	36.3
4	39	2385.3	65.7	58.18	113.0	0.68	↑	61.1
5	10	618.6	41.8	15.09	277.6	-0.36	↓	61.8
>5	6	358.3	25.3	8.74	290.4	-0.50	↓	59.7

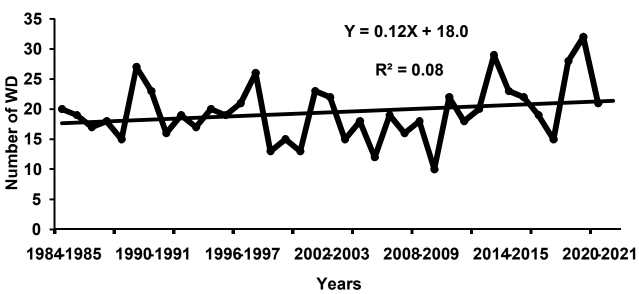

Fig. 4. Annual variation in number of western disturbances

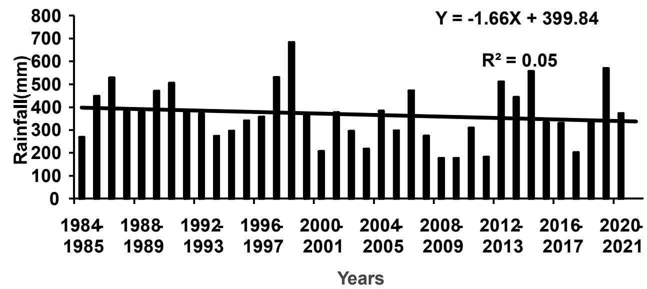

Fig. 5. Annual variation of rainfall received through western disturbances

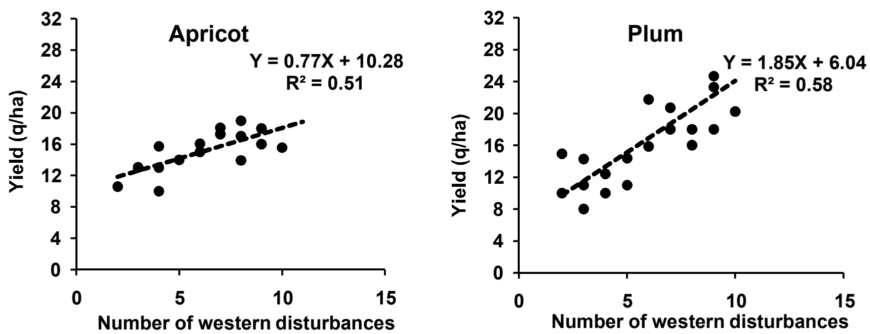

Fig. 6. Effect of number of WD on crop yield occurred at development stage

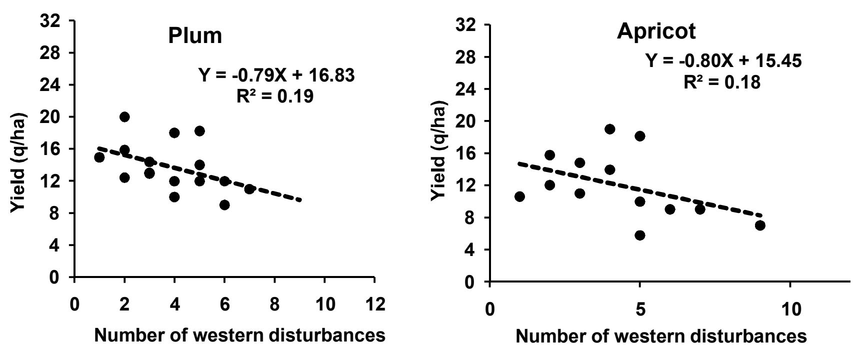

Fig. 7. Effect of number of WD on crop yield occurred at maturity stage

annual rainfall. Harshavardhan et al (2020) investigated the spatiotemporal trends in rainfall in Krishna River Basin in India from 1965 to 2012 and observed that annual and post-monsoon precipitation exhibited a significant negative trend in magnitude from the normal.

Regression relationship of number of WD with productivity of stone fruit crops: The linear regression model was developed between number of western disturbance and productivity of Plum and Apricot crop at development and reproductive stage. At development stage both the crops showed the positive relationship with variation of 58 and 51 percent (Fig. 6) whereas showed negative relationship at reproductive stage with variation of 19 and 18 per cent (Fig. 7). The results inferred that the increase in the number of western disturbances caused detrimental effects on crop yield at a rate of -0.79 and -0.80 quintal per number of WD during reproductive to harvesting stage. The occurrence of heavy rainfall accompanied with high wind speed due to western disturbances at flowering stage will be washed out pollen from the stigma of the flower, resulting in poor or no fruit setting. Similarly, at the time of maturity, it leads to fruit dropping or poor quality of fruit. Mehta et al (2022) highlighted that erratic rainfall patterns led to a shorter cropping calendar, affecting agricultural practices. Over the past three decades, farmers have observed a mismatch in rainfall, with insufficient rain during crucial periods and excessive rain when it is not needed. Dadial et al (2024) reported that rainfall at development stage showed beneficial effects on wheat, barley, and peach crops whereas, rainfall during the months of April and May impacts the harvesting and threshing of wheat crop thus decreases the quality and quantity of crop. The hailstorm events in the month of April and May reduced the yield of peach crop in mid hill zone of Himachal Pradesh.

CONCLUSIONS

The annual duration of western disturbance and amount of rainfall received from October to May depicted decreasing trend. While the western disturbance spells of day 1 to 4 showed increasing trend whereas day 5 and >5 spells showed decreasing trend thus indicated that the frequency, distribution of WD was increasing over time in mid hills of Himachal Pradesh. The regression model developed between the number of WD and productivity depicted positive relationship at developmental stages while showed negative relationship at maturity stage of selected crops. Hence, farmers should reschedule the plant protection measures and irrigation activity according to the weather forecast during critical growth stages. The farmers should sow the crops at optimum date and avoid late sowing of crops to prevent the maturity and harvesting stages from coinciding with peak WD activities. With a decline in the amount of rainfall during WDs, ensure proper irrigation management to supplement water needs during critical growth stages. Rainwater harvesting systems can be developed to store water during periods of increased WD intensity and redistribute it when needed.

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Standardization of Growing Media for Haworthia Pot Plant

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Abstract: Investigation was carried out to standardize growing media for *Haworthia attenuta*, a popular succulent pot plant at Navsari Agricultural University, Navsari. The experiment consisted of different growing media viz.,M_1- cocopeat + vermicompost + rice husk (6:1:3), M_2-cocopeat + vermicompost + perlite (6:1:3), M_3- cocopeat + vermicompost (9:1), M_4-local black soil + vermicompost+sand (6:1:3), M_5-cocopeat+ vermicompost+ charcoal (7:1:2), M_6-sand+vermicompost (9:1) and M7- white grit+vermicompost (9:1) in 10x10 cm pot. The observations were recorded at every three months interval, and pooled data analysis of three years was done. Among different growing media, sand: vermicompost (9:1) was highly suitable with regard to plant height, plant spread and number of leaves. Further, number of suckers as well as root length and number of roots were observed maximum in sand: vermicompost (9:1) growing media. Thus, growing media comprising of sand: vermicompost (9:1) was highly suitable for growing Haworthia as pot culture to obtain better plant growth and quality.

Keywords: Succulent, Haworthia, Pot plant, Growing media, Sand, Cocopeat, Vermicompost

Pot plant trading is recently gaining the impetus of an industry with the growing demand of quality ornamental plants in domestic as well as international trade. Rapidly growing urbanization and population explosion with hasty life style have created space paucity for living, wherein pot plants offers some respite (Singh et al 2016, Guddad et al 2022, Sindhuja et al 2022). In critical times that prevailed during the epidemic COVID-19, indoor gardening helped to enhance sense of emotional comfort and created sense of stress free happy environment (Altman 2011, Singh et al 2020). Succulent plants are increasingly in demand as indoor pot plant for urban horticulture (Dewir 2016, Cabahug et al 2018) because of specific characteristics like drought resistance (Baldwin 2013, Edwards and Ogburn 2013) and low light tolerance (Bell 2001, Nefzaoui 2007). Drought-tolerant plants are increasingly recognized as a resource to mitigate the consequences of climate change and need to be preserved (Grace 2019). Besides, succulents are known to exhibit crassulacean acid metabolism (CAM), resulting in CO_2 assimilation during night time (Lee 2010, Herrera 2009) and thus contribute in improving indoor air quality.

Haworthia is a small succulent ornamental plant native to South Africa, belongs to family *Asphodelaceae* and is native to South Africa. The cultivation of haworthia as pot plant is increasing in different countries owing to its small compact growth habit and drought tolerance characteristic (El Shamy et al 2018, Grace 2019). Its popularity and demand is further increasing for offices and homes as it can flourish at low light levels also. The successful potting media should provide good physical support for the plant, a reservoir for nutrients and water with sufficient drainage and aeration. Research on growing media standardization in succulents is meagre with no previous work on haworthia. Hence, research was conducted to standardize growing media for haworthia as pot plant.

MATERIAL AND METHODS

The present study was carried out at Navsari Agricultural University, Navsari-396450, Gujarat during 2017-2020 on popular succulent indoor plant *Haworthia attenuta* in a protected structure cladded with 200 micron UV stabilized film and 50 per cent shade net. The treatments consisted of seven growing media viz.,M_1- Cocopeat + vermicompost + Rice husk (6:1:3), M_2- Cocopeat + vermicompost + perlite (6:1:3), M_3- Cocopeat + vermicompost (9:1), M_4- Local black soil+ vermicompost+ sand (6:1:3), M_5- Cocopeat + vermicompost + Charcoal (7:1:2), M_6-Sand+vermicompost (9:1) and M7- White grit+vermicompost (9:1) in 10x10 cm uv stabilised plastic pot. The experiment was laid out in completely randomized design with three repetitions for three consecutive years and each year new plantation was done. Uniform sized plants were planted in different growing media and uniform management practices were given for all treatments. As nutrient management, NPK (19:19:19) at 250 mg/l was given @ 50 ml per plant at monthly interval. Observations on different parameters like plant height, plant spread (E-W and NS), number of leaves and number of suckers were recorded at every three months of interval i.e.

after 3, 6, 9 and 12 months of planting. Further, number of roots and root length was measured at the beginning and after one year of period and the incremental change was determined. The experiment was repeated for three years. Chemical and physical properties of different growing media pH, EC and bulk density was estimated before the experiment (Table 4). The data of three years were pooled and statistically analysed by using the OP stat software (Sheoran et al 12)

RESULTS AND DISCUSSION

Plant height and plant spread: Among different growing media, plant height was significantly higher in haworthia grown in the media M6 i.e. sand: vermicompost (9:1) as recorded after different intervals i.e. during the followed by M_5- cocopeat + vermicompost + charcoal (7:1:2 (Table 1). The plant spread for both sides i.e N-S and E-W, it was significantly higher in haworthia grown in the media M_6 i.e. sand: vermicompost (9:1) followed by M5 media while M4 media showed restricted plant spread. Haworthia, being succulent does not prefer water stagnation. Sand in M6 media and cocopeat and charcoal in M5 media contributed to better provision of aeration to the rooting system of haworthia that resulted in its better growth. The restricted plant growth in M4 media was due to the heavy black soil that holds excessive water that is not suitable for succulents in general as per some earlier work (Song et al 2007, Kaur et al 2015, Singh et al 2017). Significant influence of growing media on pot plants have been earlier observed on plant growth in indoor plants (Rashidha et al 2021), *Anthurium andraeanum*(Basheer and Thekkayam 2012), *Chlorophytum comosum* (Dhanasekaran et al 2020), *Dracaena reflexa* (Kavipriya et al 2019), *Epipremnum aureum* (Khayyat et al 2007), *Euphorbia milii* (Kapadiya et al 2017) and), *Senecio sp* (Lodhi et al 2021).

Number of leaves and suckers: Among different growing media, number of leaves were significantly higher in Haworthia grown in the media M6 i.e sand: vermicompost (9:1) at different intervals (Table 2). The number of suckers were significantly higher in Haworthia grown in the media M_6

Table 1. Effect of different growing media on plant height and plant spread in haworthia (cm)

Treatments	Plant height				Plant spread (N-S)				Plant spread (E-W)			
	3 months	6 months	9 months	12 months	3 months	6 months	9 months	12 months	3 months	6 months	9 months	12 months
M1	5.04	6.21	7.03	7.45	4.68	5.77	6.40	7.14	4.87	5.60	6.18	7.07
M2	5.18	6.59	7.40	7.85	4.76	6.06	6.72	7.43	5.00	5.75	6.43	7.23
M3	5.01	6.45	7.27	7.71	4.63	5.66	6.29	7.25	4.77	5.45	6.10	6.99
M4	4.76	5.88	6.88	7.32	4.42	5.35	5.67	6.37	4.50	5.29	5.81	6.65
M5	5.40	7.27	8.08	8.42	5.00	6.54	7.34	7.98	5.36	6.15	7.04	7.89
M6	5.62	8.32	9.07	9.73	5.24	7.88	8.79	9.93	5.47	7.61	8.28	9.39
M7	5.05	6.74	7.55	8.00	4.77	6.33	7.01	7.76	4.88	6.05	6.73	7.55
CD (p=0.05)	0.22	0.43	0.53	0.68	0.19	1.26	1.20	1.41	0.33	1.12	1.02	NS
CD (p=0.05) (YT)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 2. Effect of different growing media on number of leaves and number of suckers in Haworthia

Treatments	Number of leaves per plant after indicated months				Number of suckers per plant after indicated months			
	3	6	9	12	3	6	9	12
M1	16.66	21.36	26.88	30.33	0.79	1.17	1.42	1.80
M2	17.84	21.87	26.22	30.73	1.10	1.32	1.63	2.09
M3	16.84	21.85	26.22	29.84	0.83	1.23	1.34	1.75
M4	15.36	19.85	24.32	27.17	0.24	0.53	0.90	1.13
M5	19.15	24.22	30.52	33.63	1.20	1.49	1.79	2.26
M6	19.36	25.17	33.62	41.62	1.46	2.12	2.45	3.37
M7	17.14	21.62	27.70	30.47	1.12	1.34	1.74	2.28
CD (p=0.05)	0.98	2.22	2.53	4.11	0.49	0.42	0.67	0.76
CD (p=0.05) (YT)	NS	NS	NS	NS	NS	NS	NS	NS

i.e Sand: Vermicompost (9:1) after 3 (19.36), 6 (25.17), 9(33.62) and 12(41.62) months (Table 2). Better plant growth in terms of leaves and suckers was the result of better rooting system indicated with more number of roots and longer root being developed in sand: vermicompost media (9:1). An appropriate growing media provides better rooting system contributes in more water and nutrients for successful in growth and development of the plants (Wazir et al 2004, Franco et al 2011, Gohil et al 2018). Sand is an important component of growing media owing to its physical properties of low EC, neutral pH and improve plant growth in a few succulents and cacti (Kapadiya et al 2017, Bell 2021, Lodhi et al 2021).

Number of roots and length of root: Among different growing media, number of roots (3.26) and length of root (3.42 cm) significantly increased in haworthia grown in the media M_6 i.e. sand: vermicompost (9:1) at end of experiment (Table 3). Root can be considered a key parameter as it plays an important role for the plant to absorb the nutrient and capture water. Promotion or inhibition of root growth is known to be influenced by the physical and chemical characteristics of growing media like texture, structure, bulk density, porosity, water-holding capacity, EC, pH, etc. (Larsen and Guse, 1997, Hartmann et al 1997, Giuliani 2024). Thus, the physical properties like low EC and neutral pH of sand+vermicompost (9:1) media and suitable bulk density contributed to better root growth in haworthia.

Table 3. Effect of different growing number of roots and root length in haworthia

Treatments	Incremental number of roots	Incremental length of root (cm)
M1	1.35 (1.41)	1.94
M2	1.60 (2.15)	2.25
M3	1.14 (2.68)	2.04
M4	0.96 (0.44)	1.12
M5	1.78 (2.74)	2.83
M6	1.93 (3.26)	3.42
M7	1.61 (2.16)	2.96
CD (p=0.05)	0.33	0.52
CD (p=0.05) (YT)	NS	NS

Note: The values in parenthesis are original and outside are arcsine transformed values

Table 4. Effect of growing media on EC, pH and bulk density

Treatments	EC (mS/cm)	pH	Bulk density (g/cc)
M1	1.74	6.5	0.18
M2	1.33	6.8	0.30
M3	2.1	6.1	0.19
M4	1.56	6.9	0.25
M5	1.21	7.2	1.32
M6	0.16	6.7	1.70
M7	0.11	7.8	1.73

CONCLUSION

Among seven different growing media combinations evaluated for haworthia, the growth of haworthia with regard to plant height, plant spread, number of leaves, number of suckers as well as root length and number of roots was found better in media comprising of sand:vermicompost (9:1). Thus, for growing haworthia as pot plant, media consisting of sand: vermicompost (9:1) is highly suitable.

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Assessment of Roadside Ornamental Trees Potential For Mitigating Heavy Metal Pollution in Ludhiana, Punjab

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Abstract: This study examined heavy metal (HM) concentrations in roadside soil and ornamental tree leaves to identify trees with high bioaccumulation potential for mitigating HM pollution. Samples were collected from a highway site and PAU university campus, focusing on several heavy metals. The analysis revealed notable bioaccumulation factors (Bf) for chromium (Cr), nickel (Ni), copper (Cu), and lead (Pb) in the leaves of various tree species. Specifically, *Heterophragma adenophyllum* demonstrated strong affinity for zinc (Zn) and cadmium (Cd), while *Cassia siamea* showed significant uptake of Cu and Zn. These findings highlight the potential of certain tree species to help address heavy metal contamination in urban areas.

Keywords: Heavy metals (HM's), Ornamental trees, Bioaccumulation factor (Bf), Pollution, Affinity

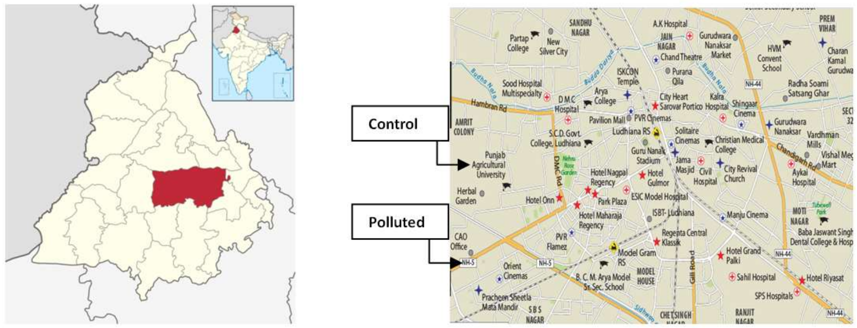
Air pollution, primarily caused by industrialization and vehicular emissions, remains a significant global concern (Latif et al 2018). Among its components, heavy metals (HMs) pose direct and indirect risks to human health, exacerbated by anthropogenic activities such as industrial growth and increasing vehicular traffic in urban areas (Ugolini et al 2013, Hu et al 2014). Certain HMs, including arsenic, cadmium, chromium, mercury, and lead, are particularly hazardous to both plant and human health (Szyczewski et al 2009), while others like copper, selenium, and zinc are essential for plant growth at lower concentrations (Wuana and Okieimen 2011, Rehman et al 2018). The non-biodegradable nature of HMs leads to their accumulation in soil and the human body, posing long-term environmental and health risks (Nagajyoti et al 2010).

Vehicular emissions significantly contribute to elevated HM levels along urban roadside environments (Chen et al 2016, Wang et al 2022). Components of vehicles such as iron, copper, and zinc, present in alloys, tires, pipes, and wires, contribute to HM emissions through mechanical wear and tear over time (Ozaki et al 2004). This accumulation is concerning due to the persistence of HMs in the environment. Given the global urgency of this issue, numerous studies have investigated HM contamination along roadsides (Hu et al 2014, Mihailovic et al 2015). Plants, particularly trees, play a crucial role as bio-monitors by absorbing HMs from soil through their roots or from the air via stomata(Hosseini et al 2020, Kord et al 2010). Thereby, plants accumulate HM 's in their different body parts process known as phytoremediation, which is economical, sustainable, and eco-friendly method to protect environment (Hosseini et al 2020).Previous research has demonstrated the effectiveness of various plant species in monitoring HM impacts on their surrounding environments (Anjum et al 2021, Onder and Dursun 2006). Trees, with their extensive leaf and root surface areas, are particularly effective in this regard (Tomasevic et al 2008, Estrabou et al 2011, Li et al 2022). This study focuses on evaluating HM concentrations in selected roadside ornamental trees and soil, aiming to contribute to our understanding of HM distribution and bioaccumulation in urban environments.

MATERIAL AND METHODS

The study was conducted in Ludhiana, which experiences a semi-arid climate characterized by three distinct seasons: summer, monsoon, and winter. The city's average annual precipitation is 809.3 mm. The study area specifically focused on National Highway 5, and lies between the North latitude of 30°46'38" and the east longitude of 76°33'23". This highway, known for high vehicular traffic and associated emissions, was selected as the polluted site (study area). As a contrast, Punjab Agricultural University campus served as the control site. The polluted conditions of Ludhiana, stemming from intensive urbanization and industrialization, provided a suitable context for investigating pollution-related phenomena in this study.

Sampling of plant and soil material: The soil and leaf samples of selected tree species (*Acacia auriculiformis, Alstonia scholaris, Cassia fistula, Cassia siamea, Chukrasia tabularis, Dalbergia sissoo, Heterophragma adenophyllum,* and *Putranjiva roxburghii*) were collected from both sites (0–1 m from the road edge). Control soil and plant leaf



a) b)

samples were collected from PAU, Ludhiana (100 m away from the road). Soil samples were collected 0, 10, 15, and 20 cm deep from each site along with both sites of road, and five representative samples of each site were prepared by the quadrant method (Rosa et al 2018). For accurate heavy metal analysis, leaf samples from five trees of each species, were harvested from each site during the mid-growing season, to ensure full leaf development (fully mature leaf) and reliable data on metal accumulation. The permissible limits for heavy metals in soil and plant leaves according to different standards, presented in Table 1.

Soil and plant samples analysis: The heavy metal content in soil samples was assessed using the method developed by Lindsay and Norvel (1978). Concentrations of heavy metals (Cr, Fe, Ni, Cu, Zn, Cd, and Pb) were determined using an ICP Spectrometer (ICP-MS 7700 Series). Similarly, heavy metal concentrations in leaf samples were analyzed using an ICP Spectrometer (Model iCAP 6000 Series). The heavy metals (Cr, Fe, Ni, Cu, Zn, Cd and Pb) were estimated by injecting filtered samples into Inductively Coupled Plasma Emission spectrophotometer and amount expressed in mg kg^{-1}(Ammann 2007). Bioaccumulation factor (Bf) is the plant potential to take up HMs (or any other chemical) from the soil/growth media and it can be calculated as a leaf to soil ratio of the HM concentration (Alahabadiet al 2017). Bf was worked out to determine HM accumulation potential of an individual tree species.

Statistical analysis: The data were analyzed using a factorial randomized block design. and comparison was performed by Tukey's test at a 5% significant level using SAS software computer version 9.2.

RESULTS AND DISCUSSION

Heavy metal concentrations in soil: The concentrations of heavy metals (chromium, iron, nickel, copper, zinc, cadmium, and lead) showed significant differences between two locations (Table 2). The content of metals (Cr, Fe, Ni, Cu, Zn, Cd, and Pb) in the soil across two sites exhibited significant variability. All examined metals were elevated in roadside soils compared to the control site soil. HM concentrations between control and polluted site soil ranged from 1.98 to 18.74mg $kg^{-1}$for Cr, 993.77 to 11947.86 mg $kg^{-1}$for Fe, 1.54 to 14.66 mg kg^{-1} for Ni, 3.09 to 19.61mg kg^{-1} for Cu, 9.12 to 68.16mg kg^{-1} for Zn, 0.49 to 0.55mg kg^{-1} for Cdand 3.01 to 16.78mg kg^{-1} for Pb. Levels of all metals were under permissible limits in both the locations. Despite being in within permissible limits, the elevated concentrations suggest that the polluted site is experiencing environmental stress, possibly due to industrial activities or pollution sources.

These findings are consistent with previous studies that have documented increasing HM (Fe, Ni, Cr, Zn, Cu, Cd and Pb) concentrations in polluted environments (He and Yang 2015). The high levels of heavy metals can have detrimental effects on soil health, plant growth, and overall ecosystem stability (Telo da Gama 2023). The highway site soil exhibited higher concentrations of heavy metals compared to the campus site, attributed to its high traffic volume (Elbagermi et al 2012, Wang and Zhang 2018). The detrimental effects of various heavy metals on both plants and humans, highlighting the need for effective management and mitigation strategies to address heavy metal contamination in Table 3.

Heavy metal concentrations in selected tree leaves: The concentration of heavy metals shows a significant increase of approximately 74.5% in polluted areas (106.52 mg kg^{-1}) compared to control sites (61.04 mg kg^{-1}) (Table 4). In comparing heavy metal concentrations between polluted and control sites, *Alstonia scholaris* shows the greatest increase at polluted site 119.43%, while *Cassia siamea* has the smallest increase at 39.45%, respectively. This trend indicates that all species significantly accumulate more heavy metals in polluted areas compared to control sites suggesting that the variations in HM levels are due to the impact of vehicular traffic (Ogutucu et al 2021). The percentage increases in heavy metal concentrations from control to polluted sites, ranked from highest to lowest, highlight several significant trends. Cu shows the most dramatic rise, with increase of 5,875%, and Cr shows the smallest increase at 20.2%. . Levels of Zn, Ni and Pb surpass permissible limits, at both sites in all tree species suggesting notable pollution, conversely, Cu, Cd, and Cr are generally within acceptable ranges, though some species show elevated levels, particularly in polluted sites. Pb is a significant pollutant from auto exhaust (Muzychenko et al 2017). Ni in roadside plant may originate from engine oil, fuel, tire and brake wear, and the corrosion of nickel alloy components (Gupta 2020, Khalid 2018). Zn is commonly associated with roadside plants due to its extensive use in construction and transportation (Barber et al 2017). Overall roadside plants, being exposed to heightened anthropogenic activities, may exhibit increased accumulation of heavy metals in their leaves (Ogutucuet al 2021).

The study demonstrates that different tree species have varying capacities for accumulating heavy metals from the environment as it depends on leaf surface area quality, stomata size, and HM's particle size (Lei et al 2006, Ugolini et al 2013, Singh et al 2017). *Alstonia scholaris* is the most effective heavy metal accumulator, making it ideal for phytoremediation, while *Cassia fistula* and *Cassia siamea* show the least affinity for heavy metals. The study also highlighted differential affinity of selected roadside trees towards these heavy metals, suggesting their potential as bio-indicators. *Alstonia scholaris* exhibit highest

Table 2. Heavy metal contents (mg kg^{-1}) in soil samples from control and polluted locations

Heavy metal	Control site	Polluted site	Percent increase in polluted location (%)
Chromium (Cr)	1.98^b	18.74^a	846.46
Iron (Fe)	993.77^b	11947.86^a	1102.28
Nickel (Ni)	1.48^b	14.66^a	890.54
Copper (Cu)	3.09^b	19.61^a	534.63
Zinc (Zn)	9.12^b	68.16^a	647.37
Cadmium (Cd)	0.49^b	0.55^a	12.24
Lead (Pb)	3.01^b	16.78^a	457.48
Overall location (Mean)	144.71^b	1726.62^a	-

* Different letters in each row are significantly different at P≤0.05 by Turkey's Test

Table 1. Acceptable limits of heavy metals (HM's) in soil and plant leaf samples

Sample	Standards	Cd	Cu	Pb	Zn	Ni	Cr
Soil (mg kg^{-1})	Indian Standard (Awashthi 2000)	3-6	135-270	250-500	300-600	75-150	-
	WHO(2006)	-	140	84	-	107	-
	European Union Standards (EU 2006)	3.0	100	300	300	50	100
Plant (mg kg^{-1})	Indian Standard (Awashthi 2000)	1.5	30.0	2.5	50.0	1.5	20.0
	WHO/FAO (2007)	0.2	40.0	5.0	60.0	-	-
	European Union Standards (EU 2006)	0.2	-	0.30	-	-	-

Table 3. Effects of heavy metals on plant and human health

Heavy metal	Effects on plants	Effects on humans	References
Pb	• Reduces growth and chlorophyll content • Causes leaf and root damage • Interferes with nutrient uptake	• Neurotoxicity, especially in children • Kidney damage • Developmental and cognitive impairments	Alloway 2013, Tchounwou et al 2012, Alengebawy 2021
Cd	• Inhibits seed germination and growth • Causes leaf chlorosis and necrosis • Interferes with enzyme activity	• Causes kidney damage and osteoporosis • Carcinogenic effects • Impaired respiratory function	Alloway 2013,Jarup 2003,Satarug et al 2011, Haider et al 2021
Cr	• Affects photosynthesis and growth • Causes root and shoot damage • Alters enzyme activity	• Causes respiratory issues and skin ulcers • Impairment of liver and kidney function • Carcinogenic	Kapoor et al 2022
Ni	• Causes reduced seed germination • Inhibits root growth and development • Alters photosynthetic activity	• Respiratory issues and dermatitis • Nausea, vomiting, and diarrhoea • Potentially carcinogenic	Hassan et al 2019, Genchi et al 2020
Cu	• Causes leaf necrosis and chlorosis • Inhibits root growth • Impairs nutrient absorption	• Causes gastrointestinal distress • Liver and kidney damage • Neurological problems	Balali-Mood et al 2021,Mir et al 2021
Zn	• Leads to leaf chlorosis and stunted growth • Affects root and shoot development • Interferes with enzyme functions	• Causes gastrointestinal issues • Impaired immune function • Possible disruption of growth and development	Ali et al 2013

Table 4. Metal concentration (mg kg^{-1}) in the leaf of selected roadside tree species growing at the control and polluted locations

Tree species	Location	Heavy metals (mg kg^{-1})							Mean (Location)	Mean (Specie)
		Fe	Cu	Zn	Cd	Cr	Ni	Pb		
Acacia auriculiformis	Control	340.11^{m}	1.62^{n}	21.23^{n}	0.05^{g}	16.30^{i}	5.93^{i}	5.55^{ef}	55.83^{b}	78.96^{e}
	Polluted	639.83^{d}	6.36^{f}	37.93^{f}	0.14^{c}	17.62^{e}	6.41^{e}	6.37^{c}	102.09^{a}	
Alstonia scholaris	Control	422.70^{j}	4.93^{i}	28.26^{l}	0.10^{de}	17.22^{h}	6.22^{h}	5.78^{de}	69.32^{b}	110.74^{a}
	Polluted	968.80^{a}	10.88^{d}	52.34^{b}	0.22^{a}	18.35^{b}	6.88^{b}	7.65^{a}	152.16^{a}	
Chukrasia tabularis	Control	336.23^{n}	2.65^{m}	23.45^{m}	0.08^{ef}	17.65^{e}	6.34^{f}	5.31^{f}	55.96^{b}	75.85^{f}
	Polluted	585.70^{f}	5.86^{g}	47.79^{c}	0.09^{ef}	17.76^{d}	6.67^{c}	6.27^{c}	95.73^{a}	
Cassia fistula	Control	321.60^{o}	4.64^{j}	18.81^{p}	0.09^{e}	17.30^{g}	5.97^{i}	4.80^{g}	53.32^{b}	73.21^{g}
	Polluted	573.83^{g}	10.14^{e}	37.44^{g}	0.17^{b}	17.49^{f}	6.42^{e}	6.16d^{c}	93.09^{a}	
Cassia siamea	Control	319.47^{p}	3.34^{l}	20.45^{o}	0.09^{e}	17.30^{g}	6.27^{g}	5.33^{f}	53.18^{b}	63.68^{h}
	Polluted	437.73^{h}	14.22^{b}	36.33^{h}	0.12^{dc}	17.83^{d}	6.85^{b}	6.20^{dc}	74.18^{a}	
Dalbergia sissoo	Control	375.51^{l}	0.24^{o}	29.67^{k}	0.10^{de}	17.34^{g}	6.25^{gh}	5.81^{de}	62.13^{b}	81.08^{d}
	Polluted	607.58^{e}	14.33^{a}	46.49^{e}	0.17^{b}	18.05^{c}	6.49^{d}	7.15^{b}	100.04^{a}	
Heterophragma adenophyllum	Control	426.57^{i}	3.94^{k}	35.09^{i}	0.08^{ef}	17.61^{e}	6.29^{g}	5.50^{ef}	70.73^{b}	97.68^{b}
	Polluted	762.61^{b}	11.14^{c}	66.31^{a}	0.29^{a}	18.34^{b}	6.67^{c}	7.10^{b}	124.64^{a}	
Putranjiva roxburghii	Control	409.19^{k}	5.10^{h}	31.15^{j}	0.06^{fg}	17.60^{e}	6.28^{g}	5.81^{de}	67.88^{b}	89.04^{c}
	Polluted	675.38^{c}	14.32^{a}	46.70^{d}	0.12^{de}	19.61^{a}	7.56^{a}	7.61^{a}	110.19^{a}	
Overall Mean	Control								61.04^{b}	
	Polluted								106.52^{a}	

accumulation of Fe and Pb as compare to other species under study. Similarly, *Dalbergia sissoo* for (Cu), *Heterophragma adenophyllum* for (Zn & Cd) and *Putranjiva roxburghii* showed amassing for (Cr & Ni). The absorption ability of a plant species changes with the leaf properties of the plant as well as with plant species (Shahid *et al* 2017). These findings can guide the selection of tree species for environmental cleanup and management of heavy metal pollution. The bioaccumulation factor of the HMs in the selected roadside tree leaves varies with site and tree species (Patel et al 2015, Greksa et al 2019). Among the tree species studied, the overall Bioaccumulation Factor (Bf) for trees, follow the order: *Putranjiva roxburghii* (0.438) >*Alstonia scholaris* (0.433) >*Heterophragma adenophyllum* (0.396) >*Acacia auriculiformis* (0.362) >*Cassia siamea* (0.337) = *Cassia fistula*(0.334) >*Chukrasia tabularis* (0.316) >*Dalbergia sissoo* (0.272). Species with higher Bf values like *Putranjiva roxburghii, Alstonia scholaris* and *Heterophragma adenophyllum* are more adept at accumulating heavy metals and are therefore preferable for phytoremediation in highly contaminated soils.

CONCLUSION

The study highlights the variable capacity of different tree species to accumulate heavy metals. *Alstonia scholaris* emerged as the most effective accumulator, particularly in polluted areas, along with others such as *Dalbergia sissoo*, *Heterophragm aadenophyllum*, and *Putranjiva roxburghii*, which demonstrates significant potential for use in phytoremediation efforts. The capacity for heavy metal accumulation varies with leaf properties and species characteristics, supporting the need for tailored approaches in environmental management. Mostly HMs under consideration was within permissible limits, but the substantial exceedance in Zn, Ni and Pb levels in plant leaves underscore specific contamination concerns. HM accumulation is a major health concern globally. In Ludhiana, high traffic and industrial activities contribute to Pb buildup in roadside plants, raising health risks and highlighting a pressing issue in India. Continued monitoring, along with the use of appropriate tree species for phytoremediation, will be essential for mitigating the impacts of heavy metal pollution and improving soil and plant health.

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Aquaponic Production of Ornamental Koi Carp (*Cyprinus carpio* Linn.) and Lettuce (*Lactuca sativa*) in Comparison with Traditional Fish Culture and Hydroponics System

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***Abstract*:** The study was conducted for comparative analysis of the production of ornamental fish, koi carp (*Cyprinus carpio* Linn.) and lettuce (*Lactuca sativa*) in aquaponics and traditional culture system. The experimental fish were stocked at three stocking densities, i.e., 20 m^{-3} (SD1), 30 m^{-3} (SD2) and 40 m^{-3} (SD3) in circular cemented tanks (10m^{-3}) of the aquaculture unit and lettuce were planted (plant to plant spacing of 12 cm) in the hydroponics unit (HM) of automated aquaponics system. For comparison with the traditional system, koi carp were stocked in cemented tank of equal size (10m^{-3}) at a standard stocking density of 2 m^{-3} and lettuce was planted as per standard protocol i.e. plant to plant space of 30 cm in outdoor conditions in soil bed traditional system (SM) The water quality parameters in both aquaponics and traditional tanks remained in optimum range for fish culture along with >95% of nutrient removal by lettuce. The survival (%) of fish was maximum in control (93.33%) followed by SD3, SD1 and SD2 . The final total body length and body weight was significantly higher in control, but the average fish yield (kg m^{-3}) was significantly higher in all aquaponic tanks, with the maximum yield of 3.73 kg m^{-3} (9.56 times) in SD3 (40 m^{-3}). The lettuce yield (32.2 q $acre^{-1}$) was 1.15 times higher in the hydroponic unit, with significantly higher pigment content and insignificant differences for nutrient content except fibre.

***Keywords*:** Aquaponics, Koi carp, Lettuce, Hydroponics, Leafy vegetables

The depletion of water resources and increased water pollution has become a major threat throughout the world, especially in developing countries, due to rapidly progressing agricultural, aquaculture and industrial activities. In addition to this, lack of adequate wastewater treatment further acts as a limiting factor for the development of all these sectors (Morrison et al 2009). Since the last two decades, aquaculture has made enormous contribution towards livelihood/employment generation and food/nutritional security around the world. The country's total fisheries production was 17.545 million metric tonnes (MMT) during 2022-23 with a contribution to the world fish production (Handbook on Fisheries Statistics 2023). With this growth, the aquaculture sector is being looked forward to fill the gap, as the marine resources are already being overexploited and are facing many ecological imbalances.

For taking up traditional aquaculture, a large volume of water and land is required, and scarcity/limited availability of these two resources are the major challenges (FAO 2022) for expansion of inland aquaculture. Additionally, surplus organic waste in the form of ammonia, nitrate and phosphate is being added in aquaculture waste water and finally in natural water bodies leading to water pollution. Therefore, it is essential to manage the heavy nutrient load of aquaculture waste waters, so that receiving water bodies can be protected from eutrophication for potential reuse of water (Endut et al 2009). Further, intensification of aquaculture farming with more advent techniques along with diversification of economically important species is considered one of the best way to achieve the goal of sustainable development of aquaculture sector (FAO 2022). Among intensive aquaculture technologies, aquaponics, is a closed loop system, in which the wastewater from fish farming is purified by the plants and returned to the fish production system. Thus, the cost of purification of water is reduced and profit margin increases significantly as the excreta from farming fish and other aquatic organisms is used as fertilizer for plants in a hydroponic system (Sas-Paszt et al 2023). Moreover, this synergestic combination of two systems, i.e., aquaculture and hydroponics (soilless agriculture system) is a sustainable arrangement with limited water and land (10-12% as compared to traditional practices) requirement (Shete et al 2016).

Punjab, one of the progressive state in North-Western

India, produced about 1.85 lakh tonnes of fish production (major contribution from freshwater carps) during 2022-23 (Handbook on Fisheries Statistics 2023). New initiatives has been taken w.r.to standardization of intensive aquaculture technologies like re-circulatory aquaculture system (RAS), biofloc aquaculture system and aquaponics in agroclimatic conditions of the region. Preliminary trials were conducted during 2020-21 to explore the possibility of combining fish with different crops/vegetables in the said system. In line with this, the present study was executed to optimize the stocking density of koi carp, one of the widely cultured ornamental fish throughout the world including India, in combination with lettuce during the winter season.

MATERIAL AND METHODS

Experimental layout: The experimental study (3 months) was conducted in an automated aquaponics unit (175 m^2) with aquaculture unit having 3 tanks (75 m^2) and hydroponic unit (100 m^2) at the Instructional cum Research Farm, College of Fisheries, GADVASU, Ludhiana. Koi carp fingerlings were stocked at three stocking densities in aquaculture unit and lettuce was planted in hydroponics (HM) unit. For comparison with the traditional system, koi carp fingerlings were stocked in cemented tanks (triplicate) at a standard stocking rate and lettuce was planted in outdoor conditions in a traditional soil bed (SM) system in completely randomized design (Table 1).

Water quality: Water quality parameters viz.; Temperature, pH, Dissolved Oxygen (DO), total alkalinity (TA), total hardness (TH), ammonia (NH_3-N), nitrite (NO_2^--N), nitrate (NO_3^--N) and ortho-phosphate (PO_4^{3-}-P) were analyzed as per standard methods of APHA (2012) every fortnight throughout the experimental period in both control and experimental tanks.

Nutrient removal (%): The nutrient removal (%) of water in terms of NH_3-N, NO_3^--N and PO_4^{3}-P in water collected from hydroponics unit was studied at fortnightly intervals.

Fish growth: Fish growth was observed at monthly intervals in terms of total body length, body weight and growth parameters in terms of average total length gain (TLG), average net weight gain (NWG), yield (Kg m^{-3}), specific growth rate (SGR), condition factor (K), feed conversion ratio (FCR) and survival (%) were calculated after the completion of experiment.

Lettuce growth, pigment analysis and nutrient composition: Lettuce growth was assessed in terms of total plant height and root length at monthly interval. The plant height increase (PHI), root length increase (RLI), yield (Kg m^{-2}) and pigment content (chlorophyll a, chlorophyll b, total chlorophyll and carotenoids) calculated/analyzed after completion of experiment. Nutrient composition (%) in terms of protein, fat, ash, carbohydrates and fiber *was analyzed (AOAC 2007).*

Statistical analysis: The data was analyzed by software statistical package CPCS-1 (Cheema and Singh 1991).

RESULTS AND DISCUSSION

Water quality: The water quality parameters viz. water temperature pH, DO, TA, TH, NH_3-N, NO_2^- -N, NO_3^--N) and PO_4^{3-}-P of control and experimental tanks remained in

Table 1. Details of experimental layout & design

Particulars	Details
Preparation of experimental & control tanks	• Before stocking of fish, experimental and control tanks were completely sun dried (10 days) for disinfection, which were further disinfected with limestone applied @ 300kg/ha. Tube well water was used for filling and maintaining the water in the experimental and control tanks. After one week of liming and filling of water, the water quality parameters of all the tanks were analyzed before stocking the fish.
Tank capacity & water volume	• Aquaponics Tanks Circular cemented & Circular) – 11m^3, with water volume of 10,000 liters • Control tanks (Rectangular cemented & rectangular – 10m^3)
Fish acclimatization	• 10-15 days under indoor conditions (fed *Ad libitum* with commercial diet)
Fish stocking density (SD)	• Experimental stocking densities (SD) – (3) i.e. 20m^{-3} (SD1), 30m^{-3} (SD2), 40m^{-3} (SD3) • Control (C) Stocking density - 2m^{-3}
Fish Size	• Average total body length 3.39±0.06 cm • Av. body weight 3.32±0.06 g
Fish feeding	• 5% of fish body weight, twice daily (10:00 and 16:00 h). Amount of feed was adjusted after each sampling (monthly) according to increase in fish weight
Crop plantation	• Plantation of Lettuce (*Lactuca sativa*) procured from local nursery of Ludhiana following completely randomized design. • Plant to plant space - 12 cm, planted in eight stands [9 pipes having 29 cups each (24 cups planted) in one stand] in hydroponics (HM) unit - (Vertical Farming). Water from aquaculture units was circulated into the hydroponic unit at fixed intervals through a biological filter, resulting in nutrient uptake by the lettuce plants • Plant to plant space - 30 cm, planted in 100 m^2 plot area with 8 beds in traditional soil bed (SM) system - (horizontal farming). Standard management practices were followed

optimum range (Table 2) for koi carp (*C. carpio*) with significant higher pH and significant lower values for NH_3-N, NO_3^--N and PO_4^{3}-P in control as compared to all the treatments. The values for water quality parameters remained in optimum range for fish culture and are in agreement with the previous studies by different researchers (Da Silva Cerozi and Fitzsimmons 2016, Nuwansi et al 2017 and Nuwansi et al 2020).

Nutrient removal (%): During experimental period, the nutrient removal (%) in terms of NH_3-N, NO_3^--N and PO_4^{3}-P (Table 3) revealed that with the progress of experiment, nutrient removal (%) increased with maximum removal of NH_3 N (98.22%) followed by NO_3^--N (97.53%) and PO_4^{3}-P (96.41%). Lin et al (2002) reported 86-98% removal of ammonium nitrogen (NH_4^+-N) from constructed wetlands system receiving aquaculture waste water. Endut et al (2009) found total phosphorus removal rates of 43 to 53% in aquaponic systems, lesser than observed in present experiment.

Fish survival and growth: Fish survival (%) in C, SD1, SD2 and SD3 after completion of experiment was 93.33, 82.00, 78.33 and 83.25, respectively. Significantly higher fish survival (%) was observed in C as compared to all the treatments (Table 4).

At the completion of the experiment, treatment with low stocking density (C) resulted in the higher fish growth. Furthermore, there was a negative correlation between the stocking density and length and/or weight increase of the fish. Similar findings were observed in terms of impact of increasing stocking density on the growth and survival rate of different fish species in different aquaculture systems (Wang et al 2017, Haridas et al 2017, Nuwansi et al 2021) by previous researchers. The biomass of Koi carp significantly increased with increasing stocking density of fish. At the end of experimental period, the average yield (kgm^{-3}) was significantly higher in all the treatments, with the maximum yield (9.417 times) recorded in SD3 followed by SD2, SD1 and C. The results in terms of total fish biomass/yield coincide with stocking density of fish. The findings of the study are consistent with those of Nuwansi et al. (2021) for Koi carp (*C. carpio* var. koi) in aquaponic system. Feed efficiency in terms of FCR was significantly higher (in all aquaponic treatments with the maximum 4.24 in SD2 followed by SD1, SD3 and control (2.85). Previous studies also revealed higher values for FCR (Shete et al 2013, Hussain et al 2014, Nuwansi et al 2020, Nuwansi et al 2021) for Koi carp in aquaponic systems.

Table 2. Mean water quality parameters in control and treatments during the experimental period

Parameters	C	SD1	SD2	SD3
Temperature (^{o}C)	18.93^{a}	18.61^{a}	18.59^{a}	18.58^{a}
pH	8.45^{a}	7.75^{b}	7.73^{b}	7.75^{b}
D.O. (mg l^{-1})	8.52^{b}	9.26^{ab}	9.32^{a}	9.38^{a}
TA ($CaCO_3$ mgl^{-1})	172.57^{a}	173.43^{a}	174.28^{a}	174.48^{a}
TH ($CaCO_3$ mgl^{-1})	187.71^{a}	185.33^{a}	184.62^{a}	184.95^{a}
NH_3-N (mgl^{-1})	0.044^{b}	0.194^{a}	0.197^{a}	0.184^{a}
NO_2^--N (mgl^{-1})	0.022^{a}	0.044^{a}	0.044^{a}	0.044^{a}
NO_3^--N (mgl^{-1})	0.331^{b}	2.035^{a}	2.037^{a}	2.030^{a}
PO_4^{3}-P (mgl^{-1})	0.047^{b}	0.86^{a}	0.861^{a}	0.862^{a}

Values with same superscript in row do not differ significantly ($p \leq 0.05$)

Table 3. Nutrient removal in water collected from hydroponics unit (%)

Nutrient removal (%)	Number of days			
	15	45	75	90
Ammonia-N	86.2	91.72	97.23	98.22
Nitrate-N	65.45	86.07	96.34	97.53
Ortho-phosphate	66.38	79.99	94.04	96.41

Lettuce growth: Lettuce growth in terms of plant height (cm) and plant root length (cm) was significantly higher in HM as compared to SM (Table 5). Plant height and root length increase (%) in HM was 1.42 and 1.28 times higher as compared to SM. Similarly, significantly ($P \leq 0.05$) higher (1.15 times) total yield/biomass (32.20 Qt $acre^{-1}$) was in HM as compared to SM (27.90 Qt $acre^{-1}$). Sabwa et al (2022) also revealed similar results in terms of biomass of lettuce and root length in aquaponics system. Purwandari et al (2017) reported that romaine lettuce grown in hydroponic system was characterized by better growth compared to plants grown in an aquaponic system fed only with wastewater coming from giant gourami (*Osphronemus goramy*) culture system. Hairani et al (2022), observed that among three plants i.e. kailan (*Brassica oleracea L.*), lettuce (*Lactuca sativa L.*) and pakcoy (*Brassica rapa L.*), lettuce showed best growth in combination with striped catfish (*Pangasianodon hypophthalmus*) in aquaponic system, due to presence of maximum number of leaves with wider leaf width. However, contrary to this, Rana et al (2018) revealed 1.14 times higher lettuce growth in traditional soil beds as compared to aquaponics grown crop along with other growth parameters like plant height, leaf number, and plant and root weight. The aquaponics grown lettuce showed significantly higher yield compared to soil based system, and is attributed to availability of nutrients from aquaponic fish tanks through water recirculation and excessive water nutrients uptake by the lettuce in the hydroponic unit.

Pigment analysis: The significantly higher pigment content i.e. chlorophyll a, chlorophyll b, total chlorophyll and carotenoid content (mg g^{-1}) was observed in lettuce grown in

Table 4. Comparative growth of koi carp in control and experimental tanks

Parameters	C	SD1	SD2	SD3
Average initial body length (cm)	3.35[a]	3.42[a]	3.43[a]	3.35[a]
Average final body length (cm)	11.35[a]	9.54[c]	9.75[c]	10.45[b]
TLG (cm)	7.99[a]	6.12[c]	6.32[c]	7.11[b]
Average initial body weight (g)	3.27[a]	3.33[a]	3.33[a]	3.33[a]
Average final body weight (g)	21.20[a]	10.53[b]	10.80[b]	11.20[b]
NWG (g)	17.93[a]	7.20[b]	7.47[b]	7.87[b]
Fish biomass (kg m^{-3}) (Av. Yield)	0.396[d]	1.727[c]	2.538[b]	3.729[a]
SGR (%)	2.08[a]	1.28[b]	1.31[b]	1.35[b]
Condition factor (K)	1.46[a]	1.22[b]	1.16[bc]	0.98[c]
FCR	2.85[c]	4.10[a]	4.24[a]	3.87[b]
Survival (%)	93.33[a]	82.00[b]	78.33[c]	83.25[b]

* SD = Stocking Density, C = 2 m^{-3}, SD1= 20 m^{-3}, SD2 = 30 m^{-3}, SD3= 40 m^{-3}
Values with same superscript (a, b,…..d) in row do not differ significantly ($p \leq 0.05$)
TLG-Total Length Gain; NWG- Net Weight Gain; SGR- Specific Growth Rate; FCR- Feed Conversion Ratio

Table 5. Comparative growth and pigment content of lettuce in SM and HM

Growth parameters	SM	HM	CD[*] (=0.05)
IPH (cm)	7.51	7.32	NS[**]
PH at 30 DAT (cm)	13.22	19.45	3.80
PH at 60 DAT (cm)	16.8	20.37	1.96
PH at 90 DAT (cm)	17.4	24.17 (1.39)	2.39
PHI (%)	2.32	3.30 (1.42)	-
IRL (cm)	3.36	3.46	NS
FRL (cm)	10.39	32.77 (3.15)	3.38
RLI (%)	20.13	25.85 (1.28)	-
Yield (Qt $acre^{-1}$)[#]	27.90	32.20 (1.15)	NS
Yield (cup^{-1} or $plant^{-1}$)	485.27	632.78 (1.30)	79.53
Chlorophyll a (mg g^{-1})	4.64	5.34	0.39
Chlorophyll b (mg g^{-1})	2.97	3.62	0.30
Total chlorophyll (mg g^{-1})	2.60	3.14	0.11
Carotenoids (mg g^{-1})	3.53	3.89	0.29

Values in parentheses indicate change over control
[#]three cuttings of lettuce during 3 month experimental period in all SM and HM
IPH/FPH – Initial/Final Plant Height, PHI – Plant Height Increase, IRL/FRL – Initial/Final Root Length, RLI – Root Length Increase, DAT –Days After Transplanting

HM as compared to SM (1.15, 1.22, 1.21 and 1.10 times higher, respectively) (Table 5). Rambe (2013) mentioned that leaf width is conducive to photosynthesis due to the presence of chlorophyll, because of which plants can independently prepare their own food for their growth. Therefore, more the number of leaves, more space for photosynthesis and better plant growth. Higher pigment content in HM is indicative of extra leaf width and more number of leaves. Coronel et al (2008), also observed that total chlorophyll content was 1.09 times greater in the lettuce grown hydroponically as compared to traditionally grown lettuce. Sabwa et al. (2022) too reported higher total chlorophyll content (0.019-0.56 ugl^{-1}) in aquaponics grown lettuce.

Table 6. Quality of lettuce in different treatments after completion of experiment (%)

Parameter (%)	Lettuce		P value
	SM	HM	
Protein	1.39±0.23	1.41±0.17	0.94
Fat	0.30±0.02	0.26±0.00	1.12
Carbohydrate	1.35±0.41	1.08±0.04	0.54
Ash	1.63±0.03	1.51±0.20	0.59
Moisture	93.33±0.29	94.00±0.12	0.10
Fiber	1.98±0.03	1.72±0.03	0.00

p-value 0.05 or less indicate significant difference

Nutrient composition of lettuce: After completion of experiment, quality (%) of lettuce in terms of proteins, fat, carbohydrates, ash, fiber and moisture, was estimated for each treatment and control. The differences for nutrient composition among treatments and control were insignificant except fiber (Table 6).

CONCLUSION

The overall results indicated the potential of aquaponic technology with higher fish productivity (over 9 times) and lettuce biomass (15%) with improved pigment content. The synergistic combination of Koi carp and lettuce in aquaponics system with encouraging results is attributed to improved water quality maintained in the aquaculture tanks of aquaponic system for fish through water recirculation and availability of copius amount/uptake of nutrients by the lettuce in the hydroponic unit, as compared to traditional soil bed system.

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AUTHOR CONTRIBUTION

Khushvir Singh – Conducted the experiment, analyzed the data and manuscript writing, Vaneet Inder Kaur – Conceived the idea and critical evaluation of data and editing of manuscript, Meera D. Ansal – Designing of experiment and evaluation of results, Dilpreet Talwar – Helped in maintenance of vegetable crops in hydroponic unit, Abhishek Srivastava - Helped in maintenance of fish in aquaponics unit, Kulbir Singh – Helped in overall maintenance of hydroponic unit.

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Nest Site Selection and Habitat Preference of Baya Weaver *Ploceus philippinus* in Agricultural Landscape

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***Abstract*:** Study on nest site selection and habitat preferences of Baya Weaver (*Ploceus philippinus*) was carried out in the breeding season of 2018 to 2020 in three districts namely Ludhiana, Rupnagar and Ferozepur. Three sites per district were selected and a total of nine nesting colonies were studied. A total of 298, 312 and 240 nests were recorded at selected locations during breeding season of 2018, 2019 and 2020 respectively. Maximum number of nesting colonies were 77.77% on date palm (*Phoenix dactylifera*) followed by 11.11% each on fishtail palm (*Caryota Urens*) and royal palm (*Roystonea regia*). The 66.66% of them were located near human habitations, 44.44 % within the houses/building premises and 22.22% were within the villages. The 33.3 and 77.73% were located in the agricultural fields and in vicinity of water bodies respectively. Positive correlation of distance from agricultural fields, water body and different species of palm trees with number of nests as well as with population number showed the significance of these habitat features for nest site selection of Baya Weaver.

***Keywords*:** Agricultural landscape, Baya Weaver, Habitat, Nest site selection, Palm, Water bodies

India is a home to 1263 bird species including four weaver species belonging to family Ploceidae, out of the 124 weaver species recorded worldwide (Hoyo et al 2016, Parveen et al 2016). Baya Weaver (*Ploceus philippinus* Linnaeus 1766) is familiar throughout the Indian subcontinent and the adjoining countries of Pakistan, Bangladesh, Thailand Malaysia and Sri Lanka (Ali and Ripley 1983). Baya Weaver is a colony nester bird; workers had recorded the nesting colonies of Baya Weaver on thorny plants (Raju 2009). Different workers had recorded baya weaver preferring palm trees as their nesting sites on the west coast of India. Borges et al (2002) observed diverse types of nesting sites including eucalyptus trees were recorded. Raju (2009) had noted the use of leaves of *Cycas sphaerica* for nest construction by baya weaver near Tirumala Hills. Sohi and Kler (2017) had observed natural and man-made materials used by different avian species including baya weaver for nesting in Punjab. There was lack of information on the population and preferred nesting sites of baya weaver in Punjab from last 40 years. Keeping that lacuna in consideration, work on nest site selection and habitat preferences for nesting of Baya Weaver was undertaken.

MATERIAL AND METHODS

The present study was carried out during the breeding season of 2018 to 2020 in three districts of Punjab State namely Ludhiana, Rupnagar and Ferozepur termed. Data was taken on nest site selection and habitat preferences of baya weaver (*Ploceus philippinus*) at nine selected sites in Baranhara (nesting colony I), Raghunath enclave (nesting colony II) and Rattan (nesting colony III) falling in district Ludhiana; Fatehpur (nesting colony IV), Mukarabpur (nesting colony V) and Manjitpur (nesting colony VI) in district Rupnagar; village Haraj (nesting colony VII), Wan (nesting colony VIII) and Toot (nesting colony IX) in district Ferozepur. Point count method was followed to observe the Baya Weaver's population and habitat preferences for nesting colonies (Verner 1985). Observations were made on weekly basis in morning between 6:00 am to 8:00 am in summers and between 7:00 am to 9:00 am in winters. For statistical analysis, correlation was carried out using SPSS v 16.0.

RESULTS AND DISCUSSION

Pre-survey was carried out in 16 villages of three districts as mentioned before. Nesting colony I, II and III were located on a Fishtail Palm *Caryota Urens* (9.75 m tree height) in residential house, Date Palm *Phoenix dactylifera* (7.62 m tree height) in residential house and on Royal Palm Roystonea regia (8.53 m of tree height) situated in religious place. Distance to the crop fields and water body was highest for colony I followed by II. Distance to crop fields was least in case of colony III (Table 3). Nesting colonies IV, V and VI were observed on the Date Palm of tree heights ranging from 10.36 to 13.10m (Fig. 1, Table 1). Nesting colonies VII, VIII and IX of baya weaver were located on date palm of varying heights. Nesting colonies of baya weaver were highest on date palm followed by fishtail palm and royal palm. In absence of preferred date palm at Baranhara and Rattan, colonies were noted on fishtail palm and royal palm (Table 1). Six colonies were present near human habitation and seven colonies were within the vicinity of water body (Fig. 1). Trees selected for nesting colony I, VII, VIII and IX were solitary trees and nesting colony III was found on trees planted in a row. The nesting colonies IV and V were found on tree groups.

In breeding season of 2018, 2019 and 2020, a total of 298, 312 and 240 nests were recorded. In breeding season 2018, 136 nests were recorded out of which 58 were noted in nesting colony I, 43 in nesting colony II and 35 in nesting colony III during breeding season of 2018. At LI, 46, 30 and 26 nests were recorded active out of 58, 43 and 35 nests in nesting colony I, II and III. Total number of nests 28, 38 and 30 were observed in the nesting colony IV, V and VI. Out of total 96 nests, 71 were recorded active while 25 were recorded abandoned. During the breeding season of 2018, the nesting colonies were extended to adjoining Date Palm trees. A number of 21, 18 and 27 nests (66 in total) were recorded in nesting colony VII, VIII and IX during breeding season of 2018. Active nests 53 and abandoned nests 13 out of total 66 nests were noted (Table 1). Maximum population number of 340 was recorded at nesting colony I and minimum population number of 111 was recorded at nesting colony VII. During present study, nesting colonies were observed on the trees with height ranging from 25-43 ft. Selection of higher tree height seemed to make nests inaccessible to predators thus giving survival advantage.

In 2019, maximum of 72 nests were noted in nesting colony I wherein 59 nests were active and 13 nests were abandoned. Thirty-seven nests were noted in nesting colony II out of which 28 nests were active and 9 were abandoned. A total of 32 active nests were recorded out of 46 nests in nesting colony III. Thirty nests were observed on main nesting tree whereas 2-10 nests were extended to other palm trees present in the row adjoining to the main nesting tree during the breeding season of 2019 at III. During breeding season of 2019, 17 nests were recorded in nesting colony IV. A total of 33 and 19 nests were recorded in nesting colony V and VI in which colonies were extended to adjoining date palm trees. A total of 80 nests were located during breeding season of 2019, out of which 19 and 41 nests were noted in nesting colony VII and IX. In nesting colony VIII, 28 nests were recorded in which eight nests were extended to the adjoining Dhek tree *Melia azedarach* (Table 1).

In 2020, there were 51 active nests out of total 64 nests recorded in nesting colony I. Thirty-nine nests were observed in nesting colony II out of which 29 nests were active. A total of 27 active nests out of total of 43 nests were recorded in nesting colony III. A total of 19 nests were noted and active nests were 14 in nesting colony IV. A total of 30 and 20 nests were recorded in nesting colony V and VI. A total of 79 nests were located during breeding season of 2020, out of which 16, 26 and 37 nests were noted in nesting colonies VII, IX and IX. In nesting colony VII, there were 16 total nests having13 active and 3 abandoned nests. In nesting colony VIII and IX, 19 and 28 active nests out of total 26 and 37 nests were recorded respectively. Baya weaver was observed using palm fronds at nesting colonies constructed at different palm trees. Broad strand leaves of sorghum *bicolor* crop were utilized in nesting colonies III, IV, V, VI, VII, VIII and IX. Leaves of pearl millet *Pennisetum glaucum* were also observed in construction of nesting colonies V, VI and VII. Thin strands from grasses and the dry strands from the heaps of husk

Table 1. Nesting tree types, active nests and population number of Baya Weaver Birds

Nesting colonies	Nesting tree	Tree height (m)	Number of nests during different breeding seasons						Population number in		
			2018		2019		2020		2018	2019	2020
			Total	Active	Total	Active	Total	Active			
Baranhara (I)	Fishtail Palm	9.75	58	46	72	59	64	51	340	354	349
Raghunath enclave (II)	Date Palm	7.62	43	30	37	28	39	29	244	180	205
Rattan (III)	Royal Palm	8.53	35	26	46	32	43	27	214	275	223
Fatehpur (IV)	Date palm	10.36	28	22	17	13	19	14	173	139	142
Mukarabpur (V)	Date palm	13.10	38	24	33	25	30	21	273	256	238
Manjitpur (VI)	Date palm	12.80	30	25	19	16	20	17	195	154	157
Haraj (VII)	Date palm	13.10	21	17	19	17	16	13	111	168	141
Wan (VIII)	Date palm	11.27	18	15	28	20	26	19	261	193	206
Toot (IX)	Date palm	12.19	27	21	41	30	37	28	128	254	248

were also observed used in the nest formation at nesting colonies I, IV, VI, VII and VIII. Males predominantly formed the nests; multiple trips from crop fields to nests were carried out. On an average, 2-4 minutes were spent in weaving nests between consecutive trips. Parent birds were noted using mud blebs as nesting material at five colonies while it was not noted at colonies II and V might be due to the presence of cemented border walls at water bodies (Table 2). Proximity of colonies to water bodies and agricultural fields seemed to reduce not only energy expenditure but also time spent in hunting food for nestlings. Females were observed collecting and plastering mud blebs on the inner wall of brood chamber at nesting colonies I, III, IV, VII and VIII. Cushioning of brood chamber was done using feathers collected by females at nesting colonies I and II.

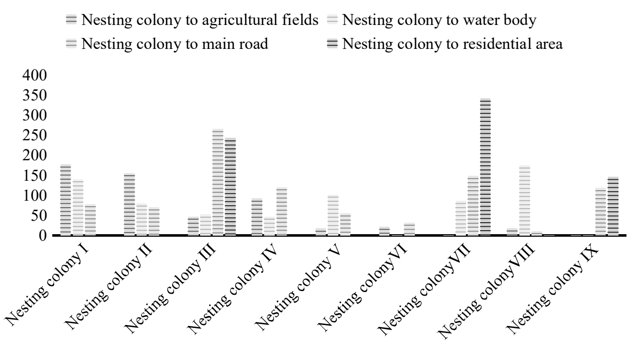

Fig. 1. Distance of nesting colonies to agricultural field, water body, main road and residential area (in meters)

Table 2. Nesting materials used at different nesting colonies

Nesting material types	Tree/crop used	Nesting Colonies
Broad strand leaves	Fishtail Palm	I
	Royal Palm	III
	Sorghum	III, IV, V, VI, VII, VIII, IX
	Pearl Millet	V, VI, VII
	Date Palm	II, IV, V, VI, VIII
Thin strands	Grasses, Weeds	I, IV, VII, VIII
	Heaps of husk	IV, VI
Mud blebs	Soil from fields, pond sides	I, III, IV, VII, VIII
Feathers	-	I, II

Dhindsa (1980) had recorded 45 colonies, out of which 20 colonies were present on small trees, bushes and other vegetation growing over abandoned wells. The most preferred trees were Babool *Acacia arabica* having 88 colonies followed by Indian date *Phoenix sylvestris* having 56 and Ber *Zizyphus jujube* having 47 colonies. Borges et al (2002) had stated affinity of Baya Weaver towards stout and tall trees because of strength attained by trees due to diameter at breast height (DBH) and safety of nestlings from predators. Workers had recorded the heights of trees having nests viz. seven to eight meter in Assam (Yashmita-Ulman et al 2017), 10m in Tamil Nadu (Ali 2009). The studied sites had experienced decline in the nests in heronries of Baya Weaver (Roshnath et al 2013, 2014).

Sohi and Kler (2017) found pendant nests of baya weaver on date palm, ber and pear trees; Baya weaver used grass blades, leaves, fibres, strips of palm fronds and cloth pieces as nesting materials. Kabir (2018) had the collection of nesting material by Baya Weaver from coconut trees and mature leaves of Palm trees. Pandian and Ahimaz (2018) had recorded 4273 nests of various stages in 52 villages in Viluppuram district of Tamil Nadu. Yasmita-Ulman et al (2017) had recorded *A. catechu*, *P. sylvasticus*, *C. nucifera* and *B. flabellifer* as potential host trees for the nesting of *P. philippinus*. Achegawe et al (2016) recorded the average tree height of nesting tree was 4.5m and nests were present on marginal parts of trees for their safety from predators. The site selection of colonial nesting can also reduce predation

Table 3. Habitat features including vegetation and sub habitat types around nesting colonies

Nesting colonies	Vegetation structure around nesting colonies			Habitat structure (distance to sub habitats)
	Number of trees	Number of crops	Number of weeds	
I	13	3	4	Agriculture fields> Water body> Main Road
II	12	-	3	Agriculture fields> Water body> Main Road
III	30	4	-	Residential area> Main Road> Agriculture fields> Water body
IV	9	2	4	Main road> Agriculture fields> Residential area> Water body
V	19	12	4	Agriculture fields> Water body> Main Road
VI	10	6	1	Main road> Agriculture fields
VII	9	4	4	Residential area> Main Road> Agriculture Water body
VIII	8	4	3	Water body> Agriculture fields> Main Road
IX	5	4	-	Residential area> Main Road

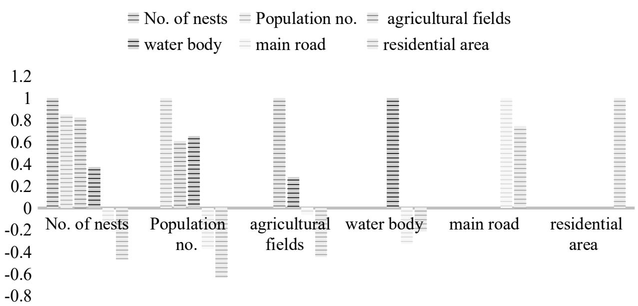

Fig. 2. Correlation of number of nests and population number of Baya Weaver with distance to the habitat structures during 2018

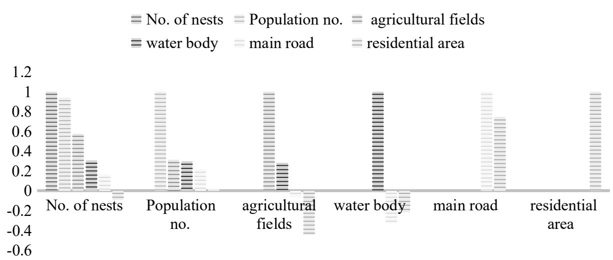

Fig. 3. Correlation of number of nests and population number of Baya Weaver with distance to the habitat structures during 2019

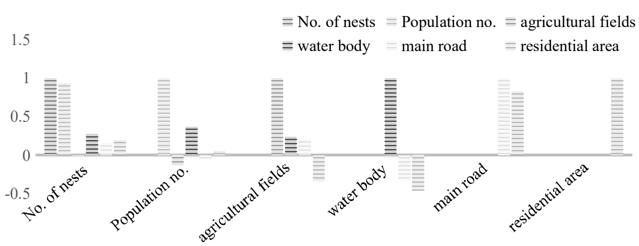

Fig. 4. Correlation of number of nests and population number of Baya Weaver with distance to the habitat structures during 2020

pressure and increase foraging efficiency (Kasprzykowski 2008). The positive correlation of avian diversity with rural ponds was observed in earlier studies (Sekhon et al 2023, Sidhu et al 2021). Statistical analysis had shown that distance from residential area is negatively correlated with population number during the year 2018 and positively correlated with population number during the year 2019 which showed the increase in population of baya weaver within the vicinity of residential premises during the breeding season of 2019 (Fig. 2, 3). Distance from agricultural fields, waterbody and main road are positively correlated with number of nests and population number of Baya Weaver that showed the importance of these habitat structures for the nesting and breeding of Baya Weaver (Fig. 3 and 4). Tree species abundance varied considerably (5-30), colony III having the highest number of trees in vicinity, while colony IX exhibited the least. Six colonies (III, V, VI, VII, VIII and IX) suggested potential dependence on crops for food and nesting materials. Four colonies (I, IV, V, VII) had substantial weed species in surrounding habitats indicating potential foraging grounds, while two colonies (III and IX) lacked it in their vicinity (Table 3).

CONCLUSION

The nest site selection by baya weaver showed preference for date palm followed by fishtail palm and royal palm. Habitat features included proximity to water bodies, agricultural fields and preferred tree heights ranging from 25-43 ft. Nest site selection seemed to be determined by factors such as safety from predators, energy expenditure during foraging trips and time saving during nest building and nestling rearing. Current investigation provides valuable information regarding significance of Palm tree diversity and small water bodies in agricultural landscape which might increase the range of habitat or nest site selection of Baya Weaver and help in sustaining stable population numbers.

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Status and Impact of Wooded Patches in Semi-Urban Landscape on Avian Community Structure in Aligarh, Uttar Pradesh, India

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***Abstract*:** This short-term study is an effort to estimate density and diversity of birds in wooded patches present at the outskirts of Aligarh city. Point count method was used to determine the diversity and abundance of birds. The total of 40 points were laid through systematic random sampling and monitored in the morning hours. In total, 140 species were recorded, with Passeriformes as the most dominating order. Seven near threatened and three threatened species were recorded. Bird density was 60 birds/ha and large grey babbler had the highest density (18.72 birds/ha). Density was significantly positively correlated with the shrub height. In addition to with resident species, many winter/summer migrants and passage migrant birds were found during the study period. These small and scattered patches are important for wildlife coping with urbanization; therefore better management of these wooded patches is required for effective conservation.

***Keywords*:** Point count, Distance, Urbanization, Wooded patches, Density

Birds provide various ecosystem services and play important roles in our agroecosystems (Mariyappan et al . 2023). The flourishing bird population is essential for any stable ecosystem and their status indicates how well the ecosystems are functioning (Mariyappan et al 2023). Rapid urbanization is an emerging threat and it is having adverse effects on the diversity and abundance of birds and in turn, negatively affects ecosystem functioning. Urbanization has led to the conversion of natural habitats and farmlands into a series of different architectures which are heavily fragmented and have a high edge effect (Shochat et al 2006, Moller 2009). In this process, some wildlife species benefit and some are negatively affected (Devictor et al 2007, Akram et al 2015, Sahni & Kler 2023).

Urban green spaces such as parks and lawns etc. are vital for birds in urban areas but still, birds flourish in islets of natural habitats located in the vicinity of urban areas (Felappi et al 2020, Machar et al 2022). Most of the studies conducted in urban areas are usually focused on urban green spaces (Shochat et al 2006, Moller 2009, Prakash and Baldodia 2013, Rajashekara and Venkatesha 2015, Mukhopadhyay and Mazumdar 2019). These spaces only harbour those species that benefit from the urban environment and are better adapted to the changing environmental conditions (Moller 2009, Verma and Murmu 2015, Singh et al 2018).

The natural habitats located on the outskirts of cities provide more opportunities for those species that are not able to adapt to the urban environments and are more elusive, as these areas are comparatively less disturbed and less prone to the frequent changes that the city experiences (Rajashekara and Venkatesha 2015, Mukhopadhyay and Mazumdar 2019). These areas are important stopover points for locally migrating birds and provide shelter as well as variable food resources (Siddiqui et al 2019, Mazumdar and Khan 2020, Yashmita-Ulman 2022). Therefore, scientific information on the diversity and abundance of birds in these natural habitats located on the outskirts of cities is essential for the effective management of these areas.

Most of the natural vegetation of the Aligarh district is lost due to the conversion of natural areas into agricultural fields and human settlements. But few small isolated wooded patches of natural vegetation and plantations still existed in the district supporting various species of wildlife. Avian diversity of Aligarh is rich and varied and more than 150 species are reported from the district (Akram et al 2015, Siddiqui et al 2019, Mazumdar and Khan 2020). Each year many migratory birds visit the area as their wintering grounds and represent the ecological significance of the Aligarh region (Mazumder and Khan 2020). Therefore, this study is an attempt to find out avian density and diversity of these isolated wooded patches and to determine the vegetation parameters affecting density and diversity of birds.

MATERIAL AND METHODS

Site location: Aligarh district is located in the western part of Uttar Pradesh state of India and spread over an area of 3650 sq. km., from 27.5714° – 28.1798°N to 77.4756° – 78.6077° E (Fig. 1). A major part of the district is primarily under agriculture (Ali 2013). There are sparsely distributed wooded patches in the district having variable sizes from 6 ha to > 200 ha surrounded by agricultural lands. Major tree species found in these patches are *Vachellia nilotica*, *Prosopis cineraria, Azadirachta indica*, along with various alien invasive species such as *Prosopis juliflora*, *Lantana camara* etc. The study was carried out from February to May 2021. Identification of probable wooded patches was conducted with the help of Google Earth Pro. A total of 14 patches were identified but after a quick reconnaissance survey and ground truthing, nine sites were selected for further study. The area of these patches varies from 19.5 ha to 256 ha (Table 1). The criteria for the selection of patches were that patches must have intact and continuous vegetation in a minimum of ~20 ha, not be owned by a private person and must not be under any agricultural practices (Fig. 1).

Diversity and density: To determine the diversity and density of birds, point count method was used. Systematic random sampling was used to lay the points in the study area. The first point in the patch had been chosen randomly and then successive points were laid at every 300 m in a fixed direction. A total of 40 points were laid for monitoring of birds.

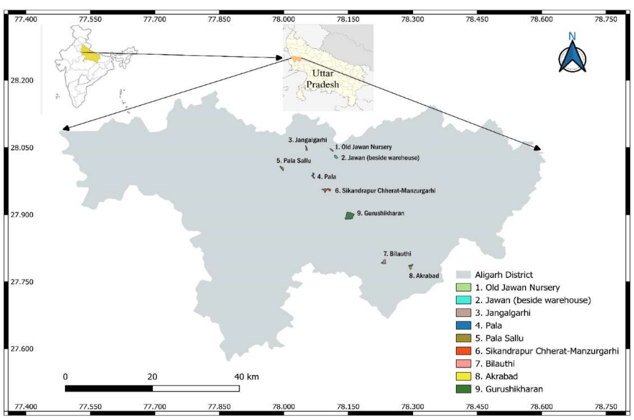

Fig. 1. Site location

The number of points in a particular patch was laid in proportion to its area. Each point was monitored four times for 15 minutes, making a total effort of 160 points. As birds are most active in the morning hours, all the monitoring was conducted in the early mornings. Variable radius point count monitoring protocol was used following Verner (1985) and Javed and Kaul (2002). No flying bird had been considered for an observation. Birds sighted outside the point count stations were recorded on a separate sheet for preparation of the checklist.

To quantify the vegetation on the point, number of trees was counted in a 20-meter circular plot. Plants having >30 cm GBH were considered as trees. An ocular estimation of canopy cover was also taken at each point. Visual obstruction technique via Robel Pole was used to measure shrub layer height. A pole with black and white 10 cm bands is used. The pole was placed at a fixed distance from a point, and then the last visible band number was recorded to estimate relative heights of shrub layer in all the patches.

Statistical analysis: PAST (paleontological statistics) statistical software was used to compute diversity indices for each point and then further for each patch after the data had been pooled. The density of birds was calculated in DISTANCE software (v_7.5). Multiple Covariate Distance Sampling (MCDS) was used using MCDS engine in Distance to estimate density after incorporating covariables such as tree density, canopy cover, shrub height, etc in the original dataset. Density estimation through MCDS engine gives more accurate results and better density figures (Marques et al 2007). Spearman's rank correlation was computed in PAST software to determine the correlation between bird density and various vegetation parameters.

RESULTS AND DISCUSSION

Species occurrence: Out of 140 bird species recorded during the study period, 71 species were recorded at point

Table 1. Wooded patches selected for the study

Patch No.	Patch name	Area (ha)	Major tree species
1	Old Jawan Nursery	19.5	*Cassia fistula, Holoptelea integrifolia, Magnifera indica* & *Vachellia nilotica*
2	Jawan Patch (beside Hitachi Warehouse)	34	*Prosopis juliflora*
3	Jangalgarhi	23.2	*Prosopis juliflora*
4	Pala	41.8	*Prosopis juliflora*
5	Pala Sallu Blackbuck Community Reserve	33.9	*Vachellia nilotica* & *Prosopis juliflora*
6	Sikandrapur Chherat–- Manzurgarhi	75.56	*Vachellia nilotica* & *Prosopis juliflora*
7	Bilauthi	54.7	*Prosopis juliflora*
8	Akrabad	43	*Vachellia nilotica* & *Prosopis juliflora*
9	Gurushikharan	256.26	*Vachellia nilotica* & *Prosopis juliflora*

stations and a total of 1785 individuals were observed belonging to 18 orders and 56 families. Passeriformes with 68 species was the most dominating order (48.6%) in the study area, while only two species each from three orders (1.43%) have been recorded (Table 2). Birds are usually better adapted to urban establishments than any other faunal group (Luniak 2004). Wooded patches situated outside the city environments are being used more extensively by the negatively affected species as a result these species are seldomly seen in the cities (Siddiqui et al 2019). These patches provide refuge to these species as they are being driven away from the city due to various developmental processes.

The number of bird species (140 species) recorded is close to the species recorded by Mazumdar and Khan (2020) (146 species) and higher than the other studies Akram et al (2015) (92 species); Siddiqui et al (2019) (63). Birds are an indicator of the health of any ecosystem (Wade et al 2014). The rich diversity of birds in the study area highlights how important these wooded patches are for the sustainance of birds and in turn overall health of various ecosystems (Wade et al 2014, Mariyappan et al 2023).

Seven recorded species are near threatened, two are vulnerable (Indian Spotted Eagle *Clanga hastata* & Sarus Crane *Grus antigone*) and one (Egyptian Vulture *Neophron percnopterus*) is endangered. Eurasian Collared Dove had the highest relative frequency (8.77%) while 16 species had only 0.13% as the lowest relative frequency (Table 3).The seven near-threatened and three threatened species recorded in the study area need immediate conservation focus (IUCN 2023). Regular assessment focused on these species will provide insights for their better management and survival. Egyptian vulture, in particular, is an endangered species (IUCN 2023), but their frequent recordings from the study area, either in the form of a single individual or in large flocks (recorded 23 individuals in a single flock), may indicate yet another success story for the revival of an endangered species in the study area (Singh and Gibson 2011, Kierulff et al 2012). Grimmett et al (2011) observed that many bird species recorded in the study are winter and summer migrants. Furthermore, some species are passage migrants and utilise these patches as their stopover points. All of these species utilise these patches for varying duration in different seasons of the year; indicating the importance of these small and scattered wooded patches for them.

Density and diversity of birds: Based on minimum AIC value, the Hazard Rate- Simple Polynomial model was selected to calculate the density of birds. After considering all the covariables, terrestrial birds' density was 60.63 birds/ha (Table 4). Highest density was recorded in Old Jawan Nursery patch with 235.21 birds/ha whereas lowest density in Jawan Patch (beside Hitachi warehouse) with 52.097 birds/ha. Bird density was is higher than Siddique et al (2019) with 36.82 birds/ha and Akram et al (2015) with 54.45 birds/ha but these studies have more focus on birds in urban areas of Aligarh district.

Further, the diversity of birds is more or less similar to the many studies conducted in nearby areas (Gupta et al 2009, Chopra et al 2012, Prakash and Baldodia 2013, Singh et al 2021). This indicates that the Aligarh region still holds importance for various species inhabiting these wooded patches and to the various migratory species that happen to visit this region annually. Density of birds and Shannon diversity index e of Old Jawan Nursery was highest in all the individual patches. This is because it holds the highest tree density and relatively high shrub height; these factors help in creating more available niches and hence greater density and diversity (Pigot et al 2016, Kaur and Kler 2019). Keeping this patch as a model, we can further enhance the carrying capacity of other patches, leading to greater avian density and diversity and also giving ideas for better management of such patches.

Large grey babbler have the highest density with 18.72 birds/ha, followed by Green Bee-eater (11.68 birds/ha) (Table 5) which was due to agroecosystems surrounding the

Table 2. Number and percentage of species in their respective orders

Order	No. of families	Percentage of species
Accipitriformes	1	7.14
Anseriformes	1	2.14
Bucerotiformes	2	1.43
Caprimulgiformes	2	1.43
Charadriiformes	5	5.71
Ciconiiformes	1	2.14
Columbiformes	1	5.00
Coraciiformes	3	2.86
Cuculiformes	1	2.86
Galliformes	1	1.43
Gruiformes	2	2.86
Passeriformes	26	48.57
Pelecaniformes	2	6.43
Piciformes	2	2.14
Podicipediformes	1	0.71
Psittaciformes	1	2.14
Strigiformes	2	2.86
Suliformes	2	2.14

Table 3. Bird species listed on points with their frequency of occurrence and relative frequency

Species	Scientific name	Frequency of occurrence	Relative frequency %
Indian Peafowl	*Pavo cristatus*	19	2.38
Grey Francolin	*Francolinus pondicerianus*	28	3.51
Rock Pigeon	*Columbia livia*	2	0.25
Oriental Turtle Dove	*Streptopelia orientalis*	12	1.50
Eurasian Collar Dove	*S. decaocto*	70	8.77
Red Collar Dove	*S. tranquebarica*	4	0.50
Spotted Dove	*Spilopelia suratensis*	3	0.38
Laughing Dove	*S. senegalensis*	61	7.64
Yellow-footed Green Pigeon	*Treron phoenicopterus*	21	2.63
Greator Coucal	*Centropus sinensis*	8	1.00
Asian Koel	*Eudynamys scolopaceus*	13	1.63
Common Hawk Cuckoo	*Hierococcyx varius*	5	0.63
Indian Cuckoo	*Cuculus micropterus*	1	0.13
Indian Thick-knee	*Burhinus indicus*	10	1.25
Red Wattled Lapwing	*Vanellus indicus*	9	1.13
Indian Pond Heron	*Ardeola grayii*	3	0.38
Red Naped Ibis	*Pseudibis papillosa*	1	0.13
Egyptian Vulture	*Neophron percnopterus*	2	0.25
Oriental Honey Buzzard	*Pernis ptilorhynchus*	1	0.13
Crested Serpent Eagle	*Spilornis cheela*	3	0.38
Black Kite	*Milvus migrans*	10	1.25
Spotted Owlet	*Athene brama*	9	1.13
Grey Hornbill	*Ocyceros birostris*	7	0.88
White Throated Kingfisher	*Halcyon smyrnensis*	4	0.50
Asian Green Bee-eater	*Merops orientalis*	67	8.40
Brown Headed Barbet	*Psilopogon zeylanicus*	1	0.13
Lesser Goldenback Woodpecker	*Dinopium benghalense*	4	0.50
Alexandrine Parakeet	*Psittacula eupatria*	2	0.25
Rose Ringed Parakeet	*P. krameri*	22	2.76
Plum Headed Parakeet	*P. cyanocephala*	1	0.13
Black Drongo	*Dicrurus macrocercus*	20	2.51
Ashy Drongo	*D. leucophaeus*	1	0.13
Isabelline Shrike	*Lanius isabellinus*	1	0.13
Bay Back Shrike	*L. vittatus*	1	0.13
Rufous Treepie	*Dendrocitta vagabunda*	37	4.64
House Crow	*Corvus splendens*	1	0.13
Large Billed Crow	*C. macrorhynchos*	11	1.38
Ashy Crowned Sparrow Lark	*Eremopterix griseus*	1	0.13
Crested Lark	*Galerida cristata*	2	0.25
Common Tailorbird	*Orthotomus sutorius*	8	1.00
Jungle Prinia	*Prinia sylvatica*	7	0.88
Ashy Prinia	*P. socialis*	23	2.88
Plain Prinia	*P. inornata*	1	0.13

Cont...

Table 3. Bird species listed on points with their frequency of occurrence and relative frequency

Species	Scientific name	Frequency of occurrence	Relative frequency %
Zitting Cisticola	*Cisticola juncidis*	1	0.13
Blyth's Reed Warbler	*Acrocephalus dumetorum*	17	2.13
Barn Swallow	*Hirundo rustica*	2	0.25
Red Vented Bulbul	*Pycnonotus cafer*	22	2.76
Red Whiskered Bulbul	*P. jocosus*	2	0.25
Hume's Leaf Warbler	*Phylloscopus humei*	1	0.13
Sulphur Bellied Warbler	*P. griseolus*	5	0.63
Common Chiffchaff	*P. collybita*	3	0.38
Greenish Warbler	*P. trochiloides*	1	0.13
Lesser White Throat	*Sylvia curruca*	30	3.76
Yellow Eyed Babbler	*Chrysomma sinense*	1	0.13
Indian White Eye	*Zosterops palpebrosus*	3	0.38
Jungle Babbler	*Argya striata*	24	3.01
Large Grey Babbler	*A. malcolmi*	45	5.64
Asian Pied Starling	*Gracupica contra*	13	1.63
Common Myna	*Acridotheres tristis*	12	1.50
Indian Robin	*Saxicoloides fulicatus*	11	1.38
Oriental Magpie Robin	*Copsychus saularis*	16	2.01
Red Breasted Flycatcher	*Ficedula parva*	7	0.88
Black Redstart	*Phoenicurus ochruros*	7	0.88
Pied Bushchat	*Saxicola caprata*	11	1.38
Purple Sunbird	*Cinnyris asiaticus*	21	2.63
Indian Silverbill	*Euodice malabarica*	5	0.63
Scaly Breasted Munia	*Lonchura punctulata*	1	0.13
Yellow Throated Sparrow	*Gymnoris xanthocollis*	7	0.88
Paddyfield Pipit	*Anthus rufulus*	4	0.50
Long Billed Pipit	*A. similis*	6	0.75
Tawny Pipit	*A. campestris*	3	0.38

Table 4. Bird density, diversity indices and number of species in different wooded patches of Aligarh district

Patch name	Density (Birds/ha)	% coef. of variation	No. of species	Evenness	Shannon (H) diversity	Simpson diversity	Margalef richness
Old Jawan Nursery	235.21	24.14	34	0.757	2.843	0.925	2.834
Jawan Patch (beside Hitachi Warehouse)	48.55	31.07	8	0.696	1.147	0.596	1.147
Jangalgarhi	58.47	34.31	15	0.699	1.726	0.751	1.726
Pala	52.47	24.38	21	0.698	1.904	0.792	1.904
Pala Sallu Blackbuck Community Reserve	99.74	26.05	15	0.755	2.018	0.831	2.018
Sikandrapur Chherat-Manzurgarhi	92.36	11.24	39	0.694	2.545	0.888	2.545
Bilauthi	54.52	19.47	29	0.664	2.093	0.826	2.093
Akrabad	60.56	29.90	13	0.762	1.557	0.734	1.557
Gurushikharan	53.60	18.10	38	0.731	2.120	0.830	2.120
Overall	60.63	9.19	71	0.715	2.028	0.806	2.028

wooded patches and adding to the fact that they remain in flocks that can go >20 in number (Brraich et al 2023). Crop fields are abundant in food resources for most of the year and LGB being an omnivorous species gains advantage of its diet variability (Puckett et al 2009). LGB flocks can have up to 40 individuals at one time, giving them an advantage over their potential predators as they lookout for each other with greater strength in numbers (Brraich et al 2023). With better utilization of available resources, their populations flourish and hence they are found with the highest density in the study area.

Correlation with vegetation parameters: Highest tree density was recorded in Old Jawan Nursery patch (131.3 trees/ha) while lowest was in Bilauthi patch (3.18 trees/ha). Similarly, highest canopy cover was in Jangalgarhi patch and lowest in Bilauthi. Shrub height in Sikandrapur Chherat-Manzurgarhi patch was highest while in Jawan patch (beside Hitachi Warehouse) recorded lowest shrub height (Table 6). Shrub height was significantly positively correlated with bird density. Although a positive correlation was recorded in bird density with tree density and canopy cover but differences were non-significant.

These wooded patches are important for the sustenance and survival of various species that are negatively affected by urbanization. These patches should be given more concern on how to conserve them and should be viewed more than just as an infertile land. Thriving species like LGB, Green Bee-eater, and Eurasian Collared Dove as well as near threatened and threatened species residing here show the vitality of these patches. For shy migratory birds, these patches are an abode and without these patches, their migration will be affected. The size of these patches also matters and no further encroachment should be allowed over them. These patches need to remain intact without any further fragmentation. In addition to birds, these patches also have a rich diversity of mammalian species and 11 species of mammals (Blackbuck *Antilope cervicapra*, Nilgai *Boselaphus tragocamelus*, Wild Pig *Sus scrofa*, Golden Jackal *Canis aureus*, Rhesus Macaque *Macaca mulatta*, Indian Hare *Lepus nigricollis*, Jungle Cat *Felis chaus*, Small Indian Mongoose *Herpestes auropunctatus*, Grey Mongoose *Herpestes edwardsii*, Five Striped Palm Squirrel *Funambulus pennantii* and Indian Flying Fox *Pteropus giganteus*) were recorded during the study. It also indicates the importance of these wooded patches as they also utilise these wooded patches in toto. More emphasis should be given on how to connect nearby patches so that there will be fewer road kills of wildlife present in the area. Studies conducted over mammalian communities will enhance the knowledge of their association with avian communities in the study area (Cook et al 2020). Few studies have been done in the district on mammals but their association and effect on avian communities is yet to be explored (Khan and Khan 2016, Ahamad et al 2021tc.). These broad studies will further

Table 5. Density of bird species having statistically significant observations individually

Species	Density (Birds/ha)	Per cent coef. of variation	95% confidence interval
Large Grey Babbler	18.72	23.47	11.82 – 29.64
Green Bee-eater	11.68	21.68	7.62 – 17.90
Lesser White Throat	9.03	21.41	5.92 – 13.77
Rufous Tree Pie	7.02	28.39	4.03 – 12.23
Laughing Dove	4.27	23.4	2.70 – 6.74
Eurasian Collared Dove	3.89	19.21	2.67 – 5.67

Table 6. Patch-wise vegetation parameters and other co-variables

Patch name	Tree density (per ha)	Canopy cover (%)	Shrub height (m)
Jawan (Old Nursery)	131.3	45	3.7
Jawan Patch (beside Hitachi Warehouse)	34.48	18.33	0.33
Jangalgarhi	106.1	68.33	0.47
Pala	77.59	48.75	0.65
Pala Sallu Blackbuck Community Reserve	39.79	31.67	1.8
Sikandrapur Chherat-Manzurgarhi	35.81	22.5	4.5
Bilauthi	3.18	1	2.6
Akrabad	35.81	27.5	1.45
Gurushikharan	85.15	49.5	2.56

help in the effective management and conservation of avian populations in the district.

CONCLUSION

Wooded patches situated at the outskirts of urban establishments provide refuge to the faunal species coping with the speed of urbanisation. Conservation and management of these patches may prove critical in ensuring the long-term conservation of biodiversity and maintaining healthy urban ecosystems.

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Assessment of Hazardous Effects of Lead on Growth Parameters of Soybean *(Glycine max* (L.) Merr.)

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Abstract: This study was designed to assessment the effects of different concentrations of heavy metal lead acetate (0, 200, 400, 600, 800, 1000 mg/kg) on growth attributes such as root shoot length, root shoot dry weight at pre, peak and post flowering stages of soybean (*Glycine max* (L.) Merr.) There was clear dose-response relationship between lead acetate concentration and the growth attributes of soybean plants. At 200 mg/kg there is no significant reduction but gradually with increased concentrations of lead acetate, there was a significant reduction in root and shoot length, as well as root and shoot dry weight, compared to the control group at all stages. The most pronounced effects were observed at 1000 mg/kg, indicating a dose-dependent toxicity of lead acetate on soybean plants. These findings highlight the importance of mitigating lead emissions and contamination to ensure agricultural productivity, environmental sustainability and public health.

Keywords: Heavy metal Pb, *Glycine max* (L.) Merr.), Soyabean, Growth parameter

Environmental contaminants due to speedup of anthropogenic activities affect nearly every aspect of the ecosystem. Among the contaminant, heavy metals (HMs) is the new emerging concern. Because the persistence bio-accumulative and harmfulness of its nature affect the plants and significantly diminish yield. (Hussain et al 2023). The noxious heavy metals in different valence states include zinc (Zn), arsenic (As), chromium (Cr), cadmium (Cd), mercury (Hg), copper (Cu), nickel (Ni) and lead (Pb), of these lead (Pb) is more pronounced at higher concentrations and durations. Exposure cause oxidative cell damage likes lipids, proteins and nucleic acids and their ultimate result is impaired host metabolism by generating reactive oxygen species (ROS). ROS such as superoxide radical (O_2^-), singlet oxygen ($_1O^2$), hydrogen peroxide (H_2O_2) and the hydroxyl radical (OH) (Qadir et al 2023). Visible symptoms include chlorotic spots, necrotic lesions etc. in leaf surface, senescence of leaf and stunted growth (Gupta et al 2016). Soybean is largest source of vegetable oil and protein in the worldwide but its yield and nutritional quality adversely affected by heavy metals. There is an urgent need to increase crop productivity for the increasing population (Gupta 2019). Hence, the present study was carried out with an objective to assessment of the hazardous effects of lead on growth of *Glycine max* (L.) Merr. (soybean).

MATERIAL AND METHODS

The experiments were conducted in the greenhouse at University of Rajasthan, Jaipur, during April under natural outdoor conditions with a photoperiod of 12 hours and an average temperature of 30°C. Pots filled with four kilograms of soil at 30 cm height and 25 cm diameter were used, with five lead concentrations (200, 400, 600, 800, 1000 mg/kg) applied as lead acetate. No other supplement nutrients were applied. Pots without added heavy metals constituted were taken as controls. Soybean seeds were surface sterilized with 0.1% mercuric chloride ($HgCl_2$) for two minutes and thoroughly washed with distilled water (DW). Ten sterilized seeds of soybean were sown equidistant at 2cm deep in each pot. Three replicates were used for each concentration. Watering was done on alternate days.

To assess plant height, plant root and shoot system was preserved while measuring the length from the soil surface to the highest leaf or flowering axis for shoot length, and from the root tip surface for root length, with measurements recorded in centimeters. Root and shoot dry weights were determined by carefully extracting plants from pots, washing roots to remove soil particles, separating roots and shoots, and subsequently drying them in an oven at 80°C for 48 hours until a constant dry weight was achieved. Statistical analysis employed SPSS ver. 25.0 and Microsoft Office Excel 2016.

RESULTS AND DISCUSSION

The plant vegetative growth indicators were affected by treatments at pre, peak and post-flowering stages (Table 1). In heavy metal lead treatment at highest concentration i.e. 1000 mg/kg resulted in the highest reduction of all the measure growth parameter at all mentioned stages. It indicates significant effect on vegetative growth parameters plant height, biomass which significantly decreased from the control plants. The highest reduction in root length (10.41cm), shoot length (21.27cm), root dry weight (0.218gm) and shoot dry weight (1.056gm) compared to untreated control plants root length (28.58cm), shoot length (47.46cm), root dry weight (0.462gm) and shoot dry weight (2.695gm) was at pre flowering stage. All studied parameters of soybean had much higher reduction due to lead treatments in comparison to control (Table 1) The reduction in root length varied from 12 to 63%, shoot length from 8 to 55%, RDW from 11 to 52 % and SDW from 19 to 68% in comparison to control (Table 2). The highest reduction at peak flowering stage in root length (15.80 cm), shoot length (28.02 cm), root dry weight (0.291 gm) and shoot dry weight (1.920 gm) was at 1000 mg/kg as compared to untreated control plants root length (36.02 cm), shoot length (55.94 cm), root dry weight (0.724 gm) and shoot dry weight (4.476 gm). The reduction in root length varied from 8 to 56%, shoot length varied from 7 to 50%, RDW varied from 8 to 59 % and SDW varied from 11 to 57% in comparison to control. At post-flowering stage result found that which highest reduction in root length (21.14 cm), shoot length (37.21 cm), root dry weight (0.375 gm) and shoot dry weight (2.345 gm) was at 1000 mg/kg compared to untreated control plants root length (48.18 cm), shoot length (67.02 cm), root dry weight (0.902 gm) and shoot dry weight (4.741 gm). The reduction in root length varied from 5 to 57%, shoot length varied from 9 to 44%, RDW varied from 21 to 58 % and SDW varied from 8 to 50% in comparison to control.

The growth parameters are important factors used to determine growth performance and crop productivity. This study revealed that under different lead concentrations, growth attributes such as root shoot length and root shoot dry weight were decreased with increasing concentrations of lead as compared to the control at pre, peak and post flowering stages of soybean (*Glycine max* (L.) Merr.) plants. Highest reduction found in these parameters at 1000mg/kg level. Similar finding presented by Li et al (2020) in the lead exposed *Lactuca sativa.* It was demonstrated that radicle growth of lettuce seed was easier inhibited by Pb at sever levels. Pb caused inhibition of cell division in plant's roots.

Table 1. Effect of lead on growth parameters of *Glycine max* (L.) Merr. at pre, peak and post-flowering stages

Parameter	Stage	Treatments (mg/kg)						Mean	CD (p=0.05)
		0	200	400	600	800	1000		
Root length (cm)	Pre-flowering	28.58	25.23	21.15	17.72	13.67	10.41	19.46	1.686
	Peak-flowering	36.02	33.05	28.39	24.31	19.29	15.80	26.14	
	Post-flowering	48.18	45.71	41.2	34.67	26.33	21.14	36.205	
	Mean	37.59	34.66	30.25	25.57	19.76	15.78	27.26	
	Mean difference between treatment	0	2.93	4.41	4.68	5.81	5.78	…	
Shoot length (cm)	Pre-flowering	47.46	43.24	36.36	31.21	26.18	21.27	34.29	0.865
	Peak-flowering	55.94	51.67	44.72	40.31	33.19	28.02	42.31	
	Post-flowering	67.02	61.04	58.16	51.32	44.17	37.21	53.15	
	Mean	56.81	51.98	46.41	40.94	34.51	28.83	43.24	
	Mean difference between treatment	0	4.83	5.57	5.47	6.43	5.68	…	
Root dry weight (gm)	Pre-flowering	0.462	0.410	0.359	0.290	0.258	0.218	0.333	0.0427
	Peak-flowering	0.724	0.662	0.59	0.454	0.373	0.291	0.516	
	Post-flowering	0.902	0.712	0.658	0.512	0.468	0.375	0.604	
	Mean	0.696	0.595	0.536	0.419	0.367	0.295	0.4843	
	Mean difference between treatment	0	0.101	0.059	0.117	0.052	0.072	…	
Shoot dry weight (gm)	Pre-flowering	2.695	2.179	1.938	1.705	1.331	1.056	1.817	0.1977
	Peak-flowering	4.476	3.987	3.612	3.343	2.204	1.920	3.257	
	Post-flowering	4.741	4.328	4.202	3.523	2.723	2.345	3.644	
	Mean	3.971	3.498	3.251	2.857	2.086	1.771	2.906	
	Mean difference between treatment	0	0.473	0.247	0.394	0.771	0.315	…	

Table 2. Effect of lead on growth parameters (Percent decrease over the control) of *Glycine max* (L.) Merr. var. JS 95-60 at pre, peak and post-flowering stages

Parameter	Stage	Treatments (mg/kg)				
		200	400	600	800	1000
Root length (%)	Pre-flowering	11.72	25.99	37.99	52.17	63.58
	Peak-flowering	8.02	21.11	32.51	46.45	56.14
	Post-flowering	5.13	14.87	28.04	45.35	56.12
Shoot length (%)	Pre-flowering	8.89	23.39	34.24	44.84	55.18
	Peak-flowering	7.63	20.05	27.94	40.67	49.91
	Post-flowering	8.92	13.22	23.42	34.09	44.48
Root dry weight (%)	Pre-flowering	11.25	22.29	37.23	44.15	52.81
	Peak-flowering	8.56	18.5	37.29	48.48	59.8
	Post-flowering	21.06	27.05	43.23	48.11	58.42
Shoot dry weight (%)	Pre-flowering	19.14	28.09	36.73	50.61	60.81
	Peak-flowering	10.92	19.3	25.31	50.76	57.1
	Post-flowering	8.71	11.37	25.69	42.56	50.53

Rapid inhibition of root growth occurs probably due to the inhibition of cell division in the root tip or decreased cell expansion in the elongation zone or both of them. Lead toxicity is reported to inhibit growth of several plant species, including *Triticum aestivum* (Kaur et al 2013), Cassia species (Khan MR, 2013), Oryza sativa (Srivastava et al 2014; Ashraf et al 2015) and *Carthamus tinctoriu* (Li et al 2015). It also seems that lead had a toxic effect on shoots elongation and overall development of shoots system as was shown in the current work and confirmed by Sedzik et al (2015), *Hordeum vulgare* (Al-Ghzawi et al 2019). The decrease in root shoot dry weights under Pb toxicity has been reported in sunflower (Saleem et al 2018), *Capsicum annum (*Kaya et al 2019), *Coriandrum sativum* (Fattahi et al 2021) and *Triticum aestivum* (Perveen et al 2022).

CONCLUSIONS

The study reveals that lead, significant heavy metal pollutant, exhibits acute toxicity to plants. Increasing lead concentrations adversely affect growth parameters like root length, shoot length, root and shoot dry weight in soybean seedlings. Particularly, the highest lead concentration of 1000 mg/kg demonstrates the most detrimental impact on these parameters. This underscores the importance of informing farmers about soil contamination by heavy metals.

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Temporal Variation in Water Quality of Dhansiri River, North East India

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Abstract: This study focused on understanding how various activities throughout the year affect water quality and contribute to seasonal fluctuations. Three sampling stations were selected for the study, and sixteen physicochemical parameters of water variables were investigated from February 2021 to January 2022. Turbidity in all seasons and TA in winter exceeded the World Health Organizations (WHO 2017) and Bureau of Indian Standards (BIS 2012) drinking water permissible limits. There was significant relationship existing among the sixteen parameters.

Keywords: Dhansiri river, Physicochemical parameters, Permissible limits, Anthropogenic activities, Variable, Correlations

Water is the most abundant natural resource and a prerequisite for all living beings. It is available as surface water (rivers, streams, ponds, and natural springs) and sub-surface water (groundwater). Among all the sources, rivers play a crucial role in sustaining livelihood and maintaining various sectors of the economy by providing water supply for drinking and industrial purposes, irrigation, hydropower generation, tourism, infrastructure, and recreational activities (Venkatramanan et al 2014). However, these rivers are continuously being tainted by extensive growth of urbanization and industrial activities, generating large amounts of solid and liquid waste in urban areas and leading to physical, chemical and microbial contamination of river water. The Ganga River near Kanpur was reported by Trivedi et al (2009) to be quite turbid, and significant relationship between total alkalinity and Cl^-, Mg^{2+}, Ca^{2+}, and TDS. In contrast, the Himalayan rivers were discovered to be degrading due to eutrophication, tourism, geogenic and anthropogenic factors (Seth et al 2016). Various workers, like Nandal et al (2020) and Rahman et al (2021), reported on water pollution load, stating that industrial discharge and toxicological substances have adversely affected the river. Sarmah et al (2020) concluded that anthropogenic activities are the cause of the decline in water quality. Thus, considering the importance of water, it is imperative to know the status of river water and the activities impacting their quality.

The Dhansiri, with a total catchment area of 1,220 square km is a major river of Chümoukedima and Dimapur district of Nagaland. It flows through 352 km from south to north before joining the Brahmaputra on its south bank. Indigenous populations living along the riverbank rely solely on this river for daily household needs. However, it is subjected to tremendous pressure and is susceptible to contamination by both natural and man-made factors. Furthermore, there are no records of seasonal studies on this river, necessitating water quality monitoring and assessment. Therefore, the objective of this research is to examine the spatiotemporal variation in the river's physicochemical qualities along the stretch of the river, as well as to determine the state of water quality and its usability for the community that relies on it.

MATERIAL AND METHODS

Study area: Following a thorough assessment of the study area, three sampling sites were chosen for the Dhansiri River water quality investigation. The activities along the riverbed and the pollutants entering the river were considered when selecting the research areas; GPS coordinates and characteristics of sampling points were distributed as follows (Table 2).

Sampling and analysis: Water samples were collected for a period of 12 months covering the four seasons: winter (December-February), spring (March-May), summer (June-august), and autumn (September-November) from 2021 to 2022. Approximate 10-20 cm depth was considered for the water sample collection. It was stored in a pre-cleaned plastic bottle, appropriately labelled, and taken to the laboratory in an ice box for subsequent analysis. The sampling, preservation, and transportation were done following standard sampling methods (APHA 1998). Physicochemical analysis of 16 water parameters was done using standard method (Trivedi and Goel 1986, APHA 2012). Pearson correlation matrix among the water parameters was estimated using statistical software SPSS version 16.0.

RESULTS AND DISCUSSION

The seasonal values of the sixteen physicochemical parameters are depicted in Table 3.

pH: The average pH of the three sites ranged from 7.82-8.07 (winter), 7.65-7.76 (spring), 7.33-7.42 (summer), and 7.41-7.47 (autumn). The seasonal pH study shows a maximum in the winter at SS1, and minimum at SS2 in the summer. Hussain et al (2021) noticed the similar tendency, stating that alkaline pH is caused mostly by carbonate production, microbial respiration at high temperatures, and organic waste deposition during rainfall.

Water temperature: The temperature of river water is dependent on the interaction with environmental factors (Hussain et al 2021). During summer, due to a rise in the atmospheric temperature, the WT was at its maximum, ranging from 29.87ºC (SS2) to 30.25ºC (SS1) in summer. Meanwhile, with the change in the seasonal pattern of the region, the WT drops to 22.97ºC (SS2) to 23.08 ºC (SS1) in winter.

Total dissolved solids: TDS estimates the amount of organic and inorganic particles in the water sample and displays the quality attributes. The lowest TDS value was recorded in SS2 during winter and highest in summer at all stations; sand mining is common in all three stations, especially in summer. The elevated level of TDS is due to the weathering of rock and the increased flow rate of river water, which causes soil erosion and resuspension of riverbed sediments (Effendi et al 2015).

Electrical conductivity: EC measures the capacity of a solution to carry electrical current and indicates the concentration of dissolved ions present in the water. Seasonally, the EC value was recorded highest and lowest in summer (193.38 µS/cm) and winter (124±11.66 µS/cm) at SS2.

Turbidity: The observed mean value of turbidity in winter (8.82-22.62 NTU), spring (14.15-30.03 NTU), summer (29.54-44.67 NTU), and autumn (23.85-33.80 NTU) were within the permissible limit of BIS/WHO. The mixing of suspended particles and activities, including sand mining, recreational fishing, washing, and irrigation, are responsible for the high turbidity level in all the sites.

Table 1. Water parameters and its analytical methods

Parameters	Unit	Method
pH		Potentiometric portable digital meter (HM Digital pH- 80)
Water Temperature (WT)	ºC	Thermometer
Total Dissolve Solids (TDS)	mg/l	Gravimetric
Electrical Conductivity (EC)	µS/cm	Electrometric method (Portable digital meter)
Turbidity	NTU	Nephelometric method
Chloride (Cl^-)	mg/l	Titrimetric method (Argentometric method using silver nitrate)
Total Hardness (TH)	mg/l	Titrimetric method (standard solution of EDTA)
Total Alkalinity (TA)	mg/l	Titrimetric method (using indicator methyl orange and phenolphthalein
Dissolve Oxygen (DO)	mg/l	Winkler's titrimetric method
Biological Oxygen Demand (BOD)	mg/l	Winkler's titrimetric method (20ºC 5 days incubation)
Potassium (K^+)	mg/l	Flame photometer
Sulphate (SO_4^{2-})	mg/l	Spectrophotometric (Turbidimetry)
Nitrate nitrogen (NO_3^-)	mg/l	Spectrophotometric (Brucine)
Inorganic Phosphorus (PO_4^{3-})	mg/l	Spectrophotometric (colorimetric)

APHA (2012) and Trivedi and Goel (1986)

Table 2. Description of the three sampling sites and coordinates

Sampling station	GPS Coordinates	Brief description of sampling points
Chümoukedima (SS1)	25º45′20"N 93º34′37"E	Recreational activities, plastic and food waste from picnics, chemicals fertilizers and pesticides used in agriculture and sand mining.
Dimapur (SS2)	25º55′14"N 93º44′54"E	Domestic sewage, drainage connections from hospitals and food factories, machinery activities, laundry, washing utensils, and bathing.
Karbi Anglong (SS3)	26º13′06"N 93º50′57"E	Suspended particles from cement factory and brick kilns, debris from religious ritual and oil leakage and urban effluents.

Table 3. Seasonal variation in the physicochemical properties of the three sampling stations of Dhansiri river

Parameters	Winter			Spring			Summer			Autumn			Permissible limits		
	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	Range	BIS	WHO
pH	8.1±0.10	7.8±0.05	7.9±0.18	7.7±0.13	7.7±0.13	7.8±0.10	7.3±0.10	7.3±0.15	7.4±0.08	7.7±0.22	7.4±0.21	7.4±0.27	8.1-7.33	6.5-8.5	6.5-8.5
WT (ºC)	23.1±1.43	22.9±1.52	23.1±1.73	27.1±0.69	27.1±0.7	27±0.76	30.2±0.48	29.9±0.57	29.7±0.48	28.3±1.21	28.7±0.99	28.1±1.09	22.9-30.2	NA	NA
TDS (mg/l)	72.78±8.7	71.60±6	81.9±3.99	82.8±11.5	82.8±11.5	84.7±6.90	109.1±11.2	119.4±5.54	124.9±10.3	108.6±9.8	96.3±12.23	117.2±9.7	71.6-124.9	500	600
EC (µS/cm)	126.8±10.9	124.6±11.7	164.6±7.8	147.9±14.7	147.9±14.7	164.4±10	178.5±11.4	193.4±7.76	186±9.84	164.6±9.7	167.1±10.3	161.5±12	124.6-193.4	NA	NA
Turbidity (NTU)	8.8±0.58	22.6±1.33	22.4±1.32	14.1±1.77	14.1±1.77	30±2.26	29.5±4.74	42.1±4.21	44.7±4.40	23.8±5.29	31.1±3.94	33.8±6.03	8.8-44.7	5	5
Cl^- (mg/l)	9.5±0.82	13.7±0.82	11.8±1.64	14±1.77	14±1.77	19.5±4.23	19.9±2.84	21.2±2.85	21.8±3.28	12.8±2.42	16.1±3.28	12.2±4.39	9.5-21.8	250	250
TH (mg/l)	111.7±7.51	106.1±9.87	109.1±7.87	86.5±8.98	86.5±8.98	82.9±10	52.9±6.73	57±2.85	60.7±8.54	73.6±13.2	65.7±1.37	76.9±8.52	52.9-109.1	200	200
TA (mg/l)	124.6±5.51	114.4±6.68	132.5±10.5	105.5±8.56	105.5±8.56	118.3±5.7	73.9±13.04	77.3±2.43	82.8±9.43	76.2±8.46	89.6±7.79	91.8±10.3	73.9-132.5	120	200
Ca^{2+} (mg/l)	19.5±3.24	19.5±2.01	17.4±2.45	11.2±3.67	11.2±3.67	13.1±2.45	9.6±1.38	10.2±1.68	9.6±1.6	12.8±4.16	13.6±2.12	13.1±1.67	9.6-19.5	75	75
Mg^{2+} (mg/l)	15.3±1.01	14.6±0.84	15.1±1.29	9.9±4.42	9.9±4.42	11.2±3	6.7±1.22	7.8±0.97	8.1±0.74	7.3±1.46	7.6±3.25	7.5±2.94	6.7-15.3	30	50
DO (mg/l)	7.9±0.61	8.6±1.52	7.1±0.60	6.4±1.06	6.4±1.06	6.9±1.29	5.6±1.13	5±0.35	5.3±0.42	8.3±0.61	7.6±1.06	7.4±0.23	5-8.59	5	NA
BOD (mg/l)	4.5±0.31	5.3±0.51	4.3±0.28	3.1±0.61	3.1±0.61	3.6±0.08	3.4±1.25	2.8±0.52	3.1±0.21	3.5±0.17	3.7±0.34	3.9±0.23	2.8-5.3	5	5
K^+ (mg/l)	2.9±0.77	3.6±0.42	3.1±0.76	4±0.87	4±0.87	4.5±0.52	6.1±0.19	6.1±0.44	6.6±1.01	4.1±0.71	4±0.27	4.4±0.41	2.9-6.6	NA	NA
SO_4^{2-} (mg/l)	7.9±0.74	9.9±0.47	10.3±0.51	8.7±1.01	8.7±1.01	11.4±0.96	11.2±0.79	15.6±1.19	14.3±1.11	10.1±0.19	11.7±1.57	12.4±0.66	7.9-15.6	200	250
NO_3^- (mg/l)	0.05±0.03	0.14±0.04	0.2±0.01	0.1±0.08	0.1±0.08	0.3±0.09	0.3±0.09	0.5±0.06	0.5±0.09	0.2±0.09	0.3±0.07	0.3±0.06	0.05-0.5	45	50
PO_4^{2-} (mg/l)	0.14±0.02	0.15±0.03	0.2±0.05	0.2±0.03	0.2±0.03	0.2±0.03	0.2±0.05	0.2±0.02	0.3±0.07	0.2±0.07	0.2±0.02	0.2±0.06	0.1-0.3	NA	NA

Chloride: Chloride is naturally available in all types of water, and when it is present in high concentrations, it is considered an indicator of organic, inorganic, and industrial pollution (Das and Semy 2023). The presence of high value of chloride in water is harmful to irrigation and aquatic life (Venkatesharaju et al 2010). Among all the seasons, Cl^- was highest in SS3 during summer (21.77 mg/l) and least at SS1 in winter (9.47 mg/l). During summer, the raised value of chloride in river water may be due to rainwater washing off municipal sewages and domestic waste into the river (Singh and Shrivastava 2015).

Hardness: Most freshwaters primarily contain calcium and magnesium ions (Kumar et al 2011). The observed values of TH in the three stations ranged from 52.88-111.46 mg/l. The seasonal Mg^{2+} and Ca^{2+} level in SS1, SS2 and SS3 ranged from 6.66-15.27 mg/l and 9.62-19.5 mg/l, respectively. The results of the seasonal analysis of the parameters TH, Ca^{2+}, and Mg^{2+} revealed that the highest levels were seen in the winter and the lowest during the summer, and that the values obtained were within the acceptable range of the BIS/WHO standard.

Total alkalinity: Alkalinity in water is due to carbonates, bicarbonates, or hydroxides from limestone, salts, dissolved rocks, and sediments (Kumar et al 2012). The average TA value obtained from all the sampling stations during the four seasons ranged from 73.95-132.50 mg/l. TA exceeded desirable limit of BIS/WHO during the winter. The value decreased in the summer and autumn, which according to Singh et al (2004) is caused due to excessive dilution by rain water.

Dissolved oxygen: It measures oxygen dissolved in water, and the concentration depends on its physical, chemical, and biological activities along the river (Bora and Goswami 2017). The maximum concentration of DO was observed in winter, 7.05 (SS3) - 8.59 (SS2), which may be attributed to the low temperature in winter resulting in increased concentration of DO. Meanwhile, the minimum DO concentration in summer (5.04 -5.63mg/l) could be attributed to high microbial activities due to organic waste in the river water (Venkatesharaju 2010).

Biochemical oxygen demand: The presence of a high level of BOD in the water indicates the presence of organic waste and active microbial respiration in the river water (Semy and Singh 2019). The BOD in Dhansiri River ranged from 3.06-5.3 mg/l, with the highest value in winter (SS2) and the lowest concentration during summer (SS3). The rise of BOD could be attributed to high microbial activities triggered by organic pollution from the discharge of domestic waste and runoff from farmland and residential and commercial areas.

Potassium: In winter, the lowest K^+ value was 2.97 mg/l at SS1, while in summer, the highest value was 6.61 mg/l at SS3. Agricultural practices along the river stretch contribute to a rise in nutrient levels downstream. Semy and Singh (2019) have reported that the increase in K^+ levels in summer corresponds to nutrient runoff from cultivated lands that reach river bodies.

Sulphate: Sulphate is naturally found in river water in minute concentration or it can also occur from anthropogenic activities like mining (Titilawo et al 2019). The average SO_4^{2-} value in river water throughout the sampling stations varied from 7.94 mg/l (winter) to 15.58 mg/l (summer).

Nitrate: The seasonal NO_3^-concentration fluctuated from 0.05- 0.52mg/l, which was under the permissible limit of WHO/BIS. As per observation in the sampling stations, NO_3^- value increased from SS1 to SS3 throughout the seasons, presumably due to the influx of fertilizers from the agricultural land, which resonates with Meher et al (2015).

Inorganic phosphorus: The PO_4^{3-}concentration was maximum in autumn at SS3 (0.27 mg/l) and minimum in winter at SS1 (0.14 mg/l). The use of fertilizers and pesticides was observed at all sampling sites. Similar to the current findings, Semy and Singh (2021) stated that the extensive use of fertilizers and pesticides in the agricultural fields along the river banks increases PO_4^{3-}concentration during the pre-monsoon period.

Correlation analysis among water physicochemical parameters: pH is negatively correlated with WT, TDS, turbidity, K^+, SO_4^{2-} and NO_3^-, while positively significant with TH, TA, Ca^{2+}, Mg^{2+} and BOD indicating that an increase or decrease in the pH value will also exhibit change in increasing or decreasing of these water parameters (Table 4). The EC was positively significant with turbidity, K^+, SO_4^{2-}, and NO_3^- meanwhile, negatively significant ($p<0.01$) with TH, TA, Ca^{2+}, Mg^{2+}, DO, and BOD. A significant positive correlation is observed between Ca^{2+} and TA, which was also reported by Hussain et al (2021) due to the presence of carbonates, bicarbonates, and hydroxide in river water. Likewise, turbidity level showed a negative correlation with TH, TA, Ca^{2+} and Mg^{2+}, DO and BOD but positively significant with Cl^-, K^+, SO_4^{2-} and NO_3^-. TH is positively significant at $p<0.01$ with TA, Ca^{2+}, Mg^{2+}, and BOD. A similar positive correlation was also observed between TH, TA and BOD (Rahman et al 2021) and TH and Mg^{2+} (Bhandari and Nayal 2008). DO shows a negative correlation with WT at $p<0.05$ indicates that oxygen decreases with increasing temperature. PO_4^{3-} did not show any significant relationship with other parameters. Some significant negative correlations were noted between pH, TA, Ca^{2+} Mg^{2+}, DO and BOD, which was consonant with the observation of Titilawo et al (2019). The correlation analysis reveals inter-relationships existing among the physical and

Table 4. Pearson's correlation coefficient matrix for the physicochemical water quality parameters

	pH	WT	TDS	EC	Turb	Cl^-	TH	TA	Ca^{2+}	Mg^{2+}	DO	BOD	K^+	SO_4^{2-}	NO_3^-	PO_4^{3-}
pH	1															
WT	-0.902**	1														
TDS	-0.953**	0.895**	1													
EC	-0.908**	0.894**	0.943**	1												
Turb	-0.915**	0.909**	0.947**	0.977**	1											
Cl^-	-0.593*	0.717**	0.567	0.661*	0.723**	1										
TH	0.933**	-0.981**	-0.919**	-0.938**	-0.941**	-0.752**	1									
TA	0.950**	-0.959**	-0.961**	-0.927**	-0.933**	-0.651*	0.976**	1								
Ca	0.790**	-0.894**	-0.740**	-0.781**	-0.802**	-0.861**	0.920**	0.845**	1							
Mg	0.846**	-0.866**	-0.802**	-0.814**	-0.839**	-0.553	0.890**	0.891**	0.815**	1						
DO	0.516	-0.628*	-0.532	-0.747**	-0.710**	-0.743**	0.690*	0.556	0.726**	0.548	1					
BOD	0.773**	-0.847**	-0.702*	-0.785**	-0.820**	-0.818**	0.862**	0.798**	0.856**	0.771**	-0.728**	1				
K^+	-0.760**	0.831**	0.753**	0.871**	0.889**	0.870**	-0.864**	-0.772**	-0.870**	-0.702*	-0.853**	-0.854**	1			
SO_4^{2-}	-0.859**	0.878**	0.893**	0.966**	0.974**	0.777**	-0.932**	-0.903**	-0.840**	-0.825**	-0.804**	-0.856**	0.913**	1		
NO_3^-	-0.867**	0.867**	0.916**	0.966**	0.990**	0.721**	-0.906**	-0.902**	-0.752**	-0.808**	-0.713**	-0.804**	0.871**	0.975**	1	
PO_4^{3-}	-0.392	0.505	0.503	0.495	0.481	0.297	-0.486	-0.536	-0.452	-0.497	-0.334	-0.411	0.433	0.465	0.461	1

**Correlation is significant at the 0.01 level (2-tailed)
*Correlation is significant at the 0.05 level (2-tailed)

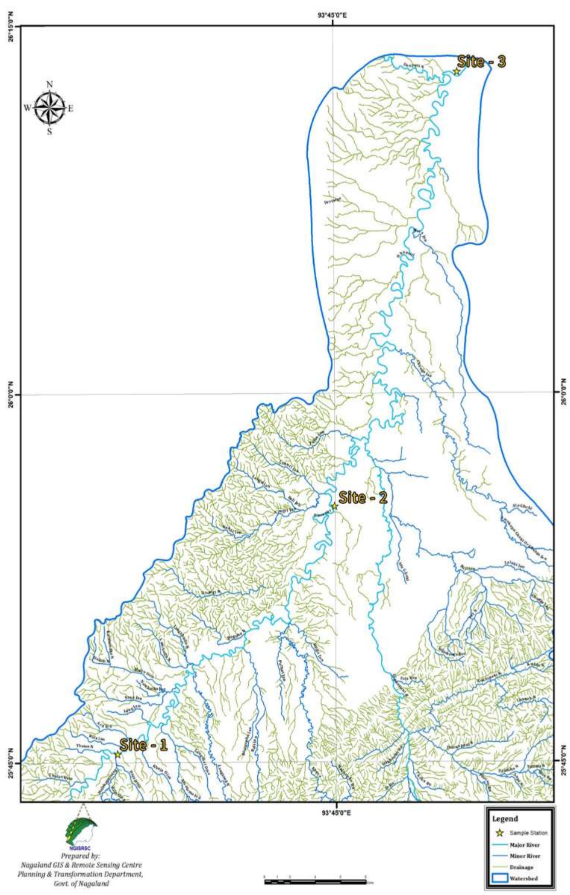

Fig. 1. Drainage area map of the three-sampling location of Dhansiri river

chemical parameters of the Dhansiri river which has its impact on the function of the river system.

CONCLUSION

The physicochemical parameters of the three stations fluctuated seasonally, and the parameters WT, TDS, EC, turbidity, and Cl^- were high during summer while the variables TH, TA, Ca^{2+}, and Mg^{2+} escalated during winter months. The anthropogenic activities, runoff waste debris, and other organic waste from the landfill areas have significantly impacted the water quality. The TA and turbidity of all three sampling locations were above the WHO/BIS permissible limit, indicating that the river water is unsuitable for use without proper treatment.

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Premonsoon Groundwater Trends for Nanjangud Taluk, India: A Spatio-Temporal Analysis

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***Abstract*:** Groundwater is a crucial natural resource that plays a vital role in providing drinking water and supporting various industries and ecosystems. The study investigates the trends in premonsoon groundwater levels in southern Karnataka state, focusing on understanding fluctuations before the monsoon season (Jan-May). The analysis reveals a predominant decreasing trend in groundwater levels, with varying rates of decline observed across monitoring wells. The spatial distribution of groundwater trends was analysed by statistical methods and IDW tool of GIS software. More than 46% of the studied region indicated a declining trend and falling from south-east to eastern parts between 2003 and 2019. The output results contribute to a comprehensive understanding of premonsoon groundwater dynamics and their implications for water resource management by analyzing decadal fluctuations in groundwater depths.

Keywords: Premonsoon, Groundwater trends, Nanjangud, GIS

Groundwater is essentially important for rural communities, where about 90% of drinking water is sourced from groundwater (Dubey et al 2022). It is estimated that as much as 50% of the global population relies on groundwater for their drinking water needs, with approximately 43% of all water used for irrigation coming from groundwater sources (Johnson et al 2022, Van Loon et al 2024). This hidden water source, stored in aquifers beneath the Earth's surface, makes up 99% of the Earth's liquid fresh water and significantly contributes to the water cycle, impacting rivers, lakes, wetlands, and other surface water bodies (Poeter et al 2020). Hot spots of groundwater depletion have been identified in arid and semiarid regions worldwide, with significant depletion has been observed in countries like India, the United States, China, Iran, Mexico, and Saudi Arabia, which collectively account for a substantial portion of global annual water extraction. This issue poses challenges such as reduced flows in streams and wetlands, land subsidence, water quality degradation (Jakeman et al 2016), and increased pumping costs, highlighting the urgent need for sustainable groundwater management practices on an international scale. Groundwater also plays a critical role in stabilizing water levels in rivers, lakes and wetlands during drier months, providing a sustainable water source for wildlife and plants in these environments.

The spatial and temporal analyses of rainfall and groundwater levels show a declining trend in the pre-monsoon groundwater levels (Halder et al 2021), with rates of decrease varying across wells in Nanjangud taluk. The decrease in pre-monsoon groundwater levels can have adverse effects on irrigation practices in the taluk, as it reduces the availability of water for agricultural purposes, impacting crop growth and productivity. Additionally, declining groundwater levels can affect domestic water supply, leading to water scarcity for households relying on groundwater sources for daily use. Sustainable management of groundwater resources is crucial to maintain a balance between water availability and demand for various purposes, especially in regions where groundwater serves as a primary source of water for agriculture, drinking, and industrial activity (Li et al 2021).

Research has shown that premonsoon water levels can vary significantly between years, impacting water availability for various uses such as agriculture, drinking water, and industry (Vaibhav Deoli and Deepak Kumar 2020). Monitoring these trends is essential for assessing changes in water availability, especially in regions heavily reliant on groundwater. Factors like rainfall patterns, land use changes, and groundwater pumping practices play a significant role in influencing premonsoon groundwater trends. Sustainable management of groundwater is paramount, especially with the expected increase in the global population by 2100, as overexploitation and pollution threaten this finite resource. Historically the groundwater was mostly used by agriculture and irrigational activities in the taluk earlier, but since last few decades its utilization was noticed by various industrial and factories observed next to Perennial River Kapila. This would immensely impact on groundwater resource management in the vicinity near future. The present aims to understand the dynamics of premonsoon groundwater levels using GIS tool in Nanjangud taluk mainly focusing on the long-term groundwater sustainability.

MATERIAL AND METHODS

Description of the Study area: The taluk of Nanjangud is measured an area of 983.95 sq km and situated between 72^0 26' and 76^0 56' E longitude and 11^0 51' and 12^0 13' N latitude (Fig. 1). The general altitude is 600-700 ft above MSL covering 184 villages (Manjunatha and Basavarajappa 2021). With the exception of a few scattered hillocks to the south and west, this forms practically a plain boundary. The highest point, 3111 ft above MSL, is located in the southwest corner and the overall slope is north to south, with a narrow but gradually expanding depression located in the Kapila river basin.

Data used and analysis: The taluk boundary was freely downloaded from K-GIS, Govt. of Karnataka website and the groundwater level data was acquired from District Groundwater Board, Mysuru, Govt. of Karnataka for a period of 16 years (2003-19) from 10 observation groundwater well points (Table 1). Spatio-temporal maps were generated by calculating depths, and drawing contours using methods like Inverse Distance Weighted (IDW) tool in ArcGIS software (Manjunatha et al 2023). IDW tool was processed on groundwater level analyses (meters, bgl) for pre-monsoon seasons (Jan-May) on four year fluctuation (2003-07, 2007-11, 2011-15, 2015-19) and long-term fluctuation study (2003-19). This study specifically focusing on premonsoon periods between Januarys to May to avoid seasonal recharge effects from rainfall.

RESULTS AND DISCUSSION

Groundwater trend analysis: The fluctuations of groundwater level yield a precise geological formation that increases the point value of recharge, which is computed from the rise in a well's water level. Over a 16-year period (2003-2019), 10 representative observation bore well points were taken into consideration in order to analyse the fluctuations in groundwater levels from January to May (pre-monsoon season) (Table 1, Fig. 2) (Manjunatha et al 2020). The deeper water levels were recorded as 29.96 m at Hanumanapura observation well measured below ground level (bgl). Groundwater levels were showing declining patterns from the south-eastern (2003) to east (2019) (Table 3, Fig. 3).

Over-exploitation of subsurface water through pumping wells was noticed in eastern parts contributing to groundwater declining levels (Table 2, Fig. 2). Bar graphs of groundwater data revealed the groundwater trend analyses over a period of 16 years (2003-19) (Table 1, Fig. 4). Prominent lineament structures like dykes and fractures are noticed along the NS, NE-SW, and NW-SE directions that control regional subsurface water flow and help in natural recharge of groundwater along various streams, rivers and ponds. More than 46% (461.92 sq km) of the study area showed declined trend from 2003-2019 in groundwater depth (Table 4). Most parts of eastern Nanjangud showed higher demands of groundwater resources, especially for domestic and agricultural activities during summer months. Inclining trend of groundwater levels in all observation well points were observed due to flash floods and heavy rainfall occurred during August 2018 in Wayanad region of Kerala state (Manjunatha and Basavarajappa 2022). More water intensive crops such as paddy, cotton, sugarcane and others could be avoided in critical and over-exploited areas. Artificial recharge structures (ARS) are the best techniques to recharge aquifers within town limits for reducing the load on urban water supply systems. Roof top Rain Water Harvesting (RRWH) structures would be most suitable for larger industrial structures to overcome their demand of groundwater.

Premonsoon groundwater fluctuations in India are

Table 1. Average pre-monsoon groundwater level meters (2003-2019)

Station name	Latitude	Longitude	2003	2007	2011	2015	2019
Deburu	12.11385	76.61656	5.24	5.37	4.81	4.52	4.14
Hanumanapura	12.06005	76.82569	0.4	13.21	21.28	29.96	27.27
Hullahalli	12.09455	76.55575	12.41	11.2	9.61	9.22	0.1
Hura	12.00258	76.54400	9.27	5.94	7.97	11.73	9.93
Kalale	12.07446	76.66335	9.26	7.84	6.86	7.7	5.31
Kothanahalli	11.90696	76.53156	6.03	6.05	7.02	7.07	4.45
Kowlande	12.03232	76.79744	17.33	19.36	18	13.09	13.97
Nanjangud	12.11626	76.67928	3.94	2.65	3.41	3.32	2.66
Sindhuvallipura	12.03095	76.63965	10.38	12.03	10.74	12.73	9.28
Thagaduru	12.09297	76.80928	0.7	17.95	7.22	17.16	23.3

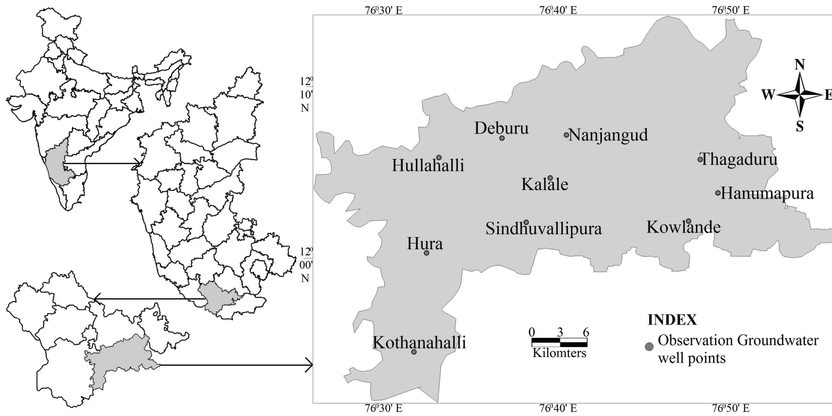

Fig. 1. Groundwater well points map of Nanjangud taluk

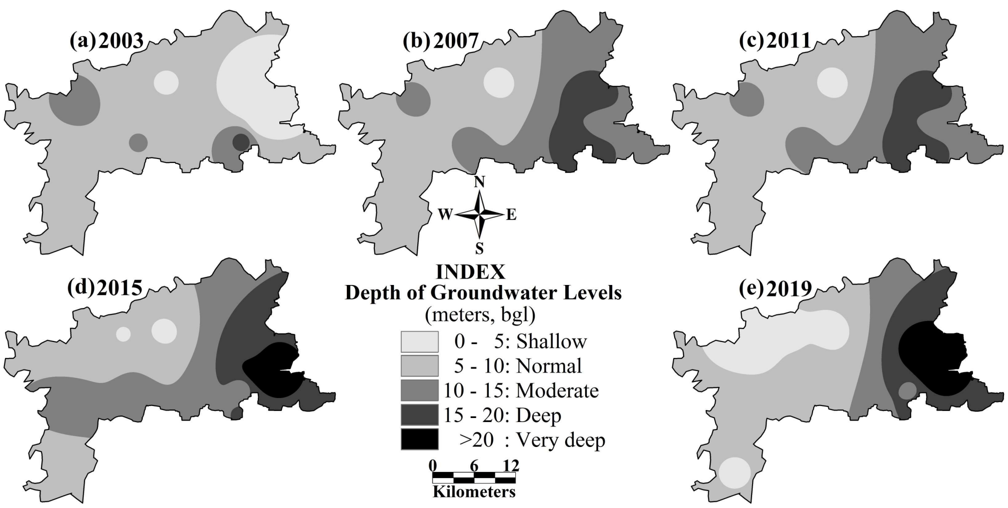

Fig. 2. Premonsoon Groundwater Depths maps for the years (a) 2003, (b) 2007, (c) 2011, (d) 2015 and (e) 2019

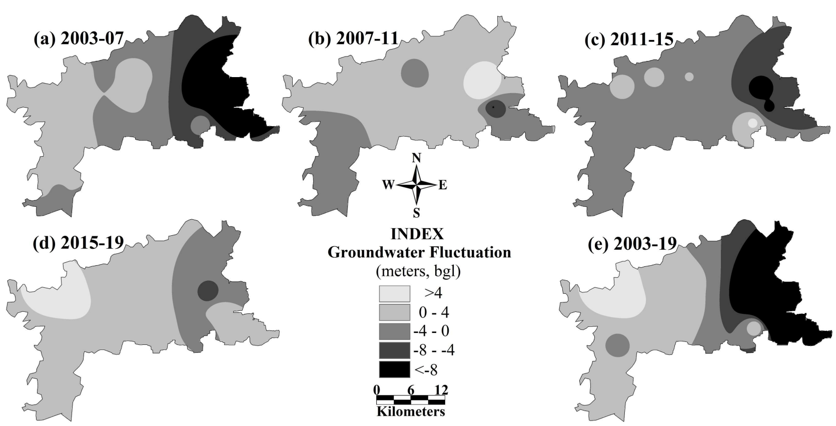

Fig. 3. Premonsoon Groundwater level fluctuation maps for various years (a) 2003-07, (b) 2007-11, (c) 2011-15, (d) 2015-19 and Long-term fluctuation for (e) 2003-19

influenced by various factors, including climate conditions, human activities, and geological characteristics (Vinod Kumar and Vipin Kumar 2020). Studies indicates that around 23% of areas in India experienced a decline in groundwater levels from 1996 to 2016 during the premonsoon period (Gopal Krishan et al 2015). Groundwater based study is a much necessary task in major towns of Karnataka due to many uprising issues of rapid increase of population, water supply & demand in various fields of major industries, factories, urbanization, mining areas and others (Urvashi Sharma et al 2020). Recent studies indicated that some northern Karnataka regions experienced a rise in groundwater levels, while southern regions often face declines. The depth of groundwater levels during the premonsoon season has been recorded between 7 to 22 mts bgl in various districts (Surender Kumar et al 2020). Insufficient premonsoon rainfall often leads to a decline in water levels due to increased evaporation and higher extraction for irrigation purposes. Agricultural practices play a pivotal role in groundwater dynamics. The extensive use of tube wells for irrigation contributes to the depletion of groundwater resources, particularly in regions dependent on monsoon rains for crop cultivation. For instance, fluctuations can range dramatically from below 2-6 mts depending on local geological conditions and rainfall distribution.

The final output maps were generated in analyzing the pre-monsoon groundwater trend using a period of 16 years (2003-19) of observation bore-well point's data. The groundwater levels of Nanjangud taluk were heavily being withdrawn through pumping wells in eastern parts due to the existence of various major, medium and minor industries contributing to groundwater decline. The presence of numerous industries in the area, such as distilleries and other manufacturing units, lead to the discharge of effluents and sewage directly into the Kapila River, which flows through the industrial zones. This pollution contributing to an increase in nutrients in the sediments, affecting the overall water quality and ecosystem health (Mohammad Amin et al 2016).

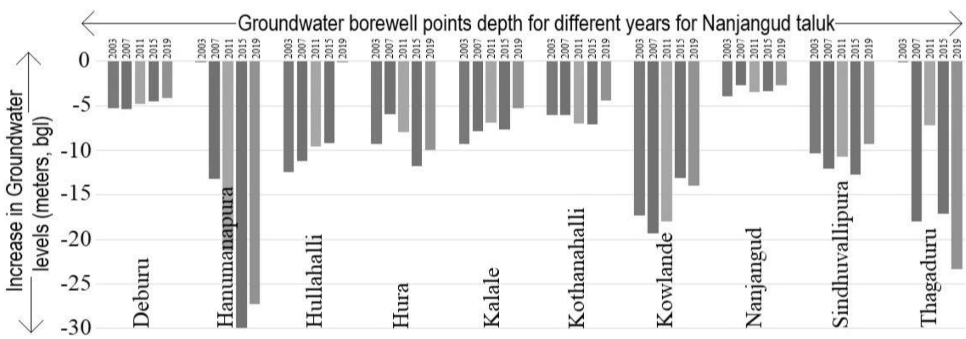

Fig. 4. Bar graph depicting groundwater fluctuations for various years (2003-19)

Table 2. Area under different groundwater depth zones in various years

Depth of groundwater levels (m, bgl)	2003	2007	2011	2015	2019
0 – 5	169.76	20.72	21.46	18.89	181.93
5 – 10	719.73	514.81	657.96	403.13	422.58
10 - 15	87.84	333.69	203.83	344.58	130.87
15- 20	6.62	114.73	96.67	154.82	146.06
>20	Nil	Nil	4.03	62.53	102.51

Table 3. Area under different groundwater depth fluctuation in various years

Fluctuation in depth to water levels (m, bgl)	Area (km^2)				Trends in fluctuation
	2003 – 07	2007 – 11	2011 – 15	2015 – 19	
<4.0	-	45.68	2.91	95.38	Inclination
0.0 – 4.0	365.47	637.07	61.47	658.13	
-4.0 – 0.0	282.71	289.38	732.33	216.29	Declination
-8.0 – -4.0	147.62	11.69	163.57	14.15	
> -8.0	188.15	0.13	23.67	-	

Table 4. Area under long-term fluctuation from 2003 to 2019

Fluctuation in depth to water level (m, bgl)	2003 - 19	Trend in fluctuation
<4.0	91.27	Inclination
0.0 – 4.0	430.76	
4.0 – 0.0	137.59	Declination
-8.0 – -4.0	78.97	
> -8.0	245.36	

Geospatial approach showed a better illustrations in continuous monitoring of groundwater levels using observation wells which is crucial for assessing trends over time. This has been very critical for successful analysis, prediction, validation and involves developing models that can guide environmental and socioeconomic planning related to groundwater resources.

CONCLUSIONS

Nanjangud taluk showed a wide variation of 29 mts in groundwater fluctuations at Hanumanapura observation well point due to natural and anthropogenic activities. Industrial activities in Nanjangud taluk showed a significant impact on groundwater quality and availability. Integrating GIS tools with statistical groundwater data would better portray the groundwater dynamics, availability and sustainability especially for the industrial town in India. Regular analysis provides valuable insights for policymakers to improve groundwater levels, aquifer-recharge potential, and regular monitoring of over-dependency regions of groundwater resources across the state. Implementing GIS based monitoring, mapping high-potential areas, community engagement and integrated water resource management can help in predicting water availability, and efficient water use practices to create a comprehensive groundwater management plan. The outcome of this study can help the farmers to take necessary steps in their crop rotation and cultivation who depend only on shallow groundwater levels. Utilizing GIS techniques in Nanjangud taluk offers a robust framework for understanding and managing premonsoon groundwater fluctuations. By focusing on aquifer characteristics, drainage patterns, and potential zones identified through GIS, stakeholders can make informed decisions to ensure sustainable groundwater use in the region.

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Spatiotemporal Variation in Litter Bacterial Community of Ayiramthengu Mangrove Ecosystem of Kerala Coast, India

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Abstract: The present study focusses on the spatiotemporal variation of litter bacterial composition isolated from Ayiramthengu mangrove ecosystem of Kerala coast. Monthly sampling was conducted from three different sampling stations of mangrove ecosystem for various physicochemical parameters and bacterial analysis. Total heterotrophic bacteria study revealed that there was significant difference in bacteria among different seasons as well as different stations. 18 genera of gram-negative bacteria and 4 genera of gram-positive bacteria were isolated. *Acinetobacter* sp. was the dominant bacteria. This indicate that, Ayiramthengu mangrove contains an abundant number of bacteria, which were directly influenced by the different physicochemical parameters in the ecosystem.

Keywords: Seasons, Spatiotemporal variation, Total Heterotrophic bacteria, Mangrove, Litter

Mangroves are unique ecosystem known for its beneficial impact on both ecological and economical aspect. They provide nutrients to the coastal water, preserve and stabilize coastal zones. Microbial community is considered as the most important population in this ecosystem. Multitude of microbial communities inhabit the mangrove ecosystem as a result of the constant supply of carbon and other nutrients, and these communities are able to adapt to the environment's fluctuations and mild salinity (Thatoi et al 2013). The accumulation of litter in the mangrove is regulated by abscission, withering, death, or other factors such as wind or birds . Mangrove forest litter plays a significant role in its ecosystem as a source of energy and nutrients for numerous decomposing organisms, leading to a significant amount of organic matter and nutrient storage or export to both marine and terrestrial environments through tidal water exchange and freshwater inputs (Feller et al, 2009). The decomposition of litter is influenced by various factors like climatic conditions (Imgraben and Dittmann 2008, Kristensen et al 2008, Arnaud et al 2020), soil properties, organic matter quality (Chomel et al 2016), and the characteristics of microbial communities (Hattenschwiler et al 2005, Gießelmann et al 2010). The leaves and wood of mangrove were mainly composed of lignocellulose, that are degradable by microorganisms. Major nutrient transformation within these bacteria sustains mangroves' ecological balance and nutritional well-being (Holguin et al 2006). The present study is to examine the spatiotemporal variation of litter bacteria in relation to various physicochemical factors of Ayiramthengu mangrove ecosystem.

MATERIAL AND METHODS

Ayiramthengu mangrove ecosystem (lat. $9^0$07' 30'' – 9^0 07' 40'' N and long. 76^0 28' 40''-$76^0$28' 50''E) was selected as the study area and was divided into three sampling stations as Station 1, Station 2 and Station 3. Station 1 near to the land area and influenced by humans, Station 2 within the middle of the mangrove with thick dense mangrove trees and Station 3 situated near to the estuary with narrow strip of vegetation. Monthly sampling was carried out for a period of one year (February 2018 to January 2019) and represented seasonally as pre monsoon (February- May), monsoon (June-September) and post monsoon (October-January).

Litter samples were taken from decaying leaf litter surface aseptically after the removal of surface contaminants. They were transferred to sterile labelled containers with 25% glycerol and transported to laboratory. Samples were serially diluted and plated on ZoBell Marine Agar (Hi Media, India) using standard plate count method and Total Heterotrophic Bacteria (THB) were determined. The individual bacterial colonies were isolated and purified. They were identified up to generic level based on cell morphology and various standard biochemical reactions as per Bergey's Manual of Determinative Bacteriology (Holt et al 2000). Several water quality and sediment parameters were recorded. The determination of various physicochemical parameters of water like temperature, pH, salinity, dissolved oxygen, nitrate, phosphate and sulphate was done according to the standard methods (APHA,1998). Sediment characteristics like temperature, pH, total organic carbon (TOC) content

(Walkley and Black method, 1934), total organic matter and nutrients like nitrate, phosphate and sulphate (Grasshoff et al 1983) were estimated.

Statistical analysis: Statistical analysis was carried out for seasonal analysis of total heterotrophic bacteria and post hoc test was done. Based on generic composition of bacteria, the similarity among the seasons were analysed by hierarchical agglomerative cluster analysis and non-metric-multidimensional scaling (MDS) based on Bray-Curtis similarities and the results obtained were plotted as ordination graphs.

RESULTS AND DISCUSSION

All the studied parameters showed variations with change in season. High temperature, pH, conductivity and salinity was during pre-monsoon season, whereas high dissolved oxygen and nutrients found during monsoon season (Table 1). During pre-monsoon season, more sunlight could increase the temperature in mangrove as well as less freshwater influx could increase the conductivity. In spite of heavy rainfall during monsoon season coupled with high wind velocity resulted in freshwater mixing in mangrove ecosystem which could be the reason for high dissolved oxygen concentration. The fluctuation in nutrient content was controlled by natural sources like igneous rock, plant decay and animal debris as well as man-made sources like fertilizers, livestock, urban and agricultural runoff and wastewater discharges (Lee et al 2002, Jalali 2005, Lotfinasabasl et al 2013). High organic content could be due to the accumulated dead and decaying planktonic organisms and large amounts of humus transported by the rivers and terrestrial land drainages .

Seasonal analysis of total heterotrophic bacteria showed significant difference among various seasons observed (Fig. 1). The post hoc analysis suggested that pre monsoon and monsoon season, and both post monsoon and monsoon season showed significant difference in heterotrophic bacterial population whereas pre monsoon and post monsoon showed no significant difference. Station-wise litter heterotrophic bacterial density indicated significant difference among stations and on post hoc analysis Station 1 and Station 2 and Station 2 and Station 3 showed significant difference whereas Station 1 and Station 3 show no significant difference.

The heterotrophic bacteria were correlated with the water and soil parameters of the region (Table 2). The water parameters like dissolved oxygen, nitrate, phosphate and sulphate when corelated with the heterotrophic bacteria of litter showed positive results. The correlation of heterotrophic bacteria of litter with the soil parameters such as organic carbon, organic matter, nitrate, phosphate and sulphate was positive when compared to the other parameters. Cotano and Villate (2006) also observed that the increase in bacterial population was contributed by the release of effluents.

The litter bacterial composition appeared to be relatively heterogeneous with various stations. This was due to the

Table 1. Physicochemical parameters of Ayiramthengu mangrove ecosystem (Mean ± SD)

Parameters	Pre monsoon	Monsoon	Post monsoon
Water quality parameters			
Temperature (°C)	30.3 ± 0.57	27.5 ± 0.49	28.8 ± 0.87
pH	7.53 ± 0.10	7.47 ± 0.06	7.51 ± 0.06
Conductivity (m/s)	23.92 ± 2.75	9.42 ± 1.24	22 ± 2.21
Dissolved Oxygen (mg/l)	2.97 ± 0.69	3.3 ± 0.74	2.06 ± 0.69
Salinity	8.1 ± 2.48	3.43 ± 0.69	4.65 ± 1.55
Nitrate (mg/l)	1.13 ± 0.2	2.47 ± 0.77	2.18 ± 0.8
Phosphate (mg/l)	1.38 ± 0.14	2.28 ± 0.26	1.32 ± 0.31
Sulphate (mg/l)	75.08 ± 2.64	138.27 ± 17.35	115.1 ± 8.73
Sediment characteristics			
Temperature (°C)	26.8 ± 0.42	23.7 ± 0.42	25.1 ± 0.51
pH	6.83 ± 0.13	6.37 ± 0.15	6.38 ± 0.11
OC (%)	0.40 ± 0.09	0.41 ± 0.09	0.61 ± 0.09
OM (%)	0.65 ± 0.15	0.75 ± 0.32	1.05 ± 0.16
Nitrate (mg/g)	2.64 ± 0.0.06	2.58 ± 0.03	2.24 ± 0.06
Phosphate (mg/g)	3.04 ± 0.05	3.20 ± 0.06	3.08 ± 0.08
Sulphate (mg/g)	82.02 ± 1.35	85.78 ± 1.42	81.50 ± 1.56

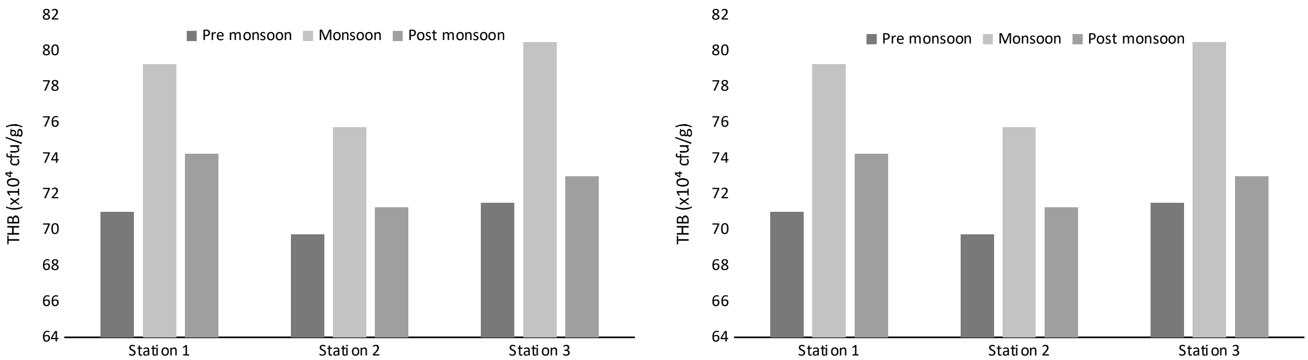

Fig. 1. Spatio-temporal variation in litter heterotrophic bacteria

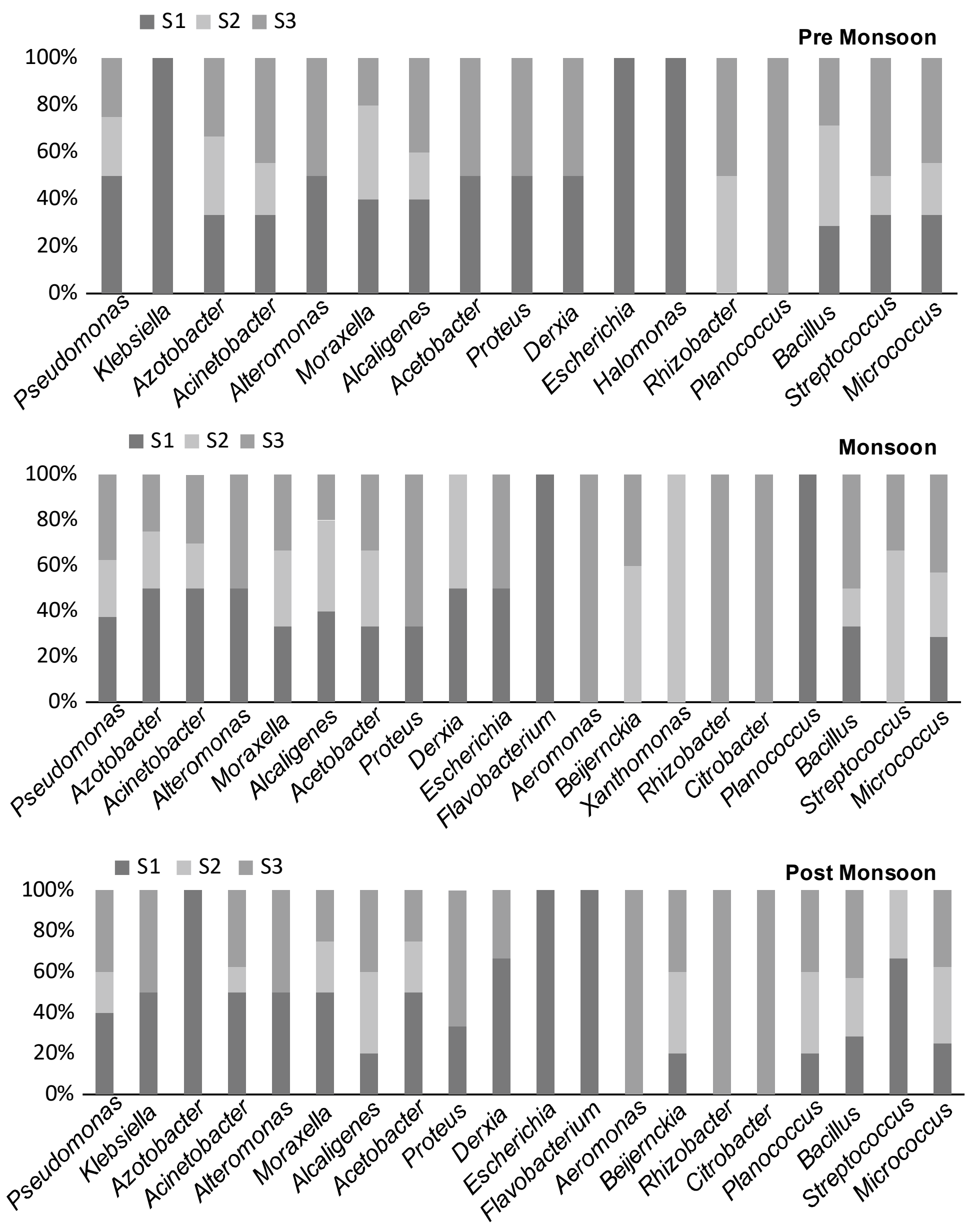

Fig. 2. Spatiotemporal variation in the generic distribution of litter bacteria (%)

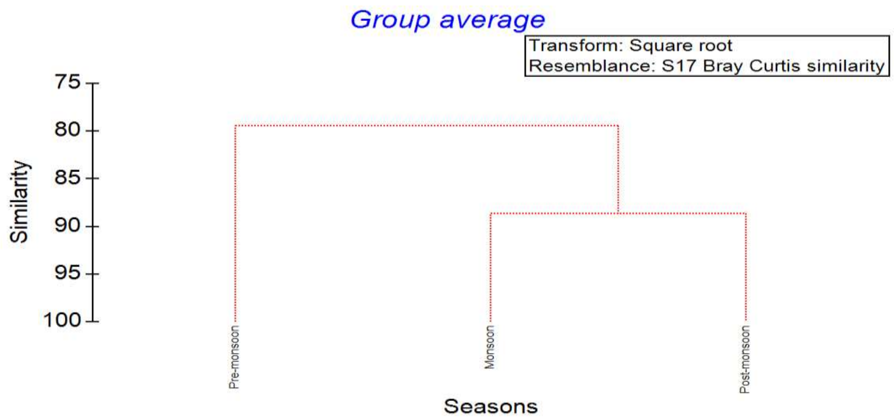

Fig. 3. Cluster diagram plotted based on similarity/dissimilarity of the various seasons in relation to the litter bacterial diversity

Table 2. Correlation analysis of litter bacteria with water and soil parameters

Parameter	Correlation	Parameters ® value)	Correlation coefficient (r)
Water	Positive correlation	Dissolved Oxygen	0.373
		Nitrate	0.466
		Phosphate	0.727
		Sulphate	0.558
	Negative correlation	Temperature	-0.379
		pH	-0.167
		Conductivity	-0.619
		Salinity	-0.480
Soil	Positive correlation	Organic carbon	0.018
		Organic matter	0.019
		Nitrate	0.172
		Phosphate	0.383
		Sulphate	0.264
	Negative correlation	Temperature	-0.58
		pH	-0.462

difference in the rate of decomposition found in different stations. Besides that, all the stations had equal importance in the detritus decomposition and were thereby actively involved in biogeochemical cycles. But the litter heterotrophic bacteria indicated changes among different seasons. However, the physicochemical variations that occurred during different seasons affected the litter production rate (Juman 2005, Zafar et al 2012). It is well known that mangrove microbial communities were strongly influenced by the environmental parameters like temperature, pH, salinity, dissolved oxygen and nutrient concentrations (Tam 1998, Li and Gu 2013). During the study, heterotrophic bacterial load from litter revealed that gram negative bacteria were relatively abundant with 18 genera (82%), while gram positive bacteria contributed only 4 genera (18%). The comparatively higher percentage of gram-negative bacteria showed higher decomposition favoured by the litter substratum for the better adapted gram-negative bacteria.

Acinetobacter sp. (13%) was the dominant followed by *Micrococcus* sp., *Bacillus* sp., *Pseudomonas* sp. (Fig. 2). The cluster analysis suggested that the monsoon and post monsoon season (88%) showed more similarity than to pre monsoon season (Fig. 3). *Acinetobacter* involved in degradation pathways of various long-chain dicarboxylic acids and aromatic and hydroxylated aromatic compounds. Dorothy et al (2003) stated that *Micrococcus* were actively involved in leaf litter decomposition in mangrove forest. *Bacillus* sp. was known for its cadmium biodegradation, hydrocarbon degradation, emulsification, phytase production, plant growth promotion and protection of plant from microbes (Holguin et al 2001, Macrae et al 2001). *Pseudomonas* had a major role in the turnover of certain nutrients like nitrogen, carbon and phosphorous appeared in the leaf biomass (Mumby et al 2004, Romero et al 2005).

CONCLUSION

The heterotrophic bacterial population was influenced by various physico-chemical parameters of soil and water. Moreover, Gram negative bacteria was comparatively high than Gram positive bacteria with a dominance of *Acinetobacter* sp. Thus, it is concluded that Ayiramthengu mangrove ecosystem have a rich litter bacterial population holding a well-organized community structure at various seasons as well as stations.

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Abundance and Diversity of Mollusks and Related to Some Physicochemical Properties in Euphrates River in Al-Muthanna Province

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***Abstract*:** Study was conducted to identify the composition of mollusks in relation to some physical-chemical parameters of the Euphrates river during the period from November 2019 to October 2020. The water temperature ranged between 11.33-38.67 ºC. The highest mean of electrical conductivity was 3026.6µS/cm, whereas the lowest was 1203.3 µS/cm. The maximum TDS was 2766.6 mg/l . The water flow was ranged from 0.133 to 0.426 m/sec.The turbidity ranged between 11.59 and 134.63NTU. TSS recorded the highest mean of 36.66 mg/l and lowest of 21 mg/l. The pH values ranged between 6.63-8.60 and the concentrations of DO and BOD5 between 5.15-10.10 and 1-12.33 mg/l, respectively. TA, TH, Ca+2, and Mg^{+2} were within 131.33-181.66, 423.33-1386.6, 125-320 mg. The $NO2^{-2}$, $NO3^{-}$ and $PO4^{-3}$varied between (0.03-3.05, 0.053-6.890 and 0.06-0.77 µg l^{-1}, respectively). The TOC ranged between 0.055-3.12 % and type of texture was silty in all stations. The study revealed the occurrence of 6 species of Mollusks with total density of 242.84 Ind. /m^2. The relative abundance index, showed that the species *M. nodosa* was dominant and *C. fluminalis* less abundant. The Shannon-Weiner and Simson diversity indices ranged between 0.39-2.95 and 0.1-0.93, respectively.

***Keywords*:** Physicochemical properties, Biodiversity, Euphrates river, Mollusks, Samawa.

Freshwater constitutes 3% of the total water on earth and the rivers as a freshwater source are complex systems containing rich diversity of living species which are in close interdependence with their surrounding physical environment (Brachet 2015). Among the organisms in the rivers, mollusks are the major grazers and playing a pivotal role in aquatic food webs, significantly influence algal primary productivity, nutrient cycling, water purification, and provide valuable information by their presence, absence, and abundance regarding their surrounding habitat and can be used to assess the local environmental impact. Freshwater mollusks are perfect organisms for rapid biological survey due to their sensitivity to changes in the environment and water quality and capacity for water filtering (Cummings 2016). The deterioration of physical and chemical water quality is often caused by human influences gradually, and the invisible adaptations of aquatic ecosystems to these changes may not always be discovered until a major transformation in the state of the ecosystem occurs (Stark et al 2000). These systems should be continuously monitored by assessing the species of organisms or measuring some physical and chemical properties.The current study was designed to study monthly variation in physicochemical parameters, which affect the abundance and diversity of Mollusk in the study area.

MATERIAL AND METHODS

Study area: The study area included three sampling sites located on a Euphrates river at Al-Muthanna province. Al-Muthanna province is located about 270 km south of Baghdad, the capital of Iraq.The first sitelocated in Al-Hilal area(31º42'40.34"N- 45º45'11.16"E), while the second siteabout 34 km south of the first site(31º31'49.46"N-45º.29'72.79"E), in the city center of Samawa near Al-Shuhada Bridge, and the third sitelocated about 16 km south of the second site (31º.29'31.17"N - 45º.45'63.35"E) (Fig. 1).

Sampling procedures: The study was conducted monthly from November 2019 to October 2020. Water samples were taken for physical and chemical parameter analysis. Water temperature (°C) was measured and water flow (m /sec) directly using the float method mentioned (US EPA (1997). Electrical conductivity (µS/cm) and pH were estimated by using a portable Multimeter (SM801). Alkalinity was measured by the titration method (Estefan et al 2013) and reactive phosphate, nitrate, and nitrite were estimated according to Nollet (2014). Total dissolved solids were measured by an evaporation method, total dissolved solids were measured by gravimetric method (APHA (2017). The total hardness, Ca hardness, Mg and dissolved oxygen were measured by using a titrimetric method (APHA 2017). Biological oxygen demand (BOD_5) measured by sensor method (Al-Fanharawi et al 2019). The turbidity was measured in the field by turbidity meter, type Hanna (WTW-Turb-550). Sediment samples were collected for analysis the total organic carbon (Estefan et al 2013) and grain size analysis was carried out by using the standard sieving and pipet techniques (Folk 1974).

Mollusks were also sampled monthly using Vanveen Grab Sampler monthly (Al-Fanharawi 2010). Mollusks have been identified according toPlaziat and Younis, (2005) and Damborenea et al (2020). Mollusks were grouped by species and density determined (Ottensmann 2018) and expressed as individual/m^2. Relative abundance was calculated (Baderan et al 2019). Shannon-Wiener diversity (H') counted according to Baderan et al (2019) and Simpson's diversity as mentioned by Vajravelu et al (2018).

RESULTS AND DISCUSSION

Physical parameters: The highest water temperature was 38.67 °C at St.3 in July and the lowest 1.33°C at St.1 in February (Table 1). The monthly fluctuation in the water temperature was due to a long day period in the summer and the short day period in winter. The spatial variations in water temperatures may be due to the difference in the time of collection of the sample at each station. The highest value of electrical conductivity (EC) was 3026.6 µS/cm recorded in July at St.3, while lowest mean value 1203.3 (µS/cm) was in November at St.1 (Table 1). The highest values of electrical conductivity may be due to higher temperatures, which lead to an increase in the solubility of the salts in addition to an increase in evaporation and an increase in the concentration of salts. Najafpoor et al (2007) indicated that highest electrical conductivity depends on the amount of total dissolved solids in water, which have the highest value of 2766.6 mg/l during July in St.2, while the lowest value 833.3 mg/l during November in St.1. The high concentrations of TDS may be due to higher temperature leads to high rates of evaporation that an increase of salt concentrations (Al-Fanharawi 2010). The highest mean water flow was 0.426 m/sec recorded in June at St.2, whereas the lowest value

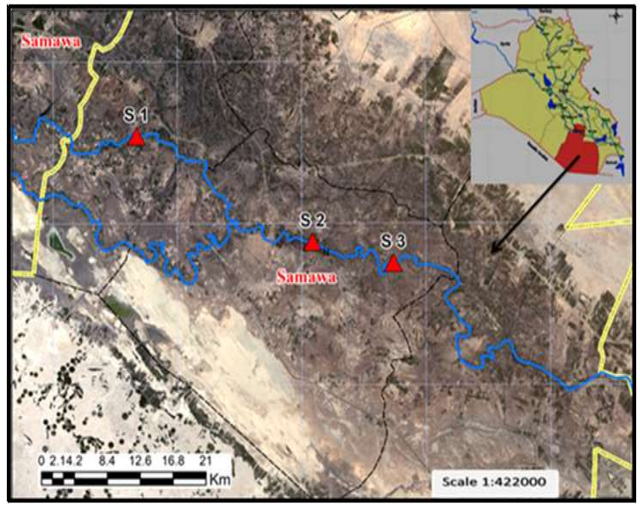

Fig. 1. Sampling site on Euphrates River

Table 1. Physical and chemical parameters in Euphrates river (Mean ± standard deviation)

Stations/Parameters	St.1	St.2	St.3
Water temperature (Cº)	25.06±8.88A	23.44±8.74A	21.92±8.53A
Electrical conductivity (µS/cm)	2032.7±548.7A	1988.8±492.8A	1810.5±486.2B
Total dissolved solids (mg/l)	1794±512.4A	1753.0±517.3A	1541.9±512.5B
water flow (m/sec)	0.236±0.065C	0.340±0.084A	0.266±0.073B
Turbidity (NTU)	40.17±29.33A	42.40±31.43A	29.74±19.27B
Total suspended solids (mg/l)	83.80±26.13A	8.16±25.63B	43.50±19.14C
pH	7.73±0.05A	7.76±0.05A	7.66±0.15A
dissolved oxygen (mg/l)	6.70±0.90B	7.23±0.99B	7.85±1.24A
biochemical oxygen demand (mg/l)	7.11±2.98A	6.19±2.93B	4.66±2.48C
Total alkalinity (mg$CaCO_3$/L)	153.63±12.57	153.00±14.72	154.47±16.59
Total hardness (mg$CaCO_3$/L)	869.44±241.1A	815.83±208.4AB	761.94±175.2B
Calcium hardness (mg$CaCO_3$/L)	185.58±50.99	175.02±37.04	162.13±30.95
Magnesium (mg/l)	165.77±46.91A	156.85±42.77AB	145.76±35.76B
Nitrite (µg/l)	1.136±0.889A	1.121±0.883A	0.993±0.7A
Nitrate (µg/l)	4.152±2.226A	3.481±0.184B	3.017±1.816C
Reactive phosphate (µg/l)	0.340±0.211A	0.295±0.178B	0.238±0.142C

Different capital letters in row indicate significant difference in parameters between stations

0.133 m/sec recorded at St.1 (Table 1). The highest mean water flow in St.2 may be due to narrowing of the river at this station, and that the velocity of the river can change at various stations along the course of a river due to the shape, the lowest mean value in St.3 attributed to the presence of aquatic plants that delayed water flow. The highest turbidity and total suspended solids values were in October were 134.63 NTU and 136.66 mg/l, respectively .This may be due to the increased discharge of water into the Euphrates River, which flows with a high suspended matter content (Rabee et al 2011) and the lowest values were recorded in November at St.1 was 11.59 NTU and 21 mg/l respectively and may be due to the presence of aquatic plants (Noaman 2008).

Chemical parameters: The pH of water in the current ecosystem can be classified as slightly alkaline, the higher pH was in February at St.2 (6.63-8.6). This may be due to reduced microbial activity, improved algal productivity and the decreased decomposition (Sisodia and Chaturbhuj 2006). The low pH in July may be due to an increased rate of decomposition, leading to acidification (Ahipathy and Puttaiah 2006). The minimum of dissolved oxygen (5.15 mg/l) and higher levels of biological oxygen demand (12.33 mg/l) was in July (Table 1). The high BOD_5 may be due to the high decomposition processes of microbial organisms due to the height of the temperature Arimoro et al (2006) and these processes require the consumption of high concentrations of dissolved oxygen that lead to low DO. The highest alkalinity, total hardness, calcium hardness, and magnesium were in July (181.66, 1386.6, 320 mg CaCO3/L and 259.2 mg/l) respectively. The high alkalinity attributed to the relationship between total alkalinity and total hardness, through common ions formed in aquatic systems, carbonate, and bicarbonate are the principal cations responsible for hardness are ions associated with alkalinity (Burton Jr and Pitt 2002). The higher total hardness, calcium hardness, and magnesium, maybe due to low water level and high rate of evaporation and decomposition that concentrating the salts (Mossa 2006).

The highest mean nitrite 3.05 µg/l was at St.2 in December, while the lowest 0.03 µg/l was at St.3 in July Low levels of nitrite concentration may be related to a complex of biological processes, including the oxidation of nitrite as an unstable form of nitrogen to nitrate by nitrifying bacteria (Abdo and El-Nasharty, 2010). The highest mean nitrate was 6.890 µg/l in July and this may be due to deep ground waters with high nitrate concentrations which is important source of nitrate in surface waters (Tesoriero et al 2013). The lowest mean was 0.053 µg/l in Januarydue to the high water level of the river and the dilution factor that effect on concentrations (Al-Fanharawi 2010). The highest reactive phosphate was 0.77 µg/l in July at St.3 due to the increasing water temperature, which causing increasing the degradation of organic matter containing phosphate compounds, including algal cells, or may be due to phosphate fertilizers used to fertilize agricultural land and discharged to the river and this agree with Mokaya et al (2004), while lowest mean of reactive phosphate was at St.1 (0.060 µg/l) and may be due to location of station more distant from the effluent discharge point.

Sediment samples: Sediment analysis in the present study showed that the lowest value of TOC % in sediments (0.055 %) was in June, while the highest (3.12 %) was at St. 3 in October (Fig. 2). The highest value may be due to contamination of this station with organic pollutants due to the direct discharge of domestic wastewater to the river (Zhibo et al 2009). Grain size analysis of sediment showed that the sediment texture of the three indicates silt, clay and sand as 90, 5 and 5%. According to the soil textural triangle, the sediments of the Euphrates River on sites can be considered as silty.

Identification and population mollusks: In the current study, from 577 individuals of Mollusks, identified 6 taxa belonging to 5 families, 3 orders, and 2 classes (Gastropoda and Bivalvia) in three sites on Euphrates river. Bivalvia class (3 species) comprised the orders Unionida (*U. tigridis*), and Veneroida (*C. fluminea, and C. fluminalis*), whereas the class Gastropoda (3 species) comprised one order Mesogastropoda were *M. tuberculata, M. nodosa, and V. bengalensis.*

Density of Mollusks: The highest mean of mollusks density was in St.2 was 390.4 Ind./m^2 and this may be due to the

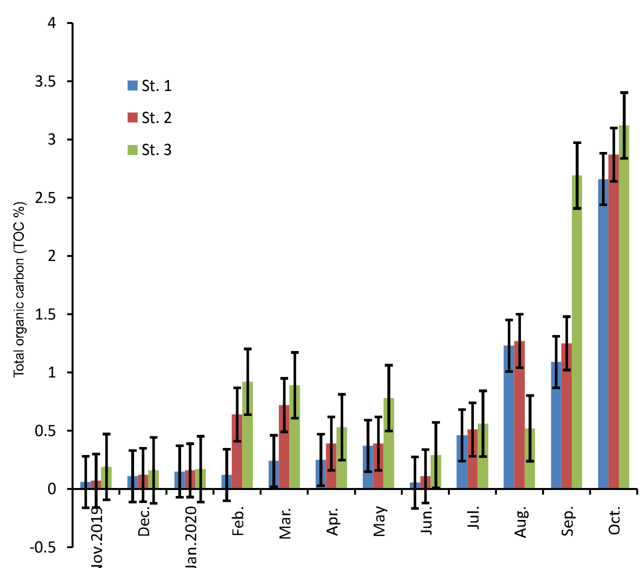

Fig. 2. Monthly variation in total organic carbon values in Euphrates river during study periods

effect of Al- Shuhada Bridge. Blettler and Marchese (2005) also showed the effect of bridges on the benthic invertebrates. The mollusks and found that the species density was highest under the bridges than upstream and downstream, while the lowest mean recorded in St.1was 127.52 Ind./m^2(Table 2).

Ecological indices: The relative abundance of species varied between study stations, St.2 was the most abundant among while St.1 was less abundant (Fig 3-A). The species *M. nodosa* was the most abundant species (75.79%), followed by *C. fluminea* (8.07%), *V. bengalensis* (6.81%), and *M. tuberculata* (6.37%), *U. tigridis* (2.59%), whereas *C. fluminalis* (0.37%) was the less abundant species. Shannon-Wiener diversity index indicate lowest monthly diversity of mollusks was 0.39 in August (Fig. 3A). This may be due to a combination of abiotic factors, including, low water flows and temperature increase, while the highest value of 2.95 was in October, may be due to the rapid migration of these organisms. Bishop et al (2009) reported that the rapid migration of mollusks reflects the behavioral response from them or may be due to the effect of temperature, the presence of vegetation cover nutrition as key factors for the success and the development of certain species. Badsi et al (2010) observed that highest organic carbon in sediment was in October. Sharmin et al (2019) reported that the lowest species diversity associated with low sediment organic carbon and low sediment organic matter. The highest value of Simpson index was 0.93 in October and may be due to the higher TOC recorded in this month, or may be due to the appropriate temperature and present the plant cover, while the lowest value was 0.1 in April (Fig. 3A).Two indices (Shannon-Wiener diversity and Simpson diversity)agreed on recording the same highest and lowest in the same stations St.1 and St.2 respectively (Fig. 3B).The lowest diversity in St.2 may be due to lack of evenness of species and decreases in the species richness, this due to the dominance of a few species with high densities, while that the opposite of what was onthe St.1 was have the highest richness of species. Kimbro (2006) reported that diversity depended on two major components, richness, and evenness of species.

Table 2. Total density of mollusk species in Euphrates river (Ind./m^2)

Stations/ Months	St.1	St.2	St.3
Nov. 2019	30.3	75.75	75.75
Dec.	30.3	45.45	60.6
Jan.2020	45.45	30.3	45.45
Feb.	75.75	15.15	121.21
Mar.	90.9	60.6	75.75
Apr.	90.9	136.36	121.21
May	151.5	121.21	121.21
Jun.	90.9	212.12	136.36
Jul.	90.9	1015.15	454.54
Aug.	106.06	1045.45	45.45
Sep.	345.45	1163.63	651.51
Oct.	381.81	763.63	618.18
Means	127.52	390.4	210.6

CONCLUSION

1. The highest mean of most physicochemical parameters (electrical conductivity, total suspended solids, biological oxygen demand, total alkalinity, total hardness, calcium hardness, nutrients, and total organic carbon) was recorded at outside city center St.3.

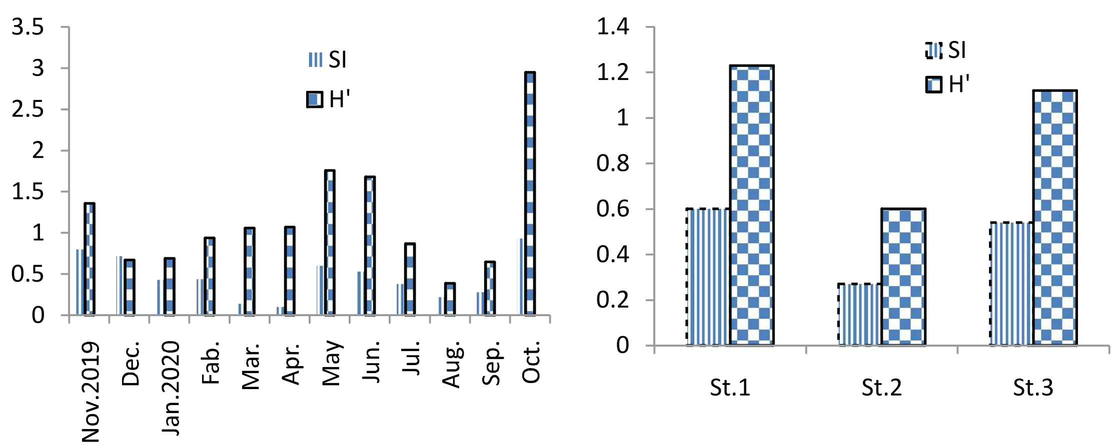

Fig. 3. Simpson and Shannon-Weiner diversity indices values of Mollusks species in stations in Euphrates river A- Monthly variation; B: Variations between stations

2. The values of density, relative abundance, and diversity (Shannon-Weiner and Simpson diversity indices) of mollusks, were impacted by total organic carbon, water flow, and temperatures.
3. The current study showed the species *M. nodosa* was the most abundant species in all stations during the study periods, while the species *C. fluminalis* was the less abundant species.
4. When more indices are used to assess the diversity, which gives a more accurate and clear picture, the two diversity indices (Shannon-Weiner and Simpson indices) agreed that the highest and lowest values were recorded in the same stations.
5. Biological diversity index showed that Euphrates river in the study area was low diversity, according to the Shannon-Weiner diversity index <1.

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CONTENTS

Indian Journal of Ecology (2024) 51(5)

Indian Journal of Ecology

CONTENTS

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