INDIAN JOURNAL OF *ECOLOGY*

ISSN 0304-5250

Volume 51 Issue-4 August 2024

THE INDIAN ECOLOGICAL SOCIETY

THE INDIAN ECOLOGICAL SOCIETY

(www.indianecologicalsociety.com)
Past President: A.S. Atwal and G.S. Dhaliwal
(Founded 1974, Registration No.: 30588-74)

Registered Office

College of Agriculture, Punjab Agricultural University, Ludhiana – 141 004, Punjab, India
(e-mail : indianecologicalsociety@gmail.com)

The Indian Journal of Ecology is an official organ of the Indian Ecological Society and is published bimonthly in February, April, June, August, October and December by Indian Ecological Society, PAU, Ludhiana. Research papers in all fields of ecology are accepted for publication from the members. The annual and life membership fee is Rs (INR) 1000 and Rs 8000, respectively within India and US $ 100 and 350 for overseas. The annual subscription for institutions is Rs 8000 and US $ 300 within India and overseas, respectively. All payments should be in favour of the Indian Ecological Society payable at Ludhiana. See details at web site. The manuscript registration is Rs 500.

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Indian Journal of Ecology (2024) 51(4): 697-706
DOI: https://doi.org/10.55362/IJE/2024/4297

Manuscript Number: 4297
NAAS Rating: 5.38

Food Loss and Food Waste: Economic Implications, Environmental Consequences, Sustainable Solutions for Management with Respect to Developing Nations

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Abstract: Food loss (FL) is the term which can be defined as "the decrease in quantity or quality of food that makes it unsuitable for human consumption" by the United Nation's organisation FAO. Food wastage is a major component of food loss and infers to food products that are discarded at the consumer and retailing level. According to the FAO of the United Nations, amount of lost or wasted food that is present in the supply chain is estimated at 1.35 billion tonnes per year that was being produced for the consumption of human beings but was not consumed. According to calculations made by the Boston Consulting Group (BCG), the quantity of food that is lost or thrown away annually will increase to one-third amount by the year of 2030. At that time, "2.1 billion tonnes will either be lost or thrown away, equivalent to 66 tonnes per second".

Keywords: Food loss, Food wastage, Food insecurity, Food waste index, Sustainability

The waste of food is emblematic of a food production and consumption system that cannot be maintained sustainably. According to calculations made by the Boston Consulting Group (BCG), the quantity of food that is lost or thrown away annually will increase to one-third by the year of 2030. At that time, "2.1 billion tonnes will either be lost or thrown away, equivalent to 66 tonnes per second" (Hegnsholt et al 2018). Over 2 billion of population throughout the world does not have regular access to food that is safe in quality terms, nutritious and sufficient enough. This number includes those who suffer from hunger as well as those who are facing moderate levels of food insecurity. Food wastage is an important problem that is directly affecting the environment, the economy, and the society (Dahiya et al 2017, Stenmarck et al 2016). Therefore, to maintain global food security and good balancing environment, food wastage needs to be addressed (Dahiya et al 2017, Stenmarck et al 2016). Food loss (FL) can be defined as "the decrease in quantity or quality of food that makes it unsuitable for human consumption" by the FAO of the United Nations (FAO). Food wastage is a component of food loss and refers to food and its related products that are discarded at the consumer and retailing levels. The possible reason behind that could be an excess purchase, supplying perishable commodity in surplus quantity where it is having a low demand, indeliberate attitude of having leftovers at the household level, and glut in market from surplus level of harvest (Georganas et al 2020, Gustavsson et al 2011).

According to FAO, the food quantity that is lost or wasted in the supply chain is estimated at 1.35 billion tonnes per year that was being produced for consumption needs of human beings but was not consumed. The United Nations (UN) has suggested as an important part of their agenda for sustainable development goals (SDG) with the objective of drastically decreasing global food loss and halving the food quantity that is wasted around the globe by the year 2030 (Commission 2018). India's food grain production has marked a record of 315.70 million tonnes as well as the production of horticulture products was almost 342.30 million tonnes during 2021-22 in spite of all the challenges faced by the economy during this time period (PIB Report 2023). Further, as per the report the production estimates for kharif food grains during 2022-23, was registered at 149.90 million tonnes which was higher than the kharif food grain production during the last five years. Other than the food grains the pulses in the country have also recorded higher than the average of 23.80 million tonnes in the past few years. Apart from all the heights, the issue of food loss and wastages is also equally important. The loss of food occurs at the six main stages viz., at harvesting level, handling and storage level, processing phase, transport and distribution stage, retail and consumption at household level. Quantity of food grains (wheat and rice) that damaged in godowns of FCI during (2016-17 to 2021-22) is mentioned below:

There needs to be a clear distinction between the term food loss and food wastage. Food wastage according to FAO is considered as "wholesome edible material intended for human consumption, arising at any point in the food supply chain that is instead discarded, lost or degrades" (Gustavsson et al 2011). It is more prominent in higher income countries majorly at restaurants, hotels, homes, etc., whereas, food loss majorly occurs when the food becomes unfit for the human consumption unavoidably even before people have a chance to eat it. Food loss problem can be seen prevalently in lower income countries. (World Food Program USA, 2022). The food grain procurement in the country is done by Food Corporation of India in a scientific manner. But after all the precautions maintained to store the food grains in the godowns, some quantity of food grains may get damaged due to leakage, contamination, national calamities, etc. The food loss damaged during the last three years in shown in the Table 2.

Food loss is one of the reasons for the cause of hunger nationwide. In the Global Hunger Index of 2022, India's rank was 107th out of 121 counties and having a score of 29.1 that showed a serious level of hunger. Food loss is not only a damage to hunger but a serious issue of threat for our natural resources as it has adverse effects on the environment because that food which is lost had consumed water, soil, nutrients, etc. during its production process and was not even available further for consumption to general public. This causes a dual loss in the form a form of increasing hunger as well as environment issues. In addition to this the world population is also growing, and by the end of 2050, 70 per cent of more food will be needed to feed the future population (Rezaei and Liu 2017). Therefore, to feed the increasing human population and to decrease the damage done to the environment, food loss should be reduced to the minimum level. The reasons behind the food loss and food wastage in the developing country are completely different from that of the developed countries. The main reasons behind the loss and wastage of food in both the type of countries was identified by (Dora et al 2021). The Table 3 given below shows the major causes of loss in food and wastage in developed as well as developing nations.

According to the UNEP Food Wastage Index Report (2021), the maximum food wastage is done by the lower middle-income groups which is equal to 91 kg/capita/year followed by high income group countries (79 kg/ capita/year). China and India together are producing more household food waste than any other country to the tune of 92 and 69 million metric tons every year, respectively. This fact is not surprising as both countries are having the largest population globally. Food wastage has often been thought to be concentrated in countries with higher income, however, in terms of wastage per capita, there are similarities between developed and developing nations. It is estimated that per capita food waste production is higher in Western Asia and Sub Saharan Africa. The total amount of annual household food wastage produced in selected countries is depicted in the Figure 1.

Food wastage and its impact on food security in India: According to an estimate 30 to 50 per cent of the food produced in the world is never consumed (Agarwal et al 2013). Food security is a serious issue in the country that is a result of food wastage. According to a project held at Wageninsen University, India is producing adequate amount of food to satisfy every individual but approximately 30-50 per cent food loss is seen in the supply chain and consequently this food becomes unavailable to the general public which results in undernourishment and hunger. Approximately 7 million children in India have died from starvation and malnutrition, and over 194 million people are undernourished. Despite India's high levels of food production, food security is the major problem prevailing in the country. Our country ranked 94th out of 107 nations. The graph shows the trend of Global Hunger Index score from 2000 to 2022.

The graph indicates that the Global Hunger Index Score has increased from 2014 (28.2) to 2022 (29.1). Contrastingly there was increase in the production of food grains from 252.02 million tonnes during 2014-15 to 316.06 million tonnes in 2021-22 (PIB, 2022). But due to food loss the food produced was not available for the general public especially to the lower income group. Therefore, food loss and wastage is considered to be a serious problem that affects our food security. According to a project report given by Wageningen

Table 1. Quantity of food grains (Wheat and rice) that damaged in godowns of FCI during 2016-17 to 2021-22 in lakh metric tonnes

Year	Quantity handled (offtake)	Damage Accrued in godowns	% of damaged food grains to the total of offtake
2016-17	473.31	0.09	0.02
2017-18	452.16	0.03	0.01
2018-19	500.08	0.05	0.01
2019-20	455.13	0.02	0.00
2020-21	688.57	0.02	0.00
2021-22	766.08	0.02	0.00

Source: India stat (FCI report FAO 2021-22)

Table 2. Summary of food loss damage from 2017 to 2020

Year	Quantity of damaged food grains (in MT)
2017-18	2663.49
2018-19	5213.36
2019-20	1930.36

Source: PIB (FCI report FAO 2020)

University and research over 194 million people from India are suffering from undernourishment and almost 7 million children perished from starvation and malnourishment. On the other hand, although the nation produces enough food to feed its people, about 40% of it is wasted or lost. The total value that is estimated for the wastage is around 6 billion euro per year. Apart from food wastage, post-harvest losses in India is also a concerning issue. According to NABCONS study done in the year 2022, the post-harvest losses are as follows; cereals (3.89-5.92 per cent), pulses (5.65-6.74 per cent), oilseeds (2.87-7.51 per cent), fruits (6.02-15.05 per cent), vegetables (4.87-11.61 per cent). According to a report by ICAR-CIPHET the losses are higher in eastern as well as hilly regions (Eastern Maharashtra, Jharkhand, Chhattisgarh and Odisha) and the east coast (Tamil Nadu, Andhra Pradesh, and Odisha coasts) (Jha et al 2015).

Factors responsible for food wastage and loss: Various factors contribute to food loss and waste, depending on the nation's economic circumstances. In developed countries, food loss primarily happens during the consumption stage as a result of food waste in restaurants, hotels, and other establishments; in underdeveloped countries, food loss is a big problem during the production stage. (Calvo-Porral et al 2017, Godfray et al 2010). Several studies show that age factor is related to the food loss. According to the study of (Secondi et al 2015, Stancu et al 2016) elder people waste less food than young people while some studies showed that food waste increases with age (Cecere et al 2014). Women were held responsible for more food wastage than man in a study done by (Visschers et al 2016), whereas vice versa situation was suggested in the study of (Cecere et al 2014, Secondi et al 2015).

Furthermore, the study done by (Secondi et al 2015) showed that that food loss occurs in case of who are engaged in any kind of employment while some studies showed that there is zero or no correlation among income of a person and food loss (Wenlock et al 1980). Other than these socio demographic factors other factors such as planning habits, knowledge, awareness, personal and subjective norms, etc are also held responsible for the loss of food in the study of (Graham et al 2014, Visschers et al 2016). Food loss and wastage also varies from commodity to commodity (Ahumada and Vilalobos 2009). Poor planning structure of harvesting such as its handling techniques, time of harvesting, inspection, etc. are also majorly responsible for post-harvest losses (Raut and Gardas 2018). The main causes of food loss during the storage stage are inadequate packaging and storage conditions. (Murthy et al 2009, Manikas and Terry 2009). Sometimes during long distances of travel the food and its quality gets deteriorated due to improper transportation conditions (Cai et al 2008, Rijpkema et al 2014). Behavioural issue is another reason which is also responsible for the loss of food at consumer level (Parfitt et al 2010).

Consequences of Food Loss and Wastage

Environmental loss: Food loss is not also responsible for food security issues but is proven to be a threat for our environment too. It represents the depletion of natural resources needed in the production of food, such as land, water, energy, etc. As a result, it also causes greenhouse gas emissions. (Gustavsson et al 2011). Food loss and wastage is responsible for almost 8 per cent of anthropogenic greenhouse anthropogenic gases (FAO 2013). FAO has also quantified food wastage footprint on natural resources, mostly it is identified as carbon footprint. Statistically, 3.3 billion tonnes of carbon dioxide are produced annually as a result of food waste. Based on FAO estimates, if food waste were a nation, it would rank third globally in terms of emissions.

Carbon footprint intensities: The entire amount of greenhouse gasses released during a food product's lifecycle is measured in kilograms of carbon dioxide equivalents, or its "carbon footprint." Carbon footprint is different for different food products since they have different life cycles. It can be shown in the following diagram. Cereals almost contribute 80 per cent for the carbon footprint followed by the animal products like eggs, meat, milk, etc. As far as fruits and vegetables are concerned carbon footprint created by this group is 6 per cent and the least is created by roots, tubers and pulses of 1 per cent. According to a study done by (Bernstad et al 2015, Salemdeeb et al 2017) food loss and wastage can save greenhouse gases emission ranging from 800 to 4400 kg carbon di oxide equivalent per ton food wastage.

Various approaches for managing food waste: The handling of food wastage can involve a wide variety of practises, including feeding garbage to animals, composting (which produces organic fertilisers), anaerobic digestion, incineration, and landfill disposal. Adhikari et al (2009) observed that illegal open dumps and landfills are the major ways that are involved regularly in the food waste management because of their high use rate for managing the wastage. The most prevalent way for treating food wastage in poor nations is dumping or putting it in landfills, which accounts for more than 90 percent of food wastage treatment, composting is the second most popular method, making for 1–6% of food wastage treatment. Anaerobic digestion is used to treat 0.6% of food waste, while alternative treatments like burning and feeding waste to animals are only very seldom used. Other than these there any many other approaches for food waste management (Fig. 2).

Food wastage used as animal feed: Animals make up 33 percent, 81 percent, and 72 one percent of the total amount of food waste generated, respectively (Gen et al 2006, Kim et al 2011). Laws in Taiwan, South Korea, and Japan all support feeding animals with food wastage. Because separating and collecting of food waste is not adequately practised in poor nations, almost all of the food waste that is generated is mixed with municipal solid waste, which cannot be purified and used for feeding of animals. As a result, almost all of the FW that is generated is wasted.

(UNEP Food waste index report 2021, Statistica)

Fig. 1. Total amount of annual household food wastage produced in selected countries

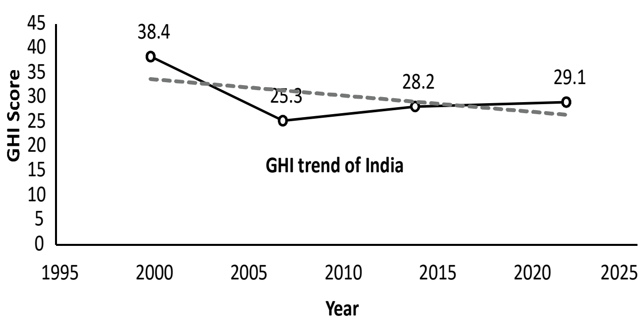

Fig. 2. Graphical representation of GHI score trend for India

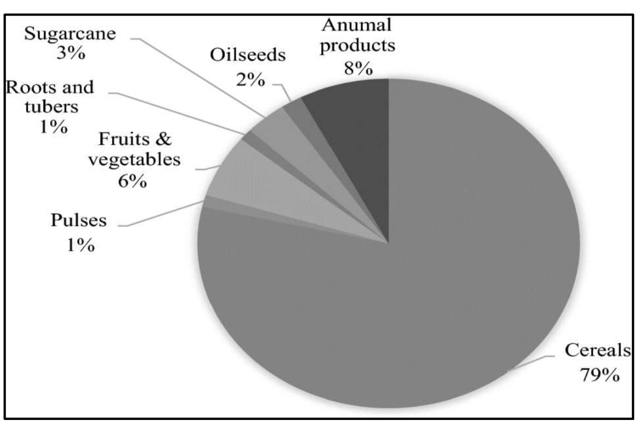

Fig. 3. Contribution of different crops to carbon footprint (Kashyap and Agarwal 2020)

Anaerobic breakdown of food waste: Since the year 2006, anaerobic digestion (AD) has been widely used for the treatment of food waste in several Asian and European Union nations (Abbasi et al 2012). However, in underdeveloped nations, AD is not yet widely used as a useful therapeutic approach for the management of food waste. According to Christian and Dubendorf (2007), a number of organisations and non-governmental organisations in China and India have established a variety of digestors which are anaerobic in function on a residential and commercial level to enhance AD technique. For example, India has established biogas facilities that are used by numerous institutions and has experimented with AD implementation. In spite of the fact that AD facilities based on food waste have not been built yet at significant level in China, twenty co-fermentation AD projects involving municipal solid waste, farm waste, and manure are either in the planning stages or are already in operation. However, according to Christian and Dubendorf (2007), the majority of these AD is not functioning well as a result of technological problems, inefficient activities, or managerial regulations. Composting and AD are usually used together in Indonesia, the Philippines, and Vietnam for the purpose of waste management in landfills. During this same time period, Jamaica and Thailand have made significant strides towards integrating food waste treatment facilities by utilising AD and the aerobic composting technology, respectively. According to Christian and Dubendorf (2007), the facility in Rayong, Thailand, utilises organic municipal solid waste from the left food, vegetables, and waste from fruit in order to make fertiliser that is organic in nature and bio gas. The Share Biogas Group in the country of Jamaica converts waste wood into biogas using agricultural residues in order to supply electricity to outlying communities.

Composting of food waste: In underdeveloped nations, composting is an important and efficient method for reducing the amount of food waste that is produced. More than 70 composting facilities currently operate in India, handling

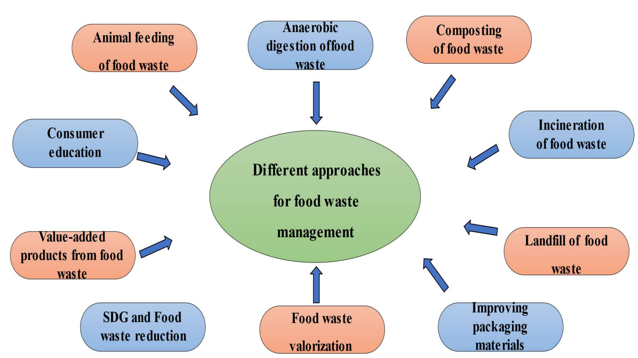

Fig. 4. Different approaches for food waste management

mixed municipal solid waste (MSW). In order to generate more than 4.3 million tonnes of compost annually, these facilities recycle up to 5.9% of the total quantity of food waste. The majority of composting facilities will take mixed garbage, however there are at least two facilities in India, one each in the cities of Vijayawada and Suryapetare, that will take organic waste that has been source-separated (Ranjith et al 2012).

Incineration of food wastage: By burning waste food in an efficient manner, one can cut down on the amount of garbage generated and the size of the landfill that is necessary. This method has been implemented in many countries, including the USA and Singapore (Khoo et al 2010). When compared to other treatment options, incineration is an expensive process because to its high maintenance and heavy capital cost. Furthermore, it demands expensive equipment and highly sophisticated processes in order to cut down on the amount of petrol emissions that are left over. Yates and Gutberlet (2011) recorded the practise of incineration for the treatment of food waste is not widely utilised in developing countries, like Ukraine and Brazil.

Landfill of food waste: Open dumps and landfills are the principal methods for treating FW that are utilised in all developing countries. Open air dumps and landfills accounts for ninety percent of total amount of food waste that is disposed of in landfills. According to USEPA (2020) number of contemporary landfills are able to potentially capture dangerous emissions from landfills and transform them into the electricity. Adhikari et al (2006) mentioned the percentage of foreign waste that has not yet been separated from municipal solid waste (MSW) is estimated between 20 and 80 percent worldwide. Currently, South Africa, Belarus, China, Jamaica, Ukraine, Nigeria, Vietnam, Brazil, Turkey, Malaysia, Mexico, Costa Rica, Romania, and South Africa are among the nations that dispose of their unsorted foreign garbage in landfills. Other participating nations are Jamaica, South Africa, Belarus, China, and Ukraine. Due to the fact that food waste can break down on its own, landfills are not currently considered a viable alternative for treating food waste (Louis 2004). This is because there is also a risk that food waste in landfills could produce disease vectors. In addition, according to (Adhikari et al 2009), greenhouse gas emissions could rise by 8% as a result of disposing of municipal solid waste in landfills.

Consumer education (awareness): Awareness involves teaching consumers to reduce and recycle food waste. Consumer education needs incremental changes in household food shopping, consumption, and storage habits (Caldeira et al 2019). One of the best ways to reduce food waste is through consumer education, which has an annual potential economic value of $2.65 billion in the US and a diversion potential of 584,000 tons (Soma et al 2020). Southern Italian case study shows how consumer behaviour affects family food waste. According to the survey age and

Table 3. Major causes of loss in food and wastage in developed as well as developing nations

On farm	Manufacturing	Storage	Distribution and retail or wholesale	Consumption	Hospitality/service industry
Developed countries					
Over production	Lack of training/worse processing ability	-	Logistic constraint	Consumer preference	Lack of staff capacity
Unharvested products remained on field	Product defects	-	Inaccurate ordering	Strong focus on freshness	Lack of staff
Poor forecasting	Rigorous quantity demand	-	Poor forecasting	Inaccurate planning of purchase	Operational barriers
	Poor Packaging	-	Overstocking	Lack of knowledge to reuse leftovers	Infrastructure
		-	Exceeding expiry date	Behaviour of households	Eating environment
Developing countries					
Poor infrastructure	Use of poor packaging	Poor infrastructure	Pathological loss	-	-
Lack of scientific techniques	Crop loss because of no aesthetic value	Lack of cold storage	Long distance travel	-	-
Poor growing techniques	Crop loss due to inefficient processing techniques	Pest and mold attack	Poor roads facilities	-	-
Low quality equipment for harvesting		Microbial infestation	Inadequate logistic infrastructure	-	-

Source: Dora et al (2021)

education affects food waste. Younger people and the less educated wasted more food (Annunziata et al 2020). Community engagement may be a way to promote food waste reduction and its effects. Participants reduced the food wastage by 50% through Yamakawa, engagement workshops of William community (Yamakawa et al 2017). This shows the power of consumer education. Reducing home food waste can be achieved by extending the shelf life of food, chilling it down and storing it safely, reading labels, finding new uses for leftovers, and sharing excess (Tomson 2018). The World Food Programme estimates that if food waste is minimized, it could feed two billion people annually, 815 million of whom would be able to lead healthy, active lives, and 25% of undernourished individuals in developing nations (World's food waste article 2020). Gamification, such as smart bins (Lim et al 2017, Bandyopadhyay et al 2017), bin cans (Comber et al 2013), and fridge cans are used to monitor and provide food waste feedback. Gamification is the application of game elements outside of games to influence consumer behaviour in online retail through applications (Tobon et al 2020). Consumers will comprehend the impact of food waste on environment and why it should be decreased through environmental campaigns (Lindgren et al 2018). Different rubbish bins are used in industrialised countries. Bin separation shows fundamental understanding of food waste owing to separating the waste at the source. Developing countries lack separation from the sources and municipal garbage pickup.

Improving packaging materials: In order to reduce food waste, items must have better packaging materials to increase their shelf life and improve their quality (Caldeira et al 2019). Retail food waste can be decreased if food products with short shelf lives or those that are about to expire can be made inexpensive and offered at a discount which will encourage customers to buy them off the shelf before they go bad and gets waste. Therefore, if the supply cannot keep up with the demand, food goods that are perishable or have a short shelf life shouldn't be overstocked. These food items can also be donated to non-profit food bank organisations or charitable trusts that assist the underprivileged, such as the homeless, low-income people who cannot afford to feed their families, and the poor (Lindgren et al 2018).

Table 4. Average amount of food wastage for different income groups for different nations (kg/capita/yr)

Income groups	Average food wastage (kg/capita/yr)		
	Household level	Food service level	Retail level
Higher income countries	79	26	13
Upper middle income countries	76	Data not found	
Lower middle income countries	91	Data not found	
Lower income countries		Data not found	

Source: UNEP food wastage index report 2021

Food waste valorisation: The adding value to food is the process of valorising food waste. Valorisation refers to turning excess food into goods with increased value or using leftovers or undesired food products-like peels-to make animal feed (Caldeira et al 2019). Food waste generating in huge amounts worldwide along the supply chain has become a valuable resource that can be used as a raw and intermediate material to produce high-value goods. Examples of such products include straw from paddy fields and shrimps used to make packaging materials for food, as well as fuels and chemicals (Cecilia et al 2019, Elhussieny et al 2020). The key component of successfully valuing food waste may be the application of the biorefinery idea. A variety of bio-based goods can be made from food waste. A biorefinery utilising food waste can partially supplement a refinery based on fossil fuels and tackle the main factors driving the bio economy, including resource security, ecosystem services, and climate change (Girotto et al 2015).

Sustainable development goals (SDG) and reduction of food waste*:* According to Sustainable Development objective 12.3 (FAO(UN) 2020), “By 2030, to half per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses”. Minimum food waste reduction initiatives are needed (FAO (UN) 2020). Reduction in food wastage will address second and twelfth sustainable development goals of zero hunger and sustainable production and consumption, respectively (FAO 2020). Many have urged adapting the sustainable development target to reduce the food wastage. World Business Council for Sustainable Development (WBCSD) case study found that DuPont improved the viable shelf life of plant-based European Yoghurt by 10 days, reducing food waste significantly (Thrane 2012). Using a specially engineered bacterium to increase the viable shelf life of plant-based fermented food reduced European yogurt waste by 30% and supply chain waste owing to early expiration (Thrane 2012). A spinach drying case study was published by International Flavours & Fragrances (IFF). The company suggested drying spinach into powder using mild infrared drying to preserve nutrients, colour, and flavour. Hershkowitz (2012) reported that this strategy reduced food wastage and earned 1.3 million USD. This method enables homes to buy powdered spinach for drinks or snack bars, increasing vitamin K intake. Innovative food waste reduction improves nutrition and food security, promotes sustainable development and efficient utilization of natural resources, and lowers production costs, meeting the SDGs 2 & 12.3 goal of zero hunger, per global capital waste at retail and consumer levels, and food losses, respectively, along global production and supply chains by 2030.

Value-added products from food waste*:* Reduce, reuse, and recycle policies should guide food waste management (Mamma 2020). A sustainable bio economy can develop innovations and value from biowaste, leftovers, and discards. Biofuels from food waste are in keeping with 2015 UN 2030 Agenda for Sustainable Development. More specifically, it relates to the 7th sustainable development goal of affordable and clean Energy, 12th goal of responsible consumption and production and 13th goal of climate action and incentives to help merchants and consumers to minimise food waste to 50% by 2030 (Commission 2018). Reusing food by products and converting food waste is still limited (Mamma, 2020). Food waste and its measurement along the food supply chain, quality and homogeneity data, and national waste legislation implementations are now barriers (Prasoulas et al 2020). Effective and stable food waste biofuel and bioproduct production is gaining attention (Girotto et al 2015). Food waste is now considered as a viable raw material containing carbohydrates (30 to 60%), proteins (5 to 10 %) and lipids (10 to 40 % w/w) (Pleissner et al 2013). After solubilizing food waste, chemical and biological/enzymatic processes can extract carbon, nitrogen, and phosphorus molecules. Various research indicates that food waste can be utilized to create animal feed, which will boost livestock output, as it contains high levels of crude protein, minerals, and other nutritionally valuable bioactive substances.

Hydrolysing of food waste is another method which requires phosphatases, cellulases, Makanjuola proteases, and glucoamylases. Makanjuola and Greetham devised a sorghum bran based on biorefining strategy for Aspergillus awamori-based glucoamylase synthesis (Makanjuola et al 2019). The glucoamylase enzyme digested 200 g/L bran of sorghum to create a sugar rich fermentation medium with 38.7 g/L glucose. Sorghum bran hydrolysate can be used as a generic fermentation feedstock for biofuel and biochemical synthesis (El-Imam et al 2019).

Prasoulas and Gentikis (2020) inducted F. oxysporum to produce enzymes from wheat straw, bran and maize cob. They hydrolysed food waste using those enzymes to make ethanol. Déniel and Haarlemmer (Déniel et al 2016) showed that hydrothermal liquefaction can produce liquid fuel from food waste, peels and rinds from fruit juice production can be used to make fibres for confectionaries and frozen meals. Fibre increases the fibre content of goods for the elderly, diabetics, and weight reduction (Badjona et al 2019). In beverage-alcohol fermentation, citrus pulp and molasses are used. Pentose sugars not used by the beverage sector provide great energy for cattle feed (Okonko et al 2009).

By-products of coffee processing include husk and pulp. Its organic content makes it appropriate for value-added products. Soccol Pandey (Pandey et al 2000) suggests using coffee husk and pulp to make fertilisers, livestock feed, and compost. Solid-state fermentation has been used to manufacture enzymes, organic acids, and flavour and fragrance compounds from coffee husk and pulp. Husks and pulp are utilised as organic fertiliser and swine feed (Okonko et al 2009). Farming can also use food waste as organic manure (Lindgren et al 2018). In Nigeria, the dumping of by products from agriculture like trash from cassava crop from processing farms and households also is hazardous to the environment. The conversion of low-value cassava waste into bio sorbent to remove harmful and precious metals from industrial wastewater will reduce environmental pollution and increase market value for millions of cassava producers (Okonko et al 2009). Uzochukwu, Oyede (2011) used cassava garri effluent starch to make 50.1% (v/v) ethanol.

Challenges and Opportunities

At consumer and retail level it is difficult to measure food waste in most cases as it is intermingled and considered non-essential waste (FAO(UN) 2020). The heterogeneous character and high level of moisture in food waste frequently provide challenges for efficient conversion of food waste into valuable products effectively, even with the availability of numerous conventional methods such as landfilling or biogas production (Sindhu et al 2019). A major barrier to effective food waste management is the inability to collect and store food waste in the right ways, as well as to prepare it according to cultural norms and procedures, and to bio convert it into valuable by-products (Lindgren et al 2018, Sindhu et al 2019). Pandemics, natural calamities, and civil upheaval may be responsible for food loss and wastage. The focus switches from the process of gathering and producing or preparing food to just staying alive and safe in such circumstances. Food waste results from a lot of items being neglected and receiving little care, which compromises their integrity and wholesomeness from the farm until they are sold to customers. There are still restrictions to the utilisation of food waste and by-products. There is presently little information available on the generated food quantity in the supply chain, as well as inconsistent national waste regulation implementation and a lack of statistics on the waste's quality and uniformity. As mentioned previously, food waste's composition is unstable. There are notable seasonal, regional, and nutritional differences that are associated with it. Anaerobic breakdown is one of the important methods of recycling food waste to achieve zero emissions, even with the unavoidable change in the composition of collected garbage (Mamma 2020). High moisture content, a high microbial load, and presence of antinutritional components in plant-based crops and food that may inhibit nutrient absorption are some of the problems that restricts converting the food waste to animal feed (Nikmaram et al 2017). But if adhere to food waste guidelines, can overcome this difficulty. Food waste utilisation has advantages from an environmental perspective as it lowers the methane gas emissions from landfills, preserves the natural resources like coal and fossil fuels, and brings social benefits due to the debate over fuel vs food (Girotto et al 2015). In order to achieve zero emissions, reduce health and environmental problems related to food waste landfills, and reap economic and social benefits, food waste must be effectively used as an intermediate raw material for the manufacturing of value-added finished products. A few technologies for food waste valorisation process have previously been established at the pilot size in the field of hydrothermal liquefaction (Déniel et al 2016). This is still an active research topic. In the process of developing HTL processes, the industry continues to face both technological and financial obstacles.

Future Prospective

The significant problems of food wastage and food loss appear to have a bright future in terms of how they will be addressed. New technologies, such as upcycling processes and management of supply chains powered by artificial intelligence, offer creative answers to the problems of excessive waste and inefficient utilisation of resources. Additionally, the shifting policy landscape is driving food waste legislation, sustainable packaging initiatives, and economic incentive programmes, which together provide a supporting framework for the reduction of waste. Local communities are given the ability to reduce food wastage and redirect the food in surplus quantity to those who are in dire need with the help of initiatives that are led by communities such as networks involved in food recovery and urban agricultural programmes. Even though obstacles still exist, these recent advancements point to a more promising future in which we will be able to construct a system that is more sustainable in nature and robust, hence reducing food wastage and maximising the value of our food resources.

CONCLUSION

It is essential to develop methods of managing food waste that are sustainable because it continues to present a substantial burden to society. Effective and efficient food waste management has positive global effects on the economy, society, and environment. Redistributing extra food to those in need or social services is a significant step in the process of forming a sustainable system for managing wastage of food. Furthermore, domestic trash, products sold by retailers that is not suitable, and agricultural wastes can all be used as feedstock to make value-added goods like colorants, enzymes, and biofuels. It is possible that educating the general people about how to consume food effectively during a pandemic plays an important role in avoiding future food wastage and ensuring that everyone has access to food. Furthermore, utilizing food waste as a feedstock for producing energy appears to be a viable option. Moreover, the utilisation of biotechnological process used for converting food waste into products with additional value is an essential approach to maximise the utilisation of food wastage, therefore it will decrease the detrimental effects that food waste has on the environment and human health.

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Received 16 February, 2024; Accepted 10 June, 2024

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Indian Journal of Ecology (2024) 51(4): 707-718
DOI: https://doi.org/10.55362/IJE/2024/4298

Manuscript Number: 4298
NAAS Rating: 5.38

Host Microbe Interaction in Soil

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Abstract: Soil is a dynamic and complex environment, comprising of myriad of microbes which contribute towards maintaining soil health and promoting plant growth. The microbe-microbe or plant-microbe interactions happen in the soil which can be positive or negative. Positive interactions include mutualism, syntrophism, commensalism and proto-cooperation whereas negative interactions include predation, parasitism, competition and ammensalism. Majority of plant-microbe interactions occur in rhizosphere because of the high concentration of root exudates. Root exudates help to establish host and microbe communication. Root exudates contain flakes of root cells, mucilage, carbon compounds, amino acids, phenols etc. The primary step in establishing an interaction is recognition of the host cell by the microbe. Microbe recognizes host-signaling molecules like secondary metabolites, siderophores, etc. Additional mechanism includes transduction signaling, biofilm production and transference of molecules and genetic information. The interactions are prone to environmental factors like temperature, moisture, circadian clock and nutritional status of soil. To study the plant-microbe-environmental interaction, a mathematical expression called metabolic modeling is used. It supports stoichiometry analysis of metabolic reactions. Efficient agro-climatic ecosystem and bioremediation of pesticide polluted soil can be achieved by exploiting plant-host interactions for realizing agriculture sustainability.

Keywords: Environment, Metabolic modeling, Plant-microbe interaction, Root exudates, Secondary metabolites

Soil impacts the above ground and below ground factors which support the growth of plants. The zone of soil extending few mm from the surface of root is known as the rhizosphere. It is this space where all interactions occur (Zhang et al 2020). There are many different types of microbial interactions that occur between various organisms in the rhizospheric soil. Microbial interactions are vital for their development, colonization and infection. A wide range of interactions that promote associations, such as mutualistic and endosymbiotic relationships, as well as competitive, antagonistic, pathogenic, and parasitic relationships, have developed as a result of the long history of co-evolution among many species (Faust and Raes 2012). These relationships have also led to adaptation and specialization among various organisms. All ecological components of the interactions include physiochemical changes, metabolite conversion and exchange, signaling, chemotaxis, and genetic exchange leading to genotypic selection. The release of root exudates causes the principal plant-microbe interactions to take place in the rhizosphere. Root cell flakes, mucus, carbon compounds, amino acids, phenols and other substances are found in root exudates. Microbes can identify these host signaling molecules in addition to secondary metabolites and siderophores. Microbial interactions in the rhizosphere also result in the production of biofilms, the transfer of chemicals and genetic information, and the transduction of signals. These interactions are sensitive to environmental factors like soil nutrition, temperature, moisture and circadian rhythm. They can be analyzed and even predicted by metabolic modeling to get greater information about relationship between environment, microbes and plants. Exploiting the interactions between plants and their hosts can result in a conducive environment which promotes agriculture sustainability.

Host Microbe Interaction in Rhizosphere

One of the most complicated ecosystems is the rhizosphere, which consists of the small, limited area where soil meets plant roots. It is home to a variety of microorganisms and invertebrates that have an impact on biogeochemical processes, plant growth and stress reduction (Bano et al 2021, Philippot et al 2013). Notably, the rhizosphere offers a rich environment in which numerous microbial communities, including some that are beneficial to plants flourish. These communities, also found residing endophytically in plants, help the plant adapt to its surroundings more effectively. The two primary phases in establishing the rhizomicrobiome in the rhizosphere are chemotaxis and colonization. Root exudates play an important function in the chemotactic migration of rhizospheric bacteria to roots and early colonisation because they are both a vital source of nutrition and signaling molecules for them. Also, root exudates secreted in the rhizospheric zone influence the relationship between plants and microbes by attracting particular rhizobacteria, beneficial fungi, mutualistic arbuscular mycorrhizal fungus (AMF) *etc.* that promote plant growth. Root microbiome constructed from rhizospheric microbial communities benefit plants through the formation of biofilm (mediated by quorum sensing), the synthesis of plant hormones (Indole Acetic Acid), nitrogen fixation and antibiosis (Jain et al 2020). Root exudates containing flavonoids are known to attract phytopathogens including *Fusarium solani* and *Phytophthora sojae* as well as symbiotic nitrogen-fixing *Rhizobium* and Arbuscular Mycorrhizal Fungi (AMF) (Del Carmen Orozco-Mosqueda et al 2022). Root exudates, in addition to acting as signaling molecules, chemo-attractants and stimulants, can also occasionally function as repellents and inhibitors in the multipartite interactions with rhizospheric microbial soil associations. Root exudates are continuously modified in response to the immediate changing environment. They have a reputation for moderating the early conversation between soil microbes and roots (Gamalero et al 2022). Root exudates have recently been found to be highly effective at luring soil microbes, according to a research using $_{13}$C labeling method (Lange et al 2015).

The synergistic relationships that plants have with rhizospheric microorganisms, such as rhizobia and AM fungus are well documented. These relationships enhance plant nutrition by facilitating the acquisition of nitrogen and phosphorus, in exchange for fixed carbon from plants (Oldroyd 2013). Application of VAM @ 10 ml per plant increased the germination and vigour of *Anthocephalus cadamba* seedlings (Chauhan et al 2023). Rhizobia are recognized as forming symbiotic relationships with legumes and *Parasponia* species whereas AM fungi are recognized as interacting with more than 80% of vascular plants. Bio-inoculation of *Neobacillus niacini* increased seed germination by 23.2% in *Vigna mung* L grown in high salinity stress (John et al 2023). The foliar application of water soluble fertilizers and PGPR significantly increased nodule count in black gram (Babu et al 2023). Along with siderophores and volatile substances like hydrogen cyanide fluorescent *Pseudomonas* in the rhizosphere is known to produce a wide range of other chemicals as siderophores. Organic acids, significant fraction of roots exudates, are known to control plant-microbe interactions (Chen et al 2012). It is recognized that organic acids, particularly those from the tricarboxylic acid cycle, serve as carbon sources and signaling molecules (Yuan et al 2015)

Several plant species use chemical signaling from root exudates to control other plant members, insects, nematodes, soil bacteria, and fungus. Rhizosphere-based chemical warfare occurs when a plant pathogen repeatedly attacks the plant and the plant responds by secreting defense proteins, phytoalexins and phenols to meet the threat. Comprehensive sequencing is used by a variety of plants, including *Arabidoposis thaliana, Medicago truncatula*, rice, maize, and others to find abundant supplies of antimicrobials, indoles, terpenoids, flavonoids and other natural compounds (Singh et al 2023). Phytoalexin generated by *Arabidopsis* root exudates provide resistance to *Phytophthora capsici*. Similarly, resistance to *F. graminearum* was afforded by the secretion of derivatives of cinnamic acid in barley (Wang et al 2013). The non-protein amino acid canavanine and other compounds have been shown to interfere with quorum sensing (QS), nodulation and the formation of EPS II, acting as suppressors of N-fixing bacteria (D'Mello 2015). The ability of some rhizobial strains to detoxify canavanine makes them favorable to other rhizospheric microorganisms found in legume roots (Vukanti 2020). Strong external antibacterial properties of phenols and terpenoids have long been recognized. They increase tolerance to biotic and/or abiotic stimuli by fostering metabolic flexibility inside the plants (Jain et al 2020).

Mechanism of Host-Microbe Cross Talk

Plant exudates in the soil are recognized by microbes as the initial stage of plant-microbe interaction. The exudates from plants, which are made up of organic acids, amino acids, and carbohydrates can change depending on the plant and its biotic or abiotic environment (Haldar and Sengupta 2015). The variety of processes, including secondary metabolites, siderophores, quorum sensing systems, biofilm formation, and cellular transduction signaling are involved in the exchange of molecular and genetic information. The expression of genes of each organism in response to environmental (biotic or abiotic) stimuli is the fundamental unit of interaction and generates the molecules that are a part of these interactions. Microorganisms grow into a community through these mechanisms. They may exhibit great variations depending on the multitrophic interactions. Cells may communicate and act in accordance with their surroundings through the synthesis of signaling molecules (also known as auto-inducers). Microbial-Associated Molecular Patterns, also known as PAMP (Pathogen Associated Molecular Patterns) are conserved at generic level (Phelan et al 2012). These facilitate cell to cell communication.

Signal Transduction

All biochemical procedures known as "signal transduction" are used by cells to convert environmental cues into targeted responses. It is now believed that signal transduction occurs through highly organized networks where a small number of modular domains regulate protein-protein interactions and the reversible construction of signaling complexes. Cell signaling can be divided into three stages *viz.,* reception, transduction and response. A signaling molecule is picked up by a cell from the extracellular environment. Signal is recognized when a signal interacts to a receptor protein either inside the cell or on its surface. Then, a change in the receptor protein occurs. Transduction is started with this modification. The pathway for signal transduction involves many steps. Each relay molecule modifies the subsequent molecule in the signal transduction pathway. Later, certain cellular responses are prompted by the signal (Zschiedrich et al 2016).

Quorum Sensing

Bacterial cells communicate with one another using quorum sensing (QS). In order for bacterial communities to express their genes collectively, this procedure involves the creation and detection of signaling molecules (known as auto-inducers) (Hawver et al 2016). Gram-negatives and Gram-positives express QS genes in different ways. The signaling molecules acyl-homoserine-lactones (AHLs) in Proteobacteria or cis-11-methyl-2-dodecanoic acid (also called diffusible signal factor-DSF) are present in Gram negatives like *in Xanthomonas* and *Xylella* and gamma-butyro lactones in *Streptomyces* and peptides are found in Gram positives (Rai and Bai 2020)**.** The first QS system was identified in the *Vibrio fischeri* (formerly known as *Photobacterium fischeri*) bacterium in the 1980s. It has a low population density in the sea and does not glow. It glows when it is in a symbiotic relationship with fish and squid. The transcriptional regulator *R* and the autoinducer synthase *I*, also known as *LuxR* and *LuxI*, are two proteins that are involved in the QS system in Gram-negative bacteria. Thus, QS can play a variety of roles, such as fluorescence emission, virulence, sporulation, competence, antibiotic production and biofilm formation (Hawver et al 2016). It can also act during the interaction of various organisms, such as bacteria-bacteria, fungal-bacteria, and bacteria-host (animals or plants). About 6–10% of the microbial genomeis regulated by Quorum sensing (Braga et al 2016).

Biofilm Formation

Bacterial pathogens typically go through five main stages while forming biofilms on every substrate or layer (Srinivasan et al 2021). These stages include attachment, colonisation, proliferation, maturation and dispersion. Initially, free-swimming planktonic cells reversibly bind to biotic or abiotic surfaces by weak interactions like acid-base, hydrophobic, Van der Waals and electrostatic forces. Stronger connections, such as those involving lipopolysaccharide, flagella, and pili allow pathogenic bacteria to permanently attach to surfaces and form colonies. Then large amount of EPS is produced and the multilayered bacterial cells get accumulated. In maturation and dispersion stage, the coupled multilayered bacterial cells developed into a mature biofilm with a typical 3D biofilm structure. After biofilm has fully developed, it is broken down or dispersed *via* mechanical and active procedures (Srinivasan et al 2021).

Siderophore

Small chemical molecules known as siderophores are created by microbes when there is shortage of iron. They help the microorganisms absorb iron more effectively. Bacteria release siderophores into the surrounding environment, which are detected by cell surface receptors and carried inside the microbial cell (Khasheii et al 2021). Thus, they are related to both cooperative and antagonistic microbial interactions. In addition, many siderophores serve other functions, such as those of signaling molecules, oxidative stress-reduction tools, antibiotics and metal sequestration agents, including those for heavy metal toxins (Johnstone and Nolan 2015). Some *Pseudomonas* species are dependent on a group of siderophores called pyoverdines, which are helpful in regulating bacterial growth for the formation of biofilm and infection (Ghssein and Ezzeddine 2022). Exotoxin A, Prp Leudoprotease and pyoverdine among other virulence factors are said to be produced as a result of a cascade that is allegedly initiated by pyoverdines (Lamont et al 2002).

Secondary Metabolites

Microorganisms often react by exchanging metabolic products which triggers complicated regulatory reactions involving the formation of secondary metabolites. Secondary metabolites include nitrogenous compounds, phenolic compounds, glycosides, tannins, terpene compounds, and flavonoids which are produced by microorganisms. They do not play a crucial role in the growth, development and reproduction of the producing organism. But these substances can play crucial roles in ecological interactions and are typically bioactive (Yin and Keller 2011). The roles of secondary molecules are extensively researched in endophyte-phytopathogen-plant interactions, parasite interactions, and symbiotic interactions.

There is still a great deal of diversity regarding the metabolites and mechanisms behind the interactions between the host plant, phytopathogen and endophyte. Endophytic fungi are known to produce a wide range of bioactive secondary metabolites that are connected to the endophyte complex interactions with the host and phytopathogens. These compounds carry out significant ecological functions such as promoting plant growth and acting as phytopathogen defense agents (Narayanan and Glick 2022). These interactions have been researched in co-cultures of the endophyte *Trichoderma harzianum* and phytopathogen *Moniliophthora roreri,* which live together in cacao plants. *Moniliophthora roreri*, a phytopathogen, and

Trichoderma harzianum, an endophyte, which coexist in cacao plants, have been co-cultured to study this relationship. *M roreri* is known to be antagonistic to *T harzianum*, which is widely used as a biocontrol agent (Tata et al 2015). Four secondary metabolites (T39 butenolide, harzianolide, sorbicillinol and an unidentified chemical), whose formation was reliant on the presence of phytopathogens were spatially localized in the interaction zone (Tata et al 2015). There have been reports of antifungal activity for harzianolide and T39 butenolide. Bisorbicillinoids, a family of secondary metabolites with a variety of functions, are produced *via* sorbicillinol as an intermediary (Bouthillette et al 2022).

Bacteria were used in other co-cultured research studies. The citrus variegated chlorosis phytopathogen *Xylella fastidiosa* was shown to be inhibited by *Methylobacterium mesophilicum* SR1.6/6 and *Curtobacterium* ER1.6/6 isolated from healthy and asymptomatic plants by Lacava et al (2004). *In vitro* co-cultivation with a citrus endophytic strain of *Methylobacterium mesophilicum* also allowed for the evaluation of *Xylella fastidiosa's* transcriptional profile (Lacava et al 2004). It was discovered that growth-related genes including those responsible for DNA replication and protein synthesis were down-regulated. Acriflavin resistance, toluene tolerance, *pilY* transporter, and dihydrolipoamide dehydrogenase were up-regulated, whereas genes involved in energy synthesis, stress, transport and motility were down-regulated (Dourado et al 2015). The genome sequencing and transposon mutagenesis of an endophyte strain of *Burkholderia seminalis*, which suppresses *Burkholdia riagladioli's* orchid leaf necrosis, provided another method for studying the relationship between endophytes, phytopathogens and plants. This method identified eight loci that are involved in biological regulation (Araújo et al 2016).

Cell membrane of few bacteria is composed of hopanoids, which serve the same purpose as cholesterol in eukaryotes (Hoshino and Gaucher 2021). They stabilize the membrane in addition to controlling the membrane's fluidity and permeability. Studies using biosynthesis genes knockouts, such as *hnpF* (squa-lene hopene cyclase-shc), reveal that the absence of hopanoids affects bacterial tolerance to a variety of stress conditions, including toxic compounds like dichloromethane (DCM), extremely acidic environments, and other environmental stresses (Ali and Mir 2020). It also affects bacterial resistance to antibiotics and antimicrobial lipopeptides as well as multidrug transport and bacterial motility. Hopanoids thus play a role in the interaction between bacteria and plants, influencing how bacteria adapt to an aerobic microenvironment and a low pH growth medium as well as how *Frankia spp.* metabolizes nitrogen (Schmerk et al 2015). For instance, the nitrogen-fixing bacterium *Bradyrhizobium diazoefficiens* needs a certain form of hopanol to co-exist with its host, the tropical legume *Aeschynomene afraspera* (Kulkarni et al 2015).

Numerous secondary metabolites that were differently expressed during the mycoparasitic interaction between *Stachybotrys elegans* and *Rhizoctonia solani* have been discovered (Chamoun et al 2015). In response, *R. solani* produces more of the gene encoding pyridoxal reductase than *S. elegans* does throughout the encounter. *S. elegans* also expresses genes linked to parasitism and synthesizes enzymes that break down cell walls. Induced secondary metabolite profiles during the interaction were revealed by a metabolomic investigation (Guan et al 2021). The mycoparasite had a considerable impact on metabolism of *R. solani* in that only a few Diketopiperazines were produced. Biosynthesis of many antimicrobial chemicals was down-regulated as a result of the interaction. Among other biological functions, diketopiperazines have antibacterial qualities that are well-documented. Trichothecenes and atranones are the major mycotoxins that the mycoparasite *S. elegans* produced. The alteration in growth and development metabolism of *R. solani* was thought to have been caused by the trichothecenes. An important class of mycotoxins called trichothecenes has been linked to oxidative stress and the inhibition of eukaryotic protein production (McCormick et al 2011).

The symbiotic association between the bacterial species *Burkholderia* and the phytopathogenic fungal genus *Rhizopus*, which causes rice seedling blight, is a complex inter-kingdom interaction (Mir and Hamid 2023). According to a report, *Rhizopus* cannot develop spores in the absence of the endosymbiont, proving that the fungus depends on the production of certain substances by the symbiont for completion of its life cycle. Studies on the metabolites and mechanisms involved in the communication and interaction in this complex symbiont-pathogen-plant connection are intriguing and ongoing work.

Environmental Factors Effecting Host Microbe Interactions

Plant relationships with beneficial microorganisms can be hampered by environmental stressors. Plant signaling pathways linked to defense hormones and reactive oxygen species are induced during stress which explains why environmental factors interfere with plant-microbe interactions. Environmental stressors frequently have an impact on a plant metabolism and physiology which can stunt its growth and ability to reproduce. Stressors also frequently interfere with plants' relationships with useful microorganisms. These microorganisms trigger host mechanisms that effectively reduce the adverse consequences of stressors. Abiotic environmental stressors such as soil nutrition, temperature, moisture and circadian rhythm are a threat to plant microbe interactions.

Temperature: Temperature is an important factor impacting plant microbe interaction as demonstrated that an increase in temperature prevents the development of type IV secretion-associated pilus and the expression of virulence (vir) genes in *Agrobacterium* infections (Velasquez et al 2018). *Pectobacterium atrosepticum*, exhibits greater virulence at higher temperatures. It is linked to increased synthesis of enzymes that break down plant cell walls, quorum-sensing signals and quicker development of illness.

Positive plant-microbe interactions are impacted by a higher temperature as well. Arbuscular mycorrhizal fungi (AMF) typically benefits from higher temperature impact. Plant colonization and hyphal growth are both positively impacted. This is possible because plants are able to allot carbon to the rhizosphere where AMF thrives quickly (Khaliq et al 2022). *Curvularia protuberate*-mediated heat tolerance has been reported in tomatoes. It indicates that the underlying process may be universally relevant to support a variety of plants' ability to withstand high temperatures. Even plants can benefit from some microorganisms' assistance in overcoming various conditions. An example *Burkholderia phytofirmans* strain *PsJN*, is reported to increase plant tolerance to heat in tomato crop, cold in grapevine crop, drought in wheat crop, and salt and freezing in *Arabidopsis* (Issa et al 2018). It has direct antifungal effects which improve plant defense. *PsJN* confers multi-stress tolerance.

Detrimental effects of temperature stress on plants may be reduced by some native rhizospheric bacteria and endophytes. Certain plants tolerate higher temperature while they live in association with other organisms. A mutualistic relationship between a fungal endophyte *Curvularia protuberate* and tropical panic grass *Dichanthelium lanuginosum* allow both species to grow at high soil temperatures. The mutualistic contact is facilitated by a double-stranded RNA (dsRNA) virus from this fungus (Márquez et al 2007). However, this plant and the fungus when present alone are unable to survive at high soil temperatures.

Circadian clock: The relationship between the internal and external circadian clocks and several elements of plant biology is extensive. Transcriptional and translational feedback loops work together to control the circadian clock. *Circadian Clock-Associated1* (*CCA1*) and *Late Elongated Hypocotyl* (*LHY*) are two important morning-phased transcription factors (Karapetyan and Dong 2018). It is generally held that the circadian clock is a self-sustaining system. However, recent studies have revealed that light, temperature and humidity can change some aspects of its operation. Studies have revealed that effector-triggered immunity (ETI) at night is enhanced by humidity implying that at night there's an increase in pathogenic infection (Karapetyan and Dong 2018).

Circadian clock regulates the temporal regulation of PAMP triggered immunity (PTI) against *P syringae* infecting *Arabidopsis* plants (Bhardwaj et al 2011). It has also been demonstrated that *Glycine-rich RNA-binding protein7* (*GRP7*, an RNA-binding protein) binds to the transcripts of the pattern-recognition receptor (*PRR*) genes *Flagellin Sensitive2* (*FLS2*) and *EFTu receptor* (*EFR*) (Nicaise et al 2013). The stomata of plants serve as entry points for a large number of pathogenic and non-pathogenic microorganisms. In response to pathogen invasion, stomatal closure is one of many downstream immunological outputs that PRRs regulate (Melotto et al 2017). *CCA1* and *LHY* may have an impact on the stomata's receptivity to pathogen invasion in a diurnal cycle by controlling the synthesis of PRRs via *GRP7* (Zhang et al 2013).

Microbes also respond or behave differently depending on the time of day. At particular times of the day, fungi and oomycete pathogens produce hyphae, produce spores and spread those spores. However, circadian-modulated pathogenicity is relatively poorly studied. The first instance of a microbial clock influenced plant-pathogen interaction was demonstrated by Hevia et al (2015). Pathogens utilize exposure to light stimulus to start an illness (Hevia et al 2015). For instance, the blue light receptor *Cercospora* regulator of Pathogenesis1 (*Crp1*) in *Cercospora zeae-maydis*, is essential for sensing plant stomata. It possibly mediates the biosynthesis of the light-activated toxin cercosporin. This cercosporin disrupts stomatal guard cell membranes. It facilitates fungal infection through stomata (Kim et al 2011). The pathogenicity of *P. syringae* is impacted by light. Red light inhibits bacterial entry through stomata by down regulating the expression of genes involved in the biosynthesis of coronatine toxin because *P. syringae* needs coronatine to open the stomata to promote bacterial entry. Together, light and circadian rhythm influence plant-microbe interaction alike temperature stress.

Moisture: Water is indispensible to sustain life. Numerous elements of plant and microbial biology can be significantly impacted by low amount of water and too much of water as well. Plants respond to water shortage by a signaling cascade initiated by an increase in ABA and leading to extensive transcriptional reprogramming, physiological modifications, including stomata closure to lessen transpiration (Zhu 2016). FLS2 in *Arabidopsis* recognizes bacterial pathogens like *P. syringae* or PAMPs like flg22 (a 22-amino-acid epitope of *Pseudomonas flagellum*). It causes stomatal closure resulting in lowering of pathogen infiltration (Melotto et al 2006). ABA-induces stomatal closure under drought stress. The mesophyll cells inside the leaf's mesophyll experience inhibition of the SA signaling pathway as a result of elevated ABA, which impairs SA-mediated resistance to invasion (Jiang et al 2010).

Plant-microbe interactions are impacted by drought as well. Researchers discovered that while the composition of microbial communities was influenced by drought in all examined sections (bulk soil, rhizosphere and root endosphere), in drought stressed rice plants tendency of composition change is more when intimate community is associated with the roots (Santos-Medellin et al 2017). Similar findings were made when researchers looked at how soil moisture affected the microbiome of sorghum roots. They discovered that while the richness of the bacterial communities in the soil around the roots remained mostly unaffected, the rhizosphere and the root endosphere were much less diverse during droughts (Xu et al 2018). Actinobacteria and Firmicutes are more prevalent under drought. The root endosphere exhibits the severe decrease in community diversity and increase in abundance of Actinobacteria and Firmicutes. The change in root metabolites results from drought stress on the host side. It is unknown if and mechanism by which drought triggered metabolites "modulate" the root microbiome to support plant stress responses. In times of drought, there are molecular interactions between plants and their associated microbiome. These interactions modify the root microbiota to adapt to drought stress. The basic understanding required to use microbiota to improve drought tolerance in crop plants can be understood by deciphering this molecular conversation (Ali et al 2022).

Many plant disease outbreaks are known to require precipitation and/or high air humidity. The hypersensitive response (HR), phenomena that frequently occurs in plants during ETI, is characterized by cell death at the site of pathogen infection. The HR is hypothesized to stimulate secondary immune responses and inhibit the growth of biotrophic infections. High atmospheric humidity reduces HR cell death in a number of plant-pathogen interactions (Leisner et al 2022). High humidity usually promotes pathogen virulence in contrast to suppressing host immune function. Water and high humidity play in boosting spore germination and bacterial motility before entry into the plant. Additionally, high humidity is essential for promoting bacterial virulence and survival post-invasion (Dechesne et al 2010) An early sign of many foliar diseases is water-soaked lesions, which develop when liquid builds up abnormally inside the leaf cells. Water soaking produces a disease-friendly micro-environment for bacteria, dilution of defense chemicals derived from plants, and/or facilitation of bacterial spread from the original infection sites (Xin et al 2016).

Root disease development is influenced by moisture. The bacterial wilt in ginger plants caused by the soil-borne *Ralstonia solanacearum* is more severe in high soil moisture (Jiang et al. 2018). Under low soil moisture, there is high expression of the *WAK16* and *WAK3-2 WAK* wall-associated kinase genes. *WAK1* is crucial for keeping track of the integrity of cell walls (Brutus et al 2010). The expression of *WAK16* and *WAK3-2* is suppressed by high soil moisture and plants become less resistant to *R. solanacearum*. This suggests that *WAK16* and *WAK3-2* may be crucial in detecting soil moisture and facilitating cell wall-based plant immunity (Jiang et al 2018).

Nutritional status: The pursuit of nutrients is one of the fundamental mechanisms that govern interactions between plants and microbes. Nutritional state of plants and the availability of nutrients in the environment have a big impact on how well plants and microbes get along. It is widely known that both the soil and plant phosphate levels tightly control the complex symbiotic connection between terrestrial plants and phosphate-acquiring AMF (Muller and Harrison 2019). The influence of phosphate on plant-microbe interactions is one aspect of plant-AMF interactions. For phosphorus-acquiring AMF, *Arabidopsis thaliana* is a non-host (Fernandez et al 2019). Hiruma et al (2016) discovered the endophytic fungus *Colletotrichum tofieldiae (Ct)* in wild *Arabidopsis. Ct* is capable of transferring phosphate to *Arabidopsis* where it stimulates plant growth. However, *Ct*-mediated growth promotion can only be seen in plants that have been grown in phosphate-deficient soils. Further research revealed that the stimulation of *Ct*-dependent plant growth required a healthy plant phosphate starvation response (PSR) system (Chiou and Lin 2011). Later research by Hacquard et al (2016) revealed transcriptional suppression of host defense responses in *Ct*-colonized plants during phosphate starvation, which is likely done to promote symbiotic relationship. These two studies show that the nutritional state of the host affects the course of the *Arabidopsis-Ct* interaction. Phosphate starvation of the host results in a mutualistic interaction whereas phosphate sufficiency results in a commensal (i.e., non-mutualistic) interaction between partners.

Symbiotic nodules are formed in the roots of legumes as a result of interactions with *Rhizobium* species. This unique biological mechanism allows for the conversion of atmospheric N_2 to physiologically useful NH_3 to aid in plant growth. However, the formation of nodules is an energetically expensive process for the legume host and is not economically viable when plants are cultivated in an optimum nitrogen environment (Yakha 2022). Plants have evolved auto-regulation of nodulation which maximizes the number of nodules generated in the root based on the requirement of nitrogen in the shoot to prevent high energy cost to the host. The shoot *CLAVATA1*-like *LRR* receptor kinase *Hypernodulation Aberrant Root Formation1* (*HAR1*), which senses *Rhizobium*/nitrate-induced, root-producing *CLV3/Embryo Surrounding Region* (*CLE*) peptides, is one of the main player in regulation of nodulation (Okamoto et al 2013). A root-acting *F-box* protein called *Too Much Love* (*TML*), which transmits shoot-derived inhibitory signals, prevents the growth of nodules after perception. Roots and shoots communicate to maintain a state that is receptive to symbiotic *Rhizobium* contact in nitrogen-deficient conditions (Takahara et al 2013). *MiR2111* abundance in lotus is found to be inversely linked with *M. loti* infection and nitrogen availability in a model system, using *Lotus japonicus* and *Mesorhizobium loti* (Tsikou et al 2018). *The s*hoot-produced *miR2111* is translocated through the phloem to the root to mute *TML*, a positive regulator of regulation of nodulation. To maintain the susceptibility of uninfected tissue to *Rhizobium,* Tsikou et al. (2018) postulated that shoots systemically regulate *TML* expression in roots through *miR2111.* The amount of *miR2111* is decreased in a *HAR1*-dependent manner and the course of nodulation is constrained if the plant has enough nitrogen or if a symbiotic relationship with *Rhizobium* is well established. The significance of the legume hosts in directing the symbiotic partners' beneficial interactions in response to environmental changes is highlighted by these findings (Tsikou et al 2018).

Certain mutualistic rhizosphere microorganisms can induce Induced Systemic Resistance (ISR), a type of plant protection that prepares the host for possible pathogen attacks. The *Arabidopsis* transcription factor *MYB72* was discovered as an important ISR regulator by microarray and mutant analysis (Pescador et al 2022). It is interesting to note that iron deprivation also significantly increases *MYB72* expression in roots (Panpatte et al 2020). ß-glucosidase *BGLU42* was found to be an important component of ISR and in response to iron shortage downstream of *MYB72.* When there is a lack of iron, *MYB72* activates the genes for the iron-mobilizing phenolic metabolite-producing enzymes. Another gene, *BGLU42* facilitates the release of phenolic compounds into the rhizosphere (Zamioudis et al 2014). Stringlis et al. (2018)observed that Scopoletin, a coumarin is a commonly found phenolic chemical generated and released into the *Arabidopsis* rhizosphere in iron deficit in a *MYB72*- and *BGLU42*-dependent manner. Rhizospheric microbial population of the scopoletin biosynthetic mutant *f60h1's* was discovered to be significantly different from that of wild-type plants. Scopoletin inhibits the growth of two recognized soil-borne pathogens of *Arabidopsis, Fusarium oxysporum f. sp. raphani* and *Verticillium dahliae JR2*, in a dose-dependent manner. This was demonstrated by *in vitro* antimicrobial activity assays (Zamioudis et al 2014). In iron-deficient settings, *MYB72, BGLU42*, and scopoletin seem to form a regulatory module to improve iron solubility and restructure rhizosphere microbiota to defend the host from pathogen attack by trigerring ISR (Verbon 2019).

Plant-Microbe-Environmental Interactions through Metabolic Modeling

Strategies are needed to boost plant productivity, resilience and tolerance to both abiotic and biotic stressors. Plant growth, environmental responsiveness and disease susceptibility are all supported by microorganisms in many ways. The density of natural communities, concurrent competition and cooperation, signaling interactions and environmental effects make it difficult to understand the precise mechanisms by which microbes interact with plants and with each other. The complexity of interactions between plants, microbes and environments can be understood by combining metabolic modelling with artificial communities. The use of metabolic models in community settings identifies various applications and emphasizes the value of ecological theory in assisting with data interpretation. It offers suggestions for how the fusion of metabolic modelling methods with big data may help close the gap between the complexity of natural plant-microbe systems and the simplicity of simplified artificial communities. An organism, ranging in complexity from prokaryotes to eukaryotes, can be represented mathematically by a metabolic model that depicts the stoichiometries of the metabolic reactions taking place within the organism. Models have been created from genomic data using various databases as BRENDA, MetaCyc, KEGG, JGI IMG/M to identify genes and their associated metabolic reactions. The information is then gathered into a metabolite-reaction stoichiometry matrix using software programmes as CellNetAnalyzer, Python (Von Kamp et al 2017). Creating a metabolic model is experimental because of many variables like genome completeness, accuracy of genomic data and annotations (which can lead to missing genes, reactions or pathways) and the accessibility of experimental data. A hypothesis that can be utilized to forecast physiological response under various environmental conditions is the result of building a metabolic model.

Although metabolic modelling was primarily used for single species, it is now possible to apply it to community models due to the improved accessibility of genomic data and the development of effective computer techniques. When Stolyar et al (2007) used a multi-compartment changeability balance model to predict metabolite exchange between the methanogen *Methanococcus maripaludis* and the sulphate reducer *Desulfovibrio vulgaris*; they became the first to apply this changeability balance analysis to a multispecies context. The study highlighted the critical role of hydrogen in mutualistic symbiosis between the two microbes (Stolyar et al 2007).

Plants pose a challenge for the development of high quality metabolic models because it has eukaryotic genome, distinct tissues and redundancy due to polyploidy. Current attempts to enhance databases, annotations, major and secondary pathways provide automated platforms as a starting point for plant-specific modelling as more genomic data is being gathered (Seaver et al 2018). A number of diverse plant species, including soybean seed, rapeseed, rice, potato, and maize have had specialized tissue types of their metabolisms modeled to date. For a more accurate representation of plant metabolism, multiple compartments within metabolic models have also enabled the reconstruction of multi-tissue models (Shaw and Cheung 2020). For instance, one of the most complete plant models created to date for *Arabidopsis* included six different tissues, allowing for a more precise prediction of whole-plant physiological responses (Gomes de Oliveira Dal'Molin et al 2015). Multi-scale models (e.g., incorporation of gene regulation or phenomic data) can enhance accuracy and offer experimental confirmation (Jez et al 2021) to further aid in understanding the physiological implications of elements like genomic redundancy and circadian rhythm. Despite these developments in modelling applications for both microbes and plants, few studies have examined plant-microbe interactions using a community metabolic model method i.e., combining both microbial and plant models into a single simulation. Additionally, there is still a considerable gap between laboratory-scale experimental results and field-scale outcomes, providing much possibility for advancements in this sector.

The precise source and recipient of metabolite exchanges cannot always be determined by experimental measurements. Therefore, modelling enables quicker *in silico* testing of a wide range of potential unidirectional and bidirectional interactions within a community (Ibrahim et al 2021). For instance, a methodical strategy for analyzing community relationships can start with the selection of certain organism pairings, followed by the dual member model's prediction of potential metabolite exchange-based interactions. Understanding how interactions might vary with more community members will then be made possible by comparing the pair wise interaction predictions with simulations of a larger community. The plant secretes metabolites that are necessary for the recruitment of microorganisms to a tissue, but it is still unclear how interactions between microbes and plants, as well as between microbes themselves affect this process. Understanding and predicting the assembly process will be made easier with the help of the integration of plant and microbial metabolic models in a dynamic format (e.g., the use of dynamic changeability algorithms to investigate time-resolved interaction effects. This is especially true for understanding what drives the differences in colonization between plant species as well as how pathogens may interfere with the colonization process.

Overall, combining computational and experimental approaches will expand our current understanding of the complex interactions between plants, microbes and the environment. Improvements in agriculture like the creation of microbial inoculants to encourage plant growth or resistance in the face of more frequent global climate catastrophes can be made more competent by these advancements (Lieven et al 2020). With these initiatives, maintaining high modelling standards across the scientific community will remain crucial when extending models and algorithms to more intricate plant-microbe systems (Carey et al 2020).

Plant-Microbe Interactions for Agricultural Sustainability

Plants grow, eat and are healthier when they are naturally associated with microorganisms (Ray et al 2020). Rhizospheric and phyllospheric microorganisms are important due to their applications in increased nutrient absorption, improved water sequestration, induced systemic resistance (ISR) and competitive exclusion of plant diseases and remediation of environmental contaminants. These positive characteristics have encouraged the use of plant-microbe interactions in agro-ecosystems to increase productivity. The use of commercially available plant beneficial microorganisms (CAPBM) in agro-ecosystems is largely attributed to their compatibility and complementarities with natural processes of nutrient cycling, plant protection and other associated biological activities (Adeleke et al 2019).

Abiotic stressors are a growing global threat to agricultural productivity (Etesami and Beattie 2017). These stresses include extreme heat and cold weather, flooding, drought, nutrient depletion, toxic metals and organic contaminants. Due to economic consequences, there is a need for reasonably priced, reliable and ecologically acceptable methods to lessen the negative impacts of abiotic stresses on plants. Some of these relationships involve extremely complex symbioses that confer stress tolerance including those with mycorrhizae and rhizobia that help meet the challenge of nutritional and water deficiencies. Work is being pursued on microbial strains for their capacity to offer protection against a specific stress, such as phosphate limitation and cross-protection against other stresses. This increased interest in the agricultural application of beneficial microorganisms is reflected in the literature. Many of these are enduring and have a negative impact on the ecosystem. For the repair of agricultural soils, pesticides can only be controlled by biological agents. Pesticides frequently cause an excessive amount of pollution in crop fields. When compared to physical and chemical methods, pesticide biodegradation has proven to be a more efficient, cost-efficient, and environmentally benign method (Chaudhari et al 2023)

The use of chemicals is both expensive and environmentally unfriendly. The effects of temperature changes and pH changes on biodegradation are important. Bioremediation/rhizodegradation is the process by which fungus and bacteria in the rhizosphere break down organic contaminants. If the right vegetation is used, the rhizosphere's pollution decomposers may grow in quantity and activity resulting in enhanced rhizodegradation of harmful pesticides (Saravanan et al 2020). Most of the pesticide-decomposing enzymes are created by plant-related microorganisms in the rhizosphere. They cause mineralization of pesticides (Kumar et al 2019). This rhizoremediation procedure could be a useful tool for removing pesticides from contaminated soil. The interaction between plants and microorganisms has led to the development of phytoremediation and bioremediation as substitutes for such technologies (Abhilash et al 2012). The development of agro-ecosystems and the remediation of environmental pollutants are both significantly aided by PGPR (plant growth-promoting rhizobacteria). In addition to PGPR, a number of fungi, endophytes, mycorrhizae, and algae associate with plants and aid in sustainable development (Mishra et al 2020).

CONCLUSION

Soil is a dynamic ecosystem that is inhabited by a vast array of microbes. These microorganisms play a crucial role in maintaining soil health and promoting plant growth. The interactions between microbes and plants can be both positive and negative depending on the nature of the relationship. Positive interactions, such as mutualism and commensalism, contribute to the overall health and productivity of the soil and its resident plants. On the other hand, negative interactions such as predation and competition, can have detrimental effects. Rhizosphere is a hotspot for plant-microbe interactions due to the release of root exudates. Root exudates contain various compounds that facilitate communication between plants and microbes. Recognition of host cells host signaling molecules by microbes is a crucial step in establishing these interactions. Environmental factors, such as temperature, moisture, circadian rhythms, and soil nutrient status, can influence these microbe-microbe and plant-microbe interactions. Understanding these factors is important for studying the dynamics of the soil ecosystem and developing sustainable agricultural practices. Metabolic modeling, a mathematical approach, can be used to analyze the stoichiometry of metabolic reactions and study the plant-microbe-environment interactions. This modeling helps in understanding the metabolic processes and nutrient flows within the soil ecosystem. Exploiting plant-microbe-environment interactions holds great potential for developing efficient agroclimatic ecosystems and bioremediation strategies for pesticide-contaminated soils. By harnessing these interactions, agriculture can become more sustainable. It also leads to improved soil health, enhanced plant growth and environmental conservation. By unlocking the potential of these interactions can optimize nutrient cycling, promote plant health, and reduce the environmental footprint of agriculture, leading to a more sustainable and resilient future.

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Received 22 December, 2023; Accepted 10 June, 2024

Indian Journal of Ecology (2024) 51(4): 719-726
DOI: https://doi.org/10.55362/IJE/2024/4299

Manuscript Number: 4299
NAAS Rating: 5.38

Species Diversity and Structural Characteristics of High Altitudinal Home Gardens in New Tehri District of Garhwal Region, Uttarakhand

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Abstract: Homegardens, among the oldest forms of traditional farming, offer a wide range of benefits to mankind. This study examines the structural and floristic diversity of homegardens in New Tehri, Garhwal region, Uttarakhand. Using semi-structured interviews and field-level species identification, we explored the species diversity and structural composition of high-altitude homegardens across ten villages. Homegarden owners were chosen through a 40% sampling of village households, and gardens were categorized into small, marginal, and large based on their sizes. The vertical stratification of these gardens and the typical placement of trees and vegetables was also observed. Our findings reveal that the diversity of species and structural elements in hilly homegardens plays a vital role in enhancing food security and the standard of living for local communities. These gardens, with their array of plant species and unique structural components, are essential for sustainable living in hilly regions. By maintaining traditional practices and incorporating diverse plant species, homegarden owners contribute significantly to the resilience and well-being of their communities. This study underscores the importance of preserving and promoting homegardens as multifunctional agricultural systems that support both ecological balance and human livelihoods.

Keywords: High altitudinal homegardens, Species diversity, Structural composition, Tehri Garhwal

Uttarakhand, a state heavily reliant on agriculture and its allied activities for development, is renowned for its diverse range of horticultural crops. These include fruits, off-season vegetables, floricultural crops, and even medicinal and aromatic plants (Parihar et al 2016, Padalia et al 2017). Agroforestry systems in the state demonstrably contribute to economic, livelihood, and eco-environmental sustainability. Notably, these systems provide ecosystem services at various scales, thereby enhancing the livelihoods and resilience of farmers in the face of climate change (Pandey et al 2017). Many agroforestry opportunities exist on hills when trees and crops are mixed in different spatial or temporal configurations. This constitutes a sustainable substitute for monoculture farming. In the hills, several indigenous agroforestry techniques have numerous potentials to promote positive socio-economic development (Yadav et al 2019). The characteristics, diversity, and productivity of various agroforestry systems were highlighted in a few studies (Bijalwan et al 2009, 2011, 2012 and 2013) in the Garhwal region, where there was limited documentation about home gardens. Understanding the structure and function of these home gardens is necessary for formulating long-term development plans for the study area.

MATERIAL AND METHODS

Study area: Ten villages of the New Tehri district were chosen and divided into two altitudinal categories, high and low (Table 1). An elevation range comparison between two altitudinal ranges was performed using random sampling to choose representative sites for the district.

Methodology

The crop species inventory was recorded using a homestead survey and verified through direct observation. The respondents who owned the home garden were chosen from a sample representing forty per cent of all households. In the state of Uttarakhand, land ownership is traditionally measured in units called Nali. One Nali is equivalent to 200 square meters. In this study, land holdings were classified into three categories: small (<5 Nali), marginal (6-10 Nali) and large (>10 Nali). Homegardens Farmers helped to document the local names of the species and samples of plants, and photographs were taken of the species that were yet unknown. The taxonomy and identity of the species were confirmed by the standard flora (Gaur 1999). Identified species were categorized based on their vertical growth habit, and a profile diagram was prepared. Based on their distribution in the study area, these species were classified as rare (present in 1-3 villages), uncommon (present in 4-6 villages), and common (present in 7-10 villages).

RESULTS AND DISCUSSION

Species diversity in homegardens: In the Tehri Garhwal district, out of 397 houses in 10 villages, 200 households were engaged in home garden agroforestry. Home gardens support a diversity of flora, including ornamental plants, multipurpose trees, herbs, shrubs, and agricultural crops, among others, in their natural habitat. Among the 200 home gardens studied, *Prunus armeniaca, Prunus domestica, Prunus persica*, and *Citrus sinensis* were the most common fruit crops. In contrast, the most common multifunctional trees were *Grewia optiva, Celtis australis, Melia azedarach,* and *Ficus roxburghii.* Maun village had the maximum (90), and Haddam (Talla) village had the minimum (58) number of species (Table 2).

Citrus sinensis, Prunus armeniaca, P. domestica, and *P. persica* were the fruit crops most often found among the 200 total identified from the home gardens. The Rosaceae family contributed the most among the fruit crops with a maximum number of species (6 species), followed by the Rutaceae family. Apart from that, the home gardens of the Garhwal region contributed a total of 18 multipurpose tree species, representing twelve families and fifteen genera. Four of them are members of the Moraceae family, and the remaining families are composed of two members: Caesalpiniaceae, Meliaceae, and Rosaceae. Twelve types of trees were used for lumber, and the remaining fourteen, multipurpose trees, were mainly used for fodder.

Nineteen species of ornamental plants from 10 families and 16 genera were identified. *Tagetes erecta, Zinnia elegans, Rosa spp.,* and *Hibiscus rosa-sinensis* were the most recorded plant species. The Apocyanaceae family had two species, the Malvaceae family with two species, and the Asteraceae family with eight species, making it the most prominent family of ornamental plants. Eight species of wild plants from six families, such as Amaranthaceae, Rosaceae, Solanaceae, Onagraceae, Oxalidaceae, and Polygonaceae, were observed in home gardens alone. *Rumex nepalensis* and *Solanum nigrum* were the most prevalent in homegardens. A total of 44 food crops, such as vegetables, cereals, pulses and oil seeds, were also recorded from the study area (Fig. 1).

Table 1. Description of the villages

Altitude category	Name of the villages	Latitude	Longitude
High alitude	Guldi	30°21'12"N	78°23'50"E
	Hadam (Talla)	30°21'35"N	78°23'05"E
	Manjyari	29°58'39"N	78°49'17"E
	Sabli (Talli)	28°42'38"N	77°45'13"E
	Dikhol Gaon Maniyar	30°20'20"N	78°23'45"E
Low altitude	Jagdahr	30°19'26"N	78°23'54"E
	Dargi	30°19'12"N	78°24'30"E
	Aarakot	30°21'53"N	78°22'37"E
	Maun	30°18'14"N	78°23'43"E
	Kotdwara	29°44'47"N	78°31'10"E

Structure of homegardens: Fruit trees and multipurpose trees were generally favoured over trees grown solely for timber. Common fruit trees guaranteed fruit quality and added nutrition to people's diets, while multipurpose trees were mainly used for fuel, fodder, and small timber requirements. Both vertically and horizontally, the home gardens in the chosen villages display intricate structures.

Spatial arrangement: Fruit-bearing and multipurpose species are typically arranged in a scattering manner around homesteads, with no observable pattern of spacing. In small and marginal home gardens, limited area forced owners to adopt a significantly higher planting density, maximizing the use of their land and resulting in higher planting density.

Proper tree planting spacing was observed in large homegardens, particularly for commercial fruit trees like plum, peach, and apple. Vegetables were grown near homestead kitchens so that women could conveniently obtain them. These are arranged in rectangular blocks

Table 2. Number of species recorded in the study area

Type of plants	Villages										Total number of species
	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	
Food crops	43	30	35	39	33	38	34	30	42	32	44
Fruit crops	10	10	10	13	10	12	12	11	18	12	20
Multi-purpose trees	10	7	8	9	11	12	13	9	15	12	18
Ornamental	14	9	11	13	14	12	11	8	10	5	19
Shrubs	4	1	2	4	3	3	3	4	2	1	3
Herbs	2	1	2	2	3	3	3	5	3	3	8
Total	83	58	68	80	74	80	76	67	90	65	112

*Abbreviations used: V1-Guldi, V2-Hadum (Talla), V3-Manjyar, V4-Sabli (Talli), V5- Dikhol Gaon maniyar, V6-Jagdhar, V7-Dargi, V8-Aarakot, V9-Maun, V10-Kotdwar according to the available space on the ground or rooftops (Table 3). Lady's fingers were scattered, while coriander, Shimla mirch, and chillies were planted in rectangular blocks. Ornamental plants are usually planted in small containers or plastic packages with some spacing patterns. Most of them were grown on rooftops or in front of homes. The fact that sacred plants like Tulsi are noticeable on the front of a homestead suggests that the people who live in rural, hilly areas appreciate the plants highly from a religious standpoint. They are often planted in plastic kits or pots with ample space between them.

Vertical stratification: An understratum, a middle stratum, and a top stratum make up the typical three-storey vertical stratification of a home garden; each stratum has a distinct species composition and diversity (Fig. 2). Not every home garden in the study region had all three layers of vegetation, indicating a dissimilar pattern of vegetation layering.

A three-storied vertical stratification was observed in the homegardens. The understorey is 1-3 m tall and a relatively dynamic layer due to seasonal changes in farming. It is distinguished by a crop composition that includes a variety of vegetables, food crops, wild shrubs, wild herbs, and ornamentals. Often occurring crop species in this layer include capsicum, chilli, Lady's fingers, onions, Arbi, coriander, cabbage, turmeric, and potatoes. Herbs like broadleaf wood sorrel and Nepal dock and shrubs like Pomegranate and Black nightshade are observed in 7-10 villages. Gudhal, Nagphani, Rose, Zinnia, and Pot Marigolds were found to be the common ornamental plants occupying the bottom layer of the strata.

The middle storey is characterised by the dominance of fruit crops, extending from around 3 m to 7 m in height. *Prunus persica, P. armeniaca, Juglans regia,* and *Citrus sinensis* were observed as the most common species in this layer, along with species like *Malus domestica* and *Pyrus communis,* which were also observed in a good number of homegardens. However, species like *Vitis vinifera, Annona squamosa,* and *Carica papaya* were documented very rarely by homegardens.

The top storey comes in the height range of 7 m to 15 m, and the dominance of the multipurpose trees is the main attraction of this layer. *Grewia oppositifolia* and *Celtis australis* are the most common species in this layer. *Morus serrata* is also seen and considered a rare species in the study region.

Temporal pattern of Hilly Homegardens: Certain tree species are planted with horticultural fruit crops. Regardless of the season, annuals such as beans, colocasia, ginger, and turmeric were intermittently planted amid horticultural crops.

Species preference in Hilly Homegardens: The crop composition of home gardens generally varies, with home garden owners favouring fruit crops such as apples, plums, peaches, pears, wild apricots, and malta. Similarly, most home gardeners favour *Grewia oppositifolia* and *Celtis*

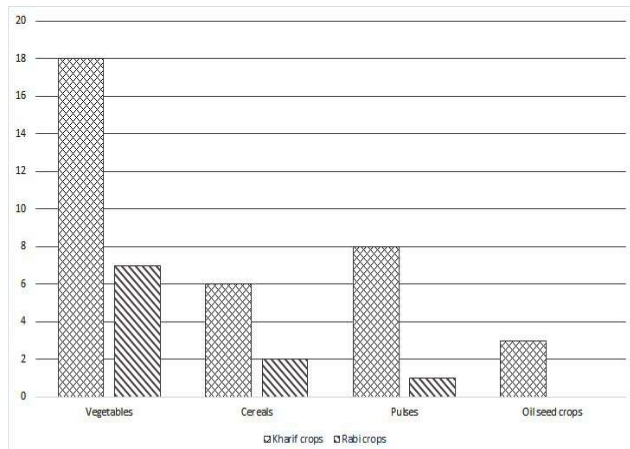

Fig. 1. Diversity of food crops in *kharif* and *rabi* seasons

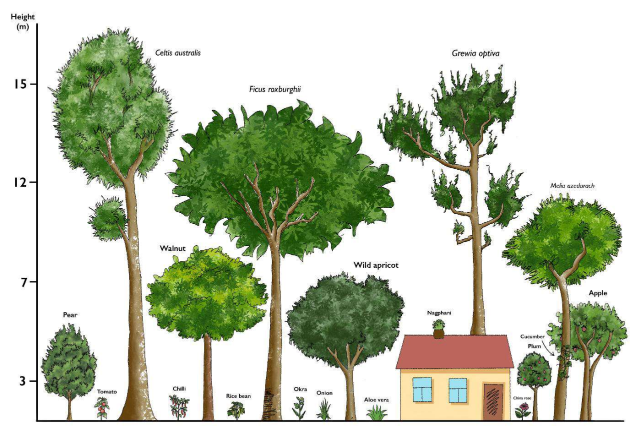

Fig. 2. Species profile of home garden with vertical stratification

Table 3. Kinds of suitable spaces for crops in the homegarden

Space	*Kharif* season	*Rabi* season
Sunny space	Cucumber, Lady finger, Amaranthus,	Brinjal, Shimla Mirch, Coriander, Onion
House roof	All cucurbits	Beans
On trees	Cucurbitaceous vegetables	No crops observed
Under trees	Kidney bean	No crops observed

Table 4. Crops associated with major tree species

Tree species	Vegetables grown under trees (Major)	Creeper vegetables grown using trees as trails	
		Major	Minor
Apricot		Pointed gourd	Pumpkin
Apple	Marshu/Amranthus	French bean	Nil
Banj Oak		French bean	
Bhimal	Rice bean	Pumpkin, pointed gourd, Ribbed Gourd, French bean	Bitter gourd
Chinaberry	Taro	Cucumber	Pumpkin
Lemon	Kidney bean	Nil	Nil
Mulberry	Taro	Nil	Nil

*No minor corps were documented from the vegetables grown under trees category

australis because they are widely used as cattle feed in most home gardens. The most popular choices for understorey crops in a home garden were beans, tomatoes, lady's fingers, chillies, and Shimla mirch. For food crops like bitter gourds, pointed gourds, and pumpkins, multipurpose trees like Bhimal and Dekkain were preferred as standing supports (Table 4).

Cropping pattern: The observed home gardens of the hills demonstrate a proper, time and space-bound integration of woody perennials like fruit-bearing and multipurpose species, along with or without animals. Long-duration crops predominate in small and medium-sized home gardens, whereas short-duration crops do so in more extensive home gardens. This may indicate that farmers depend on their homegrown produce for daily needs or to sustain their livelihoods. Large concentrations of fruit-bearing species, multipurpose trees, and agricultural crops are a good sign of integrated farming systems that guarantee sustained livelihood support in the study region.

Home gardens serve several functions in traditional agroforestry systems and contribute to sustainable production (George and Christopher 2020). Their amended micro-environment resembles wild forests within the homestead boundaries (Sarkar et al 2022). Understanding species richness and diversity patterns and the influencing variables in less-to-unexplored Himalayan regions provides essential insights into the drivers that shape and affect plant community structures (Sekar et al 2023). Farmers in several parts of Uttarakhand have successfully blended food crops (potato), leafy vegetables (spinach), and fruit vegetables (pumpkin), as well as fruit and fodder trees. Sunwar et al (2006) found 131 species in home gardens, including the vegetable crops *Brassica juncea L., Luffa cylindrica L. M. Roem, Cucurbita pepo L., and Dolichos lablab L.* In support of earlier research on the subject, the new study also demonstrated the presence of common spices in household gardens, including *Allium sativum L., Capsicum annum L., and Coriandrum sativum L.* Similarly, the presence of a good number of fruit crops in home gardens in hilly areas is documented by several authors (Das and Das 2005, Srish et al 2011), showing how crucial fruit crops are to the means of subsistence for those living in rural areas.

In the whole Garhwal region of the Western Himalaya, Bhatt et al (2010) documented the top 70 MPTs, of which 13 species grow in the lower region, 24 and 31 species were commonly found in the intermediate and upper region of the Himalayan zone respectively. The results of the current study support his conclusions by showing that the MPTs, *Grewia oppositifolia* and *Celtis australis.* were widely used multipurpose trees by home gardeners as sources of fuel, fodder, and small timber.

The physical environment, ecological characteristics, socioeconomic circumstances, and cultural components of a given place influence the appearance of home gardens in different ways (Kumar and Nair 2004, Pandey et al 2007 and Alcudia-Aguilar et al 2018). The spatial arrangement of the components in the homegardens of the study provides information about the range of spaces for crops in homestead farming, including sunny locations, house roofs, trellis, the land beneath the trellis, pond banks, slightly swampy land, trees, and so on in line with Singh et al (2014). In typical Kerala homegardens, there are three to four layers: fruit trees and spice crops predominate in the middle storey, while herbaceous food crops, fodder, medicinal plants, and other crops grow on the ground layer. Tall trees and palms like coconut, teak, mahogany, and other quickly growing multipurpose species make up most of the higher canopies (Kumar and Nair 2004, Nair 2021). However, in the current study, a three storied stratification with MPTs like *Grewia oppositifolia* and *Celtis australis* comprising much of the upper canopy or top strata was observed.

Appendix 1. Plant diversity in homegardens of the study area

Scientific name	Vernacular/English/common name	Family	Status of species
Agricultural crops			
Kharif season: a) Vegetable crops			
Abelmoschus esculentus L.	Bhindi/Lady's finger	Malvaceae	Common
Allium cepa L.	Piaz/Onion	Amaryllidaceae	Common
Brassica juncea (L.) *ssp. rugosa* (*Roxb.*)	Prain Rai	Brassicaceae	Common
Brassica oleracea var. capitata L.	Bandh gobhi/Cabbage	Brassicaceae	Common
Brassica oleracea var.botryt is L.	Phulgobhi /Cauliflower	Brassicaceae	Common
Capsicum frutescens L.	Mirch/Chilli	Solanaceae	Common
Colocasia antiquorum Schott	Pindalu/Arabi	Araceae	Common
Coriandrum sativum L.	Dhaniya/Coriander	Apiaceae	Common
Cucumis sativus L.	Kakree/Cucumber	Cucurbitaceae	Common
Cucurbita maxima Duchesne	Kaddu/Pumpkin	Cucurbitaceae	Common
Curcuma longa non L.	Haldi/Turmeric	Zingiberaceae	Common
Lagenaria siceraria (*Molina*) *Standley*	Lauki/Bottle gourd	Cucurbitaceae	Common
Luffa acutangula (L.) *Roxb.*	Torai/Ribbed Gourd	Cucurbitaceae	Common
Lycopersicon esculentum Miller	Tamatar/Tomato	Solanaceae	Common
Momordica charantia L.	Karela/Bitter gourd	Cucurbitaceae	Common
Pisum sativum L.	Mattar/Pea	Fabaceae	Rare
Spinacea oleracea L.	Palak/Spinach	Chenopodiaceae	Common
Trichosanthes dioica Roxb.	Parwal/Pointed gourd	Cucurbitaceae	Rare
Zingiber officinale Roscoe	Adarak/Ginzer	Zingiberaceae	Common
Amaranthus caudatus L.	Marshu/Amranthus	Amaranthaceae	Common
Echinochloa frumentacea Link	Jhangora/Barnyard millet	Poaceae	Common
Eleusine coracana (L.) *Gaertner*	Manduwa/Kuretha/Finger Millet	Poaceae	Common
Oryza sativa L.	Paddy/ Rice	Poaceae	Common
Perilla frutescens (L.) *Britton.*	Bhangjeera	Lamiaceae	Common
Zea mays L.	Maize	Poaceae	Common
Kharif season: c) Pulses			
Cajanus cajan (L.) *Hutch*	Tour/Pigeon pea	Fabaceae	Common
Dolichos lablab (*L*)	sweet Bean	Fabaceae	Common
Dolichos uniflorus Lam.	Gahat/Horse gram	Fabaceae	Common
Phaseolus vulgaris L.	Rajma /Chhemi	Fabaceae	Common
Psophocarpus tetragonolabus	Winged bean	Fabaceae	Common
Vigna mungo (L.) *Hopper*	Urd/Black gram	Fabaceae	Common
Vigna sinensis (L.) *Savi ex Hasskarl*	Lobia/Cow pea	Fabaceae	Common
Vigna umbellata (*Thunb.*) *Ohwi & Ohashi*	Ricebean/ Naurangi	Fabaceae	Common
Kharif season: c) Oil seed crops			
Brassica campestris ssp. *rapa Hook. f. & Anderson*	Sarson/Mustard	Brassicaceae	Common
Glycine max (L.) *Merill*	Soybean	Fabaceae	Common
Sesamum indicum L.	Til/Sesame	Pedaliaceae	Common
Rabi season: a) Vegetable crops			
Allium cepa L.	Piaz/Onion	Amaryllidaceae	Common
Allium sativum L.	Lahsun/Garlic	Amaryllidaceae	Common

Cont...

Table 5. Plant diversity in homegardens of the study area

Scientific name	Vernacular/English/common name	Family	Status of species
Capsicum annuum L.	Shimla mirch/Capsicum	Solanacea	Common
Coriandrum sativum L.	Dhaniya/Coriander	Apiaceae	Common
Daucus carota L.	Gajar/Carrot	Apiaceae	Common
Raphanus sativus L.	Muli/Radish	Brassicaceae	Common
Solanum tuberosum L.	Aalu/Potato	Solanaceae	Common
Rabi season: b) Cereals			
Hordeum vulgare L.	Jau/Barley	Poaceae	Common
Triticum aestivum L.	Wheat	Poaceae	Common
Rabi season: c) Pulses			
Lens culinaris Medikus	Musoor/Lentil	Fabaceae	Common
Fruit crops			
Annona squamosa L.	Sitaphal	Annonaceae	Rare
Artrocarpus heterophyllus Lam	Kathal	Moraceae	Rare
Carica papaya L.	Papaya	Caricaceae	Un-Common
Citrus aurantifolia (*Christman*) *Swingle*	Kagazinimbu	Rutaceae	Common
Citrus limon (L.) *Burm.f.*	Lemon/Jambri	Rutaceae	Common
Citrus reticulata	Orange	Rutaceae	Common
Citrus sinensis (L.) *Obeck*	Malta/Sweet orange	Rutaceae	Common
Emblica officinalis Gaertn.	Aonala	Euphorbiaceae	Rare
Juglans regia L.	Akhrot/Walnut	Juglandaceae	Common
Malus domestica Borth	Apple	Rosaceae	Common
Mangifera indica L.	Mango/Aam	Anacardiaceae	Un-common
Musa paradisiaca L.	Kela/Banana	Musaceae	Un-common
Prunus amygdalus Batsch	Badam	Rosaceae	Rare
Prunus armeniaca L.	Wild apricot/Khumani	Rosaceae	Common
Prunus domestica L.	Plum	Rosaceae	Common
Prunus persica (L.) *Batsch*	Peach	Rosaceae	Common
Psidium guajava L.	Amrood/Guava	Myrtaceae	Un-common
Punica granatum L.	Pomegranate	Punicaceae	Un-common
Pyrus communis L.	Nashpati/Pear	Rosaceae	Un-common
Vitis vinifera L.	Grapes	Vitaceae	Rare
Multi-purpose trees			
Alnus nepalansis D.Don	Utis	Betulaceae	Rare
Bauhinia purpurea L.	Guriyal	Caesalpiniaceae	Rare
Bauhinia variegata L.	Kachnar	Caesalpiniaceae	Rare
Boehmeria regulosa Wedd.	Genthi	Urticaceae	Rare
Celtis australis L.	Khadik	Ulmaceae	Common
Ficus glomarata Roxb.	Umra	Moraceae	Rare
Ficus palamata Forsk.	Bedu	Moraceae	Rare
Ficus roxburghii Wallich ex Miq.	Timla	Moraceae	Common
Grewia oppositifolia J.R. Drummond ex Burret	Bhimal	Tiliaceae	Common
Juglans regia L.	Akhrot	Juglandaceae	Common
Melia azedarach L.	Dekkain	Meliaceae	Common
Morus serrata Roxb.	Shatoot	Moraceae	Common

Cont...

Table 5. Plant diversity in homegardens of the study area

Scientific name	Vernacular/English/common name	Family	Status of species
Myrica esculenta Buch-Ham. ex D.Don	Kaphal	Myricaceae	Rare
Prunus cerasoides D. Don	Painya	Rosaceae	Common
Pyrus pashia BuchHam. Ex D.Don	Mole	Rosaceae	Common
Quercus leucotrichophora A. Camus	Banj	Fagaceae	Common
Rododendron arboreum Smith	Burans	Ericaceae	Rare
Toona serrata (*Royle*) *M. Roemer*	Tun	Meliaceae	Rare
Ornamental plants			
Catharanthus rosaseae (L) *G. Don*	Rosy periwinkle	Apocynaceae	Rare
Helianthus annus L	Suraj mukhi	Asteraceae	Rare
Bellis perennis L	Daisy	Asteraceae	Uncommon
Calendula officinalis L	Pot Marigold/Marigold	Asteraceae	Common
Chrysanthemum sp.	Daisy Guldawadi	Asteraceae	Uncommon
Columnea crassifolia	Brongn Columnea	Gesneriaceae	Rare
Gladiolus gandavensis	Gladiolus	Iridaceae	Common
Hibiscus rosa-sinensis L	China Rose/Gudhal	Malvaceae	Common
Lavatera trimestris L	Silver Cup	Malvaceae	Rare
Rosa spp.	Gulab/Rose	Rosaceae	Common
Tagetes erecta L.	Marigold/Gainda	Asteraceae	Common
Tropaeolum majus	Nasturtium	Tropaeolaceae	Common
Zinnia elegans Jacq	Zinnia	Asteraceae	Common
Oenothera rosea L'Herit. ex Benth	Primrose	Onagraceae	Rare
Opuntia spp.	Nagphani	Cactaceae	Common
Nerium oleander L.	Kaner	Apocyanaceae	Rare
Cosmos sulphureus Cav.	Yellow Cosmos	Asteraceae	Rare
Dahlia imperialis (*Linden & Andre*) *G.S. Bunting*	Bell tree dahlia	Asteraceae	Uncommon
Epipremnum aureum Roezl exortgies	Money plant	Araceae	Rare
Wild shrubs			
Nerium oleander L	Kaner	Myrtaceae	Rare
Punica granatum L.	Anar	Puniaceae	Common
Ocimum gratissimum L	Ram- Tulsi	Lamiaceae	Common
Wild herbs			
Amaranthus viridis L.	Jungli chaulai	Amaranthaceae	Uncommon
Datura metel L.	Dhatura	Solanaceae	Rare
Fragaria nubicola Lindley ex Lacaita	Wild strawberry	Rosaceae	Rare
Oenothera rosea L'Herit.ex Benth	Primrose	Onagraceae	Rare
Oxalis latifolia Humb.	Khatura	Oxalidaceae	Common
Rumex hastatus D.Don	Amilada	Polygonaceae	Common
Rumex nepalensis Sprengel	Pahadi palak	Polygonaceae	Common
Solanum nigrum L.	Makoi	Solanaceae	Common

CONCLUSION

The diverse species and unique structural characteristics of hilly homegardens play a crucial role in meeting the needs of households in the New Tehri district of the Garhwal region, Uttarakhand. These traditional farming systems, with their rich variety of cultivated crops and multipurpose trees, significantly enhance tree cover and provide numerous benefits to home gardeners. The study highlights the importance of these homegardens as essential land use systems in the hills, showcasing their horizontal and vertical diversity. This intricate structure contributes to improved food security and living standards for the local population. Therefore, it is imperative to properly document and compile records of both cultivated and non-cultivated species. Implementing practical policies to support and preserve these homegardens is essential for sustaining their benefits to the community.

ACKNOWLEDGEMENT

The authors are grateful to Veer Chandra Singh Garhwali University of Horticulture and Forestry, and the College of Forestry and Hill Agriculture, Ranichauri, for providing the necessary support. Also grateful to ICAR for providing a junior research fellowship during the study period. Moreover, our sincere gratitude extends to the present institutions for their moral support during the preparation of the manuscript.

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Received 30 April, 2024; Accepted 20 June, 2024

Indian Journal of Ecology (2024) 51(4): 727-731
DOI: https://doi.org/10.55362/IJE/2024/4300

Manuscript Number: 4300
NAAS Rating: 5.38

Livestock Depredation by Large Carnivores in Kargil, Indian Trans-Himalaya: Patterns and People's Perceptions

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Abstract: Livestock depredation by large carnivores is an important livelihood concern among Trans–Himalayan pastoralists. The livestock depredation by the snow leopard and Tibetan wolf in the Chiktan Valley, Kargil, Ladakh, where human–wildlife conflict is rampant but poorly understood was assessed. The study was carried out through open-ended structured interviews in December 2021. The carnivores killed a total of 161 livestock in three years. Sheep and goats (86%) were the primary victims. Snow leopard was the most important predator (60 %). However, wolf is the most despised, perhaps due to occurrence of relatively higher incidences of depredation events. Wolf killed animals more in the open pastures (58), while the snow leopard killed inside the corrals (83). Livestock were killed mostly in the winter (42%) and autumn (26%). Each of the total 80 household incurred an estimated monetary loss of approx. Rs. 11800 annually due to depredation. The strengthening of livestock corrals to reduce depredation and sensitizing local communities on conflict mitigation strategies as important conservation interventions is recommended.

Keywords: Snow leopard, *Panthera uncia*, Tibetan wolf, *Canis lupus chanko,* Agro-pastoralism, Kargil, Livestock depredation

Carnivore-caused livestock mortality and consequent economic loss dates back to medieval times when humans started domesticating livestock (Anand and Radhakrishna 2017). It is considered a serious global problem, as affected farmers resort to retaliatory killing (Treves and Karanth 2003, Karamanlidis et al 2011, Carter and Linnell 2016). Such actions result in extermination of carnivores from certain areas, as observed in the case of wolves *Canis lupus* in Northern America (Musiani and Paquet 2004, Chavez and Gese 2005), bears *Ursus arctos* in Europe (Zedrosser et al 2011), lions *Panthera leo* and spotted hyenas *Crocuta crocuta* in Africa (Holmern et al 2007). The issue of human-carnivore conflict in the Indian Sub-Continent, which has an agrarian economy, is very acute. Anand and Radhakrishna (2017) documented that nearly 90% of inhabited area in India affected by human– wildlife conflict. Several species such as snow leopard *Panthera uncia*, Tibetan wolf *Canis lupus chanko* and Himalayan brown bear *Ursus arctos isabellinus* face similar threats of persecution in retaliation of livestock killing (Jackson and Wangchuk 2004, Namgail et al 2007, Bargali 2012, Habib et al 2013). Investigating the trend of human – wildlife conflict (HWC) in India, Anand and Radhakrishna (2017) reported over 69% conflicts occurring outside protected areas whereas only 31% of conflicts are reported from PAs. Such increase in livestock depredation by large carnivores outside protected areas has been attributed to the increase in their population due to strict carnivore conservation laws (Treves et al 2004, Wang and Macdonald 2006). But predation on livestock is predicted to increase if population of natural prey species is low and access to alternate prey species such as livestock is easy (Bereczky et al 2012). Moreover, misidentification of underlying threats such as disease and political instability in addition to inconsistent and sparse data on HWC make this problem more complex (Dar et al 2009, Carter et al 2012).

Ladakh in the Trans-Himalayas (TH) is a mosaic of different habitats where wild and domestic herbivores extensively share the same rangeland resources. Here predation on livestock by wild carnivores is a major conservation issue. Seven large carnivore species in the region are known to prey on domestic livestock. Moreover, irate farmers resort to retaliatory killing yet its occurrence at a regional level is not known. Heavy livestock mortality due to snow leopard *Panthera uncia* in the Indian Trans – Himalaya is reported from Spiti, Himachal Pradesh (Mishra 1997), Gya-Miru area in Eastern Ladakh and Hemis National Park in central Ladakh (Jackson and Wangchuk 2004). In addition to these, Tibetan wolf and Eurasian lynx *Lynx l. isabellinus* are also reported to kill livestock in these areas (Namgail et al 2007, Jamwal et al 2019)..

In general, data on human-wildlife conflict in Kargil is scarce, although people reported livestock depredation by bear, wolf and snow leopard. The wolf often kill livestock in rangelands while grazing whereas snow leopards often enter corrals at night. Additionally, they reported that snow leopard ambush livestock while grazing in pastures. Jackson and Wangchuk (2004) attributed high livestock depredation by wild carnivores in Ladakh to poorly constructed livestock corrals (sheds) and poor herding practices. However, understanding of the underlying causes of livestock depredation in the Kargil district remains rudimentary. Therefore, in present study livestock depredation by large carnivores in the Chiktan Valley of Kargil District to understand spatio – temporal patterns of depredation, its economic impact and peoples' attitude towards wild predators.

MATERIAL AND METHODS

Study area: The Chiktan Valley (34.4571 N and 76.5197 E) of Kargil District is located in western Ladakh at a distance of *ca.* 70 kms from the district headquarters. Spanned over an area of 400 KM^2 we included villages in between Kanji Nala stream and Indus River, of the proposed Nindum Wildlife Sanctuary and Elevation ranges from average 2800 meters at Sanjak m asl to 5500 m asl in Nindum. The terrain on the northern side of the valley is rugged while those in the south are undulating. Thus, the southern part supports Ladakh urial (*Ovis vignei vignei*), while the northern part supports Asiatic ibex (*Capra ibex sibirica)*. Besides these, smaller prey species such as long-tailed marmot(*Marmota caudata)*, cape hare (*Lepus capensis)*, pika (*Ochotona* spp.) and other rodents are also present.

Major predators include snow leopard, Tibetan wolf and red fox (*Vulpes v. montana)*. Precipitation in the valley is mainly in the form of snow in the winter (November to March), when 3-5 feet of snow accumulate on the ground. Vegetation in the region is characterized by sub-alpine desert steppe and alpine meadow with low primary productivity. The area is virtually devoid of forest cover except for isolated patches of junipers *Juniperus* spp. and planted varieties of poplar (*Salix* spp.) and birch (*Betula* spp.) along major water courses. There are willow and juniper trees all along the Kanji River (Fox et al 1991, Hartmann 2009), although juniper trees were sparsely distributed.

People are dependent on agriculture and livestock farming for livelihood. Water for irrigation, drinking and livestock is sourced from Kanji River. Sheep, goat, yak, cow, horse and donkey are the main livestock types reared by farmers. Poultry rearing is also common in the region. Agriculture provides food (barley, wheat and vegetables) whereas silviculture provides timber and fuel wood (willow and poplar). Rangelands are used year round for livestock grazing, avoiding only if snow exceeds to obstruction level for livestock movement. They are herded communally in each village. Traditionally pastures are divided among villages. Movement of sheep and goats are regulated in pastures whereas cow, yak hybrids and horse are free to roam in the catchment area of the Valleys.

Data were collected from six hamlets in Hagnis, Kukshow, Pacharik, Chiktan, Samrah Khangral, Staktse in December 2021with open – ended structured interviews. Both women and men from 80 households participated in the questionnaire survey. The area was stratified into three zones: rocky cliff and valley mouth (Zone-1), open near ridgelines (Zone-2) and open valleys without obstructions (Zone-3). The vulnerability of livestock to predators varies across a village and we randomly selected different households in the outer, middle and inner areas of a village.

For every livestock depredation case, recorded the zone including name of carnivore and livestock type, number killed, year, time and site of depredation. The distance of the house from the nearest gorge opening was recorded to measure vulnerability and signs used to authenticate predator in case killing occurred in their absence. Besides this, interviewed six elders from the survey villages to understand livestock herding practices in the Valley.

Further, we cross checked livestock depredation reported by a household from neighbors and the village headman. This verification was necessary as respondents exaggerate the number of livestock loss to predator, perhaps in the hope of getting monetary compensation from the government (Bhatnagar et al 1999). Possibility of such inflation was also minimized through building a rapport with the villagers by spending some time with them before carrying out the survey. Moreover, a local guide explained the purpose of the interview to the villagers. Additionally, in order to evaluate economic loss per household due to depredation, market survey was carried out to know market value of different livestock types.

Prey selection by predators was tested using modified chi-square test: log-likelihood chi-square test (Manly et al 1993). In case of rejection of the null hypothesis (no selection), Bonferroni-adjusted 95% confidence intervals were constructed to determine which animals were killed selectively. The livestock type was killed more than expected based on its relative abundance if the lower confidence interval was greater than its population proportion, whereas it was killed less than expected when the upper confidence limit excluded its population proportion.

RESULTS AND DISCUSSIONS

Patterns of livestock depredation by large carnivores: In 2021, eighty households in the seven villages owned 944 livestock, which translates to an average herd size of 12 livestock per household. Most of the households owned cows (98%) and sheep/goats (99%). Yak hybrids and donkey were owned by 44 and 18% of the households, respectively. Horse was owned by only 4% households. Sheep and goats (77%) followed by cow (14%) were the most abundant livestock type (Table 1). The villagers incurred a total loss of 161 livestock heads or 22.50% of the total livestock population over a period of three years (January 2019 to December 2021). This amounted to a loss of 2.01 livestock/ household/year. Overall, snow leopard was the most important predator accounting for (60%) of the total loss, followed by Tibetan wolf (37 %). Livestock loss to other carnivores were negligible only 4% (Table 2). Such patterns of livestock depredation by wolf were also reported from Spiti, Himachal Pradesh (Mishra 1997) and Gya – Miru, Ladakh (Namgail et al 2007). Additionally, livestock depredation by wolves is also reported from the Tibetan plateau, Europe and North America (Li et al 2015). There were significant difference in vulnerability of livestock types to predators (Muhly and Musiani 2009). Sheep and goats were the main victim (86%) followed by cow (5%) and horse (1%). Likewise, sheep and goats (Meriggi and Lovari 1996) were killed significantly more than expected from their relative abundance. Overall, snow leopard killed sheep and goat more than expected as the lower confidence interval for this livestock type was greater than population proportion. However, snow leopard killed cow and yak hybrids less than expected, as their population proportion exceeded the upper confidence limits. They never killed horse and donkeys. Similarly, Tibetan wolf killed donkeys and horse more than expected, lower confidence interval for these livestock types was greater than its population proportion. Cow and yak hybrids were killed less than expected, as its population proportion exceeded the upper confidence limits. Wolves killed sheep and goats in proportion of its relative abundance (Table 3). Although, sheep and goats were killed by both wolf and snow leopard, the number of livestock killed per incident were higher for the snow leopard. Such high losses per incident were also reported from other parts of Ladakh, Himachal Pradesh and Tibet (Namgail et al 2007 and Li et al 2013). Most of the livestock killed by the snow leopard were sheep and goats. This could be attributed to the depredation by snow leopards inside corrals that mostly sheltered sheep and goats. Although livestock depredations by snow leopard was higher than wolf, people lamented livestock depredation by wolf more woefully.

Spatio-temporal pattern of livestock depredation: Out of the three zones, maximum livestock depredation occurred in

Table 2. Major carnivores involved in livestock depredation in the Chiktan Valley, Kargil, Ladakh

Species	Snow leopard	Tibetan wolf	Others
Sheep/goat	91	42	5
Cow	2	5	1
Yak hybrids	3	3	0
Donkey	0	7	0
Horse	0	2	0
Total killed	96	59	6
Percent killed	60	37	4

Table 1. Livestock types and their percentage losses in the Chiktan Valley, Kargil – Ladakh

Livestock type	Population	Percent population	Number Killed	Percent killed
Sheep/goat	727	77	138	86
Cow	129	14	8	5
Yak hybrids	66	7	6	4
Donkey	20	2	7	4
Horse	2	0.0001	2	1
Total	944	100	161	100

Table 3. Livestock populations (proportions) killed by major carnivores)\ in the Chiktan valley, Kargil – Ladakh (Bonferroni confidence limits)

Species	Population proportion (n = 944)	Snow leopard			Wolf		
		Proportion killed (n = 95)	Lower	Upper	Proportion killed (n = 60)	Lower	Upper
Donkey	0.021 (20)	0.000 (00)	0.000	0.000	0.119 $^{+}$ (07)	0.093	0.144
Cow	0.137 (129)	0.021 $^{-}$ (02)	0.020	0.022	0.085 $^{-}$ (05)	0.071	0.099
Yak hybrids	0.070 (66)	0.031 $^{-}$ (03)	0.029	0.033	0.051 $^{-}$ (03)	0.045	0.056
Sheep & Goat	0.770 (729)	0.948 $^{+}$ (91)	0.942	0.954	0.712 ^{0} (42)	0.614	0.809
Horse	0.002 (02)	0.000 (0)	0.000	0.000	0.034 $^{+}$ (02)	0.031	0.036

n = total number of livestock, figures in the parenthesis indicates population of each species, proportion = figures in parenthesis / n, $^{+}$= killed more than expected, $^{-}$= killed less than expected, ^{0} = killed in proportion to abundance

Zone- 2 (Open near ridgeline areas; 58%), followed by Zone-1 (Rocky cliff and Valley mouth; 37%), and Zone-3 (open areas without obstructions; 5%). Snow leopard killed livestock mostly in villages near rocky cliff (54%) whereas wolf killed livestock in villages near open ridgeline areas (78%). Snow leopard never killed livestock in open valleys. Out of the 161 livestock killed, 52% were killed in corral and the rest (48%) in open areas (Table 4). Snow leopard killed livestock, mostly at night, inside corral (87%5). Wolf killed livestock mostly during daylight in open areas (97 %). Pattern of livestock killing varied across seasons. Maximum depredations occurred in winter (42%) followed by autumn (26%), summer (18%) and spring (14%). Snow leopard killed livestock mostly in winter (48%) and the least in summer (1%). Wolf killed livestock mostly in summer (49%) and the least in spring (4%). However, livestock killed in autumn by both the species, snow leopard and wolf, were 29 and 25% respectively (Fig. 1).

Livestock depredation differed across space and time. Snow leopard, the most important predator killed livestock in open as well as in corrals, whereas wolf killed livestock mostly in open areas. Also, more number of livestock were killed in areas close to open ridgeline followed by rocky cliff. Thus, livestock are more vulnerable to wolves when they graze in open areas, and they are more vulnerable to snow leopard near cliffs. Thus, their herding practices need to be improved to prevent depredation by wolf, while the corrals need to be strengthened to protect livestock from snow leopard. Overall, lax livestock herding practice is the root cause of livestock depredation in the region. Pertinently, a single individual; often children herd large group of sheep and goats in the rangelands thus making the livestock vulnerable to depredation (Jackson and Wangchuk 2004). Moreover, vulnerability of livestock depredation in winter also increases due to preferences of lower elevation by carnivores, particularly snow leopard in this season.

Economic loss and people's attitude towards predators: The villagers incurred an economic loss of approx. Rs. 35600/ household due to depredation during the study period, which translates to an annual economic loss of approx. Rs. 11800/household. The estimated losses were based on approximate market value of the animals at the time of survey. Yak was the most valuable animal with a market value of approx. Rs. 82000 followed by cow (58000), horse (25000), donkey (15000), and sheep and goats (14500). The average annual monetary loss of Rs. 11800 per household due of depredation represents 23% of the average per capita annual income in the erstwhile state of Jammu and Kashmir (Economic Survey, J and K, 2013 – 14). Nonetheless, in an area with limited livelihood options, this amounts to a substantial loss. In a similar study in Gya – Meru, Ladakh, Namgail et al (2007) reported annual monetary loss of 18 % of the average annual per capita annual income. Similarly, in Kibber (Himachal Pradesh), India, reported loss attributed to depredation was 11% of the average annual per capita income of the state (Mishra 1997).

Most of the individuals interviewed to find out peoples' attitude towards large mammals expressed negative attitude towards the predators wolf and snow leopard on account of livestock depredation. Most of the respondents advocated for their persecution or trapping. On the contrary twenty three percent individual adored snow leopard followed by wolf (18%). Respondents expressed positive attitude (85%) towards urial and ibex also. Similar, attitude on account of depredation and economic losses are also reported from other areas of the Ladakh (Namgail et al 2007), Nepal (Aryal et al 2014) and Tibet (Li et al 2015). Moreover, despite the high rate of livestock depredation nobody received any compensation till the end this study. Those who applied for monetary compensation reported that the procedure of filing cases is complicated and compensation received are minimal. Further did not come across any incident of retaliatory killing of snow leopard in the area. However, informants reported that people allegedly resort to killing of wolf. Communal killing or *Lings* is a common method used to kill wolves in the valley. Such activities are most often carried out during spring season targeting sub adults and cubs. There was no observation on pit traps as reported from Gya –

Table 4. Spatial variation in livestock depredation by different carnivores in the Chiktan valley, Kargil, Ladakh

Location	Snow leopard	Wolf	Others	Total
Open	12	58	6	76
Corral	83	2	0	85
Total	95	60	6	161

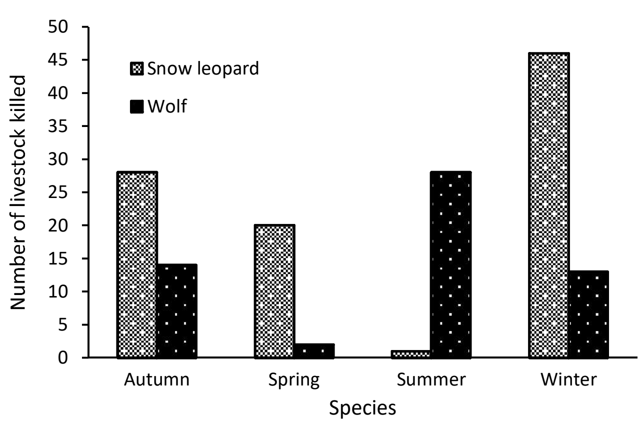

Fig. 1. Seasonal variation in livestock depredation by large carnivores in the Chiktan valley, Kargil. Ladakh

Miru area of Ladakh (Namgail et al 2007) and Spiti, Himachal Pradesh (Mishra 1997) except report on the practices of hunting wolf pups by angry farmers in the area. Altogether, the practice of retaliatory killing still exists as livestock killing is frequently reported and monitoring and mitigation measures are not spread evenly to curb it.

CONCLUSION

Snow leopard is the most important predator in the Chiktan Valley of the Indian Trans – Himalaya. Snow leopard killed sheep and goats more than expected, while it avoided other livestock types. Snow leopard mostly killed livestock inside corral at night. This occurred most often in winter season in villages near ridgeline and valley cliffs. Wolf killed livestock in open areas often in daytime compared to snow leopard. They killed all livestock types and killed livestock mostly in summer season. Lax herding practices is the primary reason for livestock depredation in the valley. Additionally, hunting of wolf pubs is a primary conservation threat that needs to be addressed in the region. Improvement in corral structure, compensation mechanisms and initiating a livestock insurance scheme combined with conservation education programe will be required to change people's attitude towards large carnivores. This will help in curbing retaliation of wolf pubs besides garnering local support in conservation of threatened species in the region.

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Received 23 March, 2024; Accepted June 20, 2024

Indian Journal of Ecology (2024) 51(4): 732-737
DOI: https://doi.org/10.55362/IJE/2024/4301

Manuscript Number: 4301
NAAS Rating: 5.38

Comparison of Phenolic Content, Flavonoid Content and Antioxidant Activities of *Phyllanthus emblica* L. From North-East, India

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Abstract: The study was focused on investigating the antioxidant activity of *Phyllanthus emblica* fruits collected from different regions of North-East, India. The antioxidant properties of the fruit were examined using a DPPH radical scavenging test and a reducing power assay after it was extracted with methanol and ethyl acetate. There were significant variations in the total phenolic, flavonoid, and antioxidant activity depending on the population and solvent used. The phenol ranges from 57.87 (Khasi Hills) to 126.32 mg GAE/g (Garo Hills). The maximum and minimum flavonoid was between 20.14 (KRB) and 45.25 mg QE /g (LNL). The IC_{50} of the extracts ranges between 10.67 (GH) to 42.96 (RTM).The findings highlight the considerable potential of aonla extracts from North-East India as antioxidants. Furthermore, chemical composition and biological activity of these extracts are influenced by the specific population and solvent employed in the extraction process. These results contribute to understanding of the diverse antioxidant properties of Indian gooseberry and emphasize the need for further investigation into its regional variations and optimal extraction methods.

Keywords: DPPH, *Emblica officinalis*, North-East India, Population, Reducing power

Aonla, also known as the Indian gooseberry (*Phyllanthus emblica* L. syn *Emblica officinalis* Gaertn.), is a medium-sized tree growing up to 20 m in height. It is one of the major native fruits of the Indian subcontinent and valued for its therapeutic and medicinal benefits (Wali et al 2015). Aonla fruits are utilised in a variety of ayurvedic formulations and value-added products, and contain a wide range of chemical components, like tannins, phenols and alkaloids (Sachan et al 2013). Due to its potent biological and antioxidant properties, amla prevents a wide range of ailments as it contains essential nutrients and a high concentration of vitamin C (Dasaroju and Gottumukkala 2014). ROS produced as a result of cellular metabolism and many other biochemical reactions, like hydroxyl radicals, superoxide radicals and hydrogen peroxide are the main causes of oxidative damage in aerobic cells, including protein denaturation, mutagenesis, and lipid peroxidation.

Free radicals play a significant role in the etiology of some severe diseases, including diabetes, inflammation, atherosclerosis, cataracts, liver cirrhosis, cancer, neurological disorders, and liver disease, these diseases could potentially be improved by compounds that can scavenge free radicals (Liu et al 2008). Phenolic compounds are one of the most diverse and commonly found groups of secondary metabolites from plants, and are responsible for a wide range of beneficial impacts in a wide range of illnesses due to their Antioxidant activity, which aids in the protection of cells from oxidative harm induced by reactive oxygen species (Soobrattee et al 2005). Antioxidants, which are produced by the body as well as obtained from dietary sources and nutraceuticals, regulate the amount and availability of free radicals. The combined effects of phenols, flavonoids, and ascorbic acid were discovered in the study by Reddy et al (2011), which indicated the antioxidant nature of *Emblica officinalis.* The phenolic content and antioxidant properties of aonla populations and various solvents used in fruit extracts have been studied. For instance, Liu et al (2008) reported a great degree of variability in the phenolic and anti-oxidant properties of fruit extracts from several populations of aonla from China. A significant variation was also recorded in the phenolic and antioxidant properties of aonla extract from different solvents used for extraction (Verma et al 2018). However, the diversity of the antioxidant properties from Northeast India's aonla population hasn't received much attention even though the region has wide geographic variations in terms of altitudes, climates, soils and forest type etc. The region also comes under the Indo-Burma biodiversity hotspot. Therefore, this paper aimed to study the phenolic and antioxidant activity of methanolic and ethyl acetate extract of *Emblica* fruits collected from different regions of northeast India, using well-established in vitro testing methods.

MATERIAL AND METHODS

The study was conducted in the Forestry Department of Mizoram University in 2021-2022. The aonla fresh fruits were collected at harvest maturity from nine locations of seven states of North-East, India, viz., Aizawl-Mizoram (AZW), Champaknaga- Tripura (CPK), East Karbi Anlong-Assam (KRB), Garo hills- Meghalaya (GH), Khasi hills - Meghalaya (KH), Lunglei,- Mizoram (LNL), Maram-Manipur (MRM), Roing-Arunachal Pradesh (RNG), Rotomi-Nagaland (RTM). The fruits were stored in air-tight packets until analysis.

The fruits were oven air-dried at 40ºC for 24 hours and the dried fruits were ground uniformly. Two solvents were used for the preparation of extraction i.e., methanol and ethyl acetate. Dried aonla fruit powder (100 g) was extracted with 800 ml of the respective solvents for 24 hours in a conical flask and the extracts were shaken from time to time, after 24 hours and were filtered through Whatman paper 1. The methanolic and ethyl acetate extracts were then concentrated at 45 ºC in a Rota-vapor under low pressures. The end residue was collected in a container (air-tight) and stored at 4ºC for further analysis.

Blois (1958) approach was modified slightly to evaluate the extracts' ability to scavenge DPPH free radicals. The absorbance was measured in a UV-visible spectrophotometer at 517 nm. The IC_{50} values were calculated using a non-linear regression method. Ascorbic acid was used as the standard reference. The DPPH scavenging % was determined as

$$\text{DPPH scavenging \%} = \frac{\text{Control absorbance} - \text{Sample absorbance}}{\text{Control absorbance}} \times 100$$

The reducing power of aonla was determined using the Oyaizu method (1986) at absorbance 700 nm. Reducing power increases as the absorbance of the reaction mixture increases. With slight modifications, the Folin-Ciocalteu technique was employed to assess the total phenolic content of the extract (Baba and Malik 2015) at 650 nm absorbance. The total phenolic content was calculated using the calibration curve and expressed in mg of gallic acid equivalent per gram of dry weight. The aluminum chloride colorimetric technique was used to determine flavonoid concentration (Liu et al 2008). The absorbance was measured at 510 nm, and quercetin was used to create a standard curve. The flavonoid concentration was measured in milligrams of quercetin equivalent (QE) per gram of dry basis.

Statistical analysis: SPSS (25) and Microsoft Excel were used for statistical analysis. IC_{50} values were obtained using least-squares-based linear regression methods.

RESULTS AND DISCUSSION

Plant antioxidant activity is related to the redox characteristics of phenolic chemicals, which are important components of plants. There were significant differences in phenolic from various *P. emblica* populations in both methanol and ethyl acetate extracts. The phenol content in methanol extract ranged from 69.80 (CPK) to 126.32 mg GAE/g (GH) (Table 2). The maximum phenol content in ethyl acetate extract was in MRM (115.15 mg GAE/g) while the minimum content was in KH (57.87 mg GAE/g). MRM with 35.35 QE/g had the highest flavonoid content and KRB with 20.14 mg QE/g, the lowest flavonoid content from methanol extract. Among ethyl acetate extracts the flavonoid content ranges between 26.08 mg QE/g (KH) and 45.25 mg QE/g (LNL). Liu et al (2008) also reported significant variations in phenol and flavonoid content from different regions in China. The variation in the total polyphenol content among different aonla extracts could be attributed to factors such as distinct maturity stages, diverse genetic makeup, and varying

Table 1. Coordinates of the different regions of North-East India selected for aonla fruit collection

Region	State	Code	Latitude	Longitude	Elevation (m)
Aizawl	Mizoram	AZW	23°45'32"N -23°48'26.19"N	92°38'45"E - 92°39'51"E	622 - 850
Champaknagar	Tripura	CPK	23°47'42"N - 23°49'22"N	91°29'04"E - 91°31'32"E	79 -137
East Karbi Anlong	Assam	KRB	25°50'00"N - 25°53'55"N	93°24'23"E - 93°28'29"E	218 - 230
Garo Hills	Meghalaya	GH	25°29'50"N - 25°31'51"N	90°35'22"E - 90°37'30"E	293 - 524
Khasi Hills	Meghalaya	KH	25°38'45"N - 25°54'59"N	91°52'15"E - 91°59'26"E	903 - 1114
Lunglei	Mizoram	LNL	22°50'53.0"N -22°48'58"N	92°47'45.3"E - 92°49'11"E	927 - 1452
Maram	Manipur	MRM	25°24'18"N - 25°25'44"N	94°04'58"E - 94°05'56"E	1309 - 1667
Roing	Arunachal Pradesh	RNG	28°05'58"N -28°11'26"N	95°49'01"E - 95°51'35"E	358 - 797
Rotomi	Nagaland	RTM	26°03'51"N -26°05'09"N	94°23'57"E - 94°26'22"E	702 - 1112

growing conditions (Hilton 1973). Other studies have found considerable differences in the phenolic content of *Syzygium jambos* and *Scrophularia striata* related to climatic parameters such as average temperature, rainfall and concentration of nutrients in the soil (Rezende et al 2015, Zargoosh et al 2019).

Extracts from all *Phyllanthus emblica* exhibited substantial free radical scavenging activities (Table 3, 4). Among the methanolic extracts, Garo population showed the highest activity (IC_{50} 10.67 µg/ml) with 89% inhibition, while the CPK (IC_{50} 16.76 µg/ml) population showed the lowest activity with 59.3% inhibition. Among ethyl acetate extracts the highest activity was from KRB regions (IC_{50} 9.82 µg/ml) with 82.32% inhibition whereas the lowest activity was recorded from RTM regions (IC_{50} 42.96 µg/ml) with 25.67% inhibition. The IC_{50} scavenging activity of ascorbic acid was 8.22 µg/ml.

The reducing power is a rapid and easy screening method for determining antioxidant capability. The presence of antioxidants causes the Fe3+/ferricyanide complex to be converted into its ferrous state in this assay. This change can be seen by observing the production of Perl's Prussian blue at a wavelength of 700 (Alam et al 2016). A greater absorbance value at 700 nm indicates an increase in sample reduction power (Lih et al 2001). This study evaluated the ferric-reducing activity of different extracts of aonla from different regions (Table 5). With increasing concentrations of the extracts, the absorbance increases too. There were significant differences among the aonla populations, whereas low significant differences were observed between ethyl acetate and methanolic extracts. All the aonla populations' extracts showed high reducing power activity. Ascorbic acid and gallic acid were used as standards to compare with aonla extracts.

Methanol extracts from RNG (0.445 ± 0.008) populations showed the maximum reducing power while the least reducing power was recorded in CPK MET (0.273±0.007) populations at 300µg/ml concentration. In the extracts of ethyl acetate, the reducing power also ranges from 0.230 ± 0.014 (RTM population) to 0.454 ±0.009 (KRB population) at 300 µg/ml concentration. Compared to the tested extracts, the positive reference standards had a relatively stronger reducing power. The reducing power of ascorbic acid at 300 µg/ml concentration was recorded at 0.79 and gallic acid at 0.89.Compounds of phenolic and flavonoids play a significant role in antioxidant activity by neutralizing free radicals through hydrogen atom donation. Additionally, their chemical structure is well-suited for scavenging free radicals (Amarowicz et al 2004). Other literature also reported a linear correlation between the phenol and flavonoid with antioxidant activity capacity (Liu et al 2008, Jan et al 2013,

Table 3. IC_{50} values of methanolic and ethyl acetate extracts of *Phyllanthus emblica* fruits from North-East India

Sample	IC_{50}	
	Methanol	Ethyl acetate
AZW	14.41	12.47
CPK	16.76	14.03
GH	10.67	10.67
KH	14.32	26.75
KRB	14.85	9.82
LNL	15.82	11.91
MRM	14.12	15.50
RNG	12.48	12.16
RTM	16.00	42.96
Standards (Ascorbic acid)	8.22 (IC_{50})	

Table 2. Phenol and flavonoid content of aonla fruits from different regions of North-East India

Sample	Phenol (mg GAE/g)		Flavonoid (mg QE/g)	
	Methanol	Ethyl acetate	Methanol	Ethyl acetate
AZW	98.05^{d}	82.12^{e}	22.81^{bc}	39.14^{bc}
CPK	69.80^{g}	105.96^{b}	21.73^{bc}	41.06^{ab}
GH	126.32^{a}	89.67^{d}	33.25^{a}	43.11^{ab}
KH	123.92^{a}	57.87^{g}	23.79^{bc}	26.08^{e}
KRB	102.79^{c}	99.52^{c}	20.14^{c}	37.39^{bcd}
LNL	87.49^{e}	98.95^{c}	21.85^{bc}	45.25^{a}
MRM	116.75^{b}	115.15^{a}	35.35^{a}	31.59^{de}
RNG	104.48^{c}	78.59^{e}	26.86^{b}	34.18^{cd}
RTM	81.21^{f}	67.28^{f}	21.23^{c}	34.43^{cd}

Means within the same column followed by the same letter, do not differ significantly at P ≤0.05

Table 4. DPPH radical scavenging activities of aonla extracts (methanol and ethyl acetate) from different regions of North-East India (Mean ± SD)

Parameters	Concentration (µg/ml)						
	2.50	2.50	5.00	7.50	10.00	15.00	20.00
Ascorbic acid	16.06 ± 0.9	16.06 ± 0.9	28.81 ± 1.8	47.90 ± 2.5	61.07 ± 1.0	89.64 ± 1.1	92.22 ± 0.7
AZW MET	9.13 ± 1.0	9.13 ± 1.0	16.69 ± 1.1	26.47 ± 1.1	34.91 ± 0.4	52.11 ± 1.2	69.33 ± 1.0
CPK MET	9.76 ± 0.9	9.76 ± 0.9	16.34 ± 0.8	24.44 ± 1.1	27.60 ± 0.5	46.37 ± 0.7	59.30 ± 1.5
GR MET	15.51 ± 1.5	15.51 ± 1.5	25.37 ± 0.9	37.33 ± 0.9	46.64 ± 0.8	68.13 ± 0.4	89.07 ± 1.0
KH MET	13.44 ± 1.1	13.44 ± 1.1	21.18 ± 1.4	29.67 ± 1.1	35.60 ± 0.7	52.43 ± 0.3	67.53 ± 0.5
KRB MET	8.95 ± 0.8	8.95 ± 0.8	16.58 ± 0.9	23.57 ± 1.3	34.68 ± 1.0	50.50 ± 0.7	67.31 ± 1.5
LNL MET	8.98 ± 1.4	8.98 ± 1.4	16.49 ± 0.8	25.19 ± 1.0	30.81 ± 0.7	47.79 ± 0.6	62.88 ± 1.0
MRM MET	12.81 ± 1.4	12.81 ± 1.4	20.77 ± 0.8	28.53 ± 0.8	36.47 ± 1.1	52.93 ± 0.9	68.82 ± 1.3
RNG MET	15.72 ± 0.8	15.72 ± 0.8	23.47 ± 0.8	33.06 ± 0.7	42.92 ± 1.6	61.66 ± 1.1	72.78 ± 0.8
RTM MET	9.53 ± 1.2	9.53 ± 1.2	17.25 ± 0.8	24.09 ± 1.0	32.84 ± 0.9	46.76 ± 0.7	61.88 ± 0.7
AZW.A	12.78 ± 1.0	12.78 ± 1.0	22.40 ± 1.0	32.48 ± 1.1	40.39 ± 1.0	58.95 ± 1.3	78.18 ± 0.9
CPK E.A	15.14 ± 0.7	15.14 ± 0.7	21.29 ± 0.9	29.78 ± 1.8	37.98 ± 0.9	52.94 ± 1.4	68.40 ± 0.9
GR E.A	14.46 ± 1.6	14.46 ± 1.6	25.48 ± 1.7	36.52 ± 0.9	47.03 ± 0.7	69.02 ± 0.7	89.86 ± 1.0
KH E.A	4.48 ± 0.6	4.48 ± 0.6	8.57 ± 0.9	12.22 ± 1.0	17.98 ± 1.1	28.10 ± 0.5	37.14 ± 0.9
KRB E.A	21.26 ± 1.2	21.26 ± 1.2	32.61 ± 0.9	42.15 ± 1.0	51.19 ± 0.7	74.38 ± 0.5	82.32 ± 0.5
LNL E.A	14.68 ± 1.1	14.68 ± 1.1	24.20 ± 1.1	34.09 ± 1.7	42.78 ± 1.1	61.26 ± 0.4	80.07 ± 0.9
MRM E.A	8.98 ± 2.1	8.98 ± 2.1	16.55 ± 1.	23.85 ± 1.1	32.71 ± 1.0	48.41 ± 1.1	64.34 ± 1.0
RNG E.A	21.29 ± 1.1	21.29 ± 1.1	33.08 ± 0.9	44.79 ± 1.6	56.56 ± 1.9	76.14 ± 0.2	83.51 ± 1.7
RTM E.A	8.03 ± 0.8	8.03 ± 0.8	8.99 ± 1.0	11.77 ± 0.8	15.15 ± 0.4	20.72 ± 1.1	25.61 ± 0.8

MET – Methanol, E.A – Ethyl acetate, LNL – Lunglei, KH- Khasi hills, AZW – Aizawl, MRM – Maram, KRB – Karbi Anglong, RTM – Rotomi, GR- Garo hills, CPK – Champaknagar, RNG – Roing

Table 5. Reducing power of aonla fruits from nine populations of North-East India (at absorbance 700nm) (Mean ± SD)

Parameter	Concentration(µg /ml)					
	50	100	150	200	250	300
Ascorbic Acid	0.206 ±0.009	0.354 ± 0.007	0.471 ± 0.004	0.547 ± 0.007	0.681 ± 0.008	0.787 ± 0.007
Gallic Acid	0.259 ±0.008	0.437 ±0.003	0.527 ±0.006	0.636 ±0.007	0.790 ±0.011	0.892 ±0.013
AZW MET	0.073 ±0.005	0.121 ±0.004	0.205 ±0.032	0.251 ±0.027	0.306 ±0.009	0.370 ±0.009
CPK MET	0.052 ±0.003	0.105 ±0.007	0.156 ±0.014	0.197 ±0.007	0.215 ±0.007	0.273 ±0.007
GAR MET	0.090 ±0.005	0.163 ±0.014	0.205 ±0.014	0.291 ±0.037	0.333 ±0.011	0.378 ±0.011
KH MET	0.064 ±0.002	0.115 ±0.006	0.218 ±0.008	0.250 ±0.015	0.312 ±0.018	0.352 ±0.021
KRB MET	0.086 ±0.006	0.154 ±0.005	0.220 ±0.037	0.269 ±0.024	0.313 ±0.005	0.345 ±0.005
LNL MET	0.058 ±0.006	0.091 ±0.002	0.149 ±0.045	0.204 ±0.02	0.242 ±0.020	0.288 ±0.020
MRM MET	0.085 ±0.003	0.147 ±0.006	0.174 ±0.01	0.225 ±0.018	0.296 ±0.017	0.330 ±0.017
RNG MET	0.096 ±0.003	0.175 ±0.004	0.234 ±0.005	0.319 ±0.013	0.382 ±0.008	0.445 ±0.008
RTM MET	0.177 ±0.004	0.222 ±0.009	0.244 ±0.01	0.303 ±0.021	0.350 ±0.029	0.403 ±0.029
AZW E.A	0.095 ±0.008	0.151 ±0.005	0.242 ±0.019	0.306 ±0.009	0.346 ±0.046	0.341 ±0.030
CPK E.A	0.070 ±0.009	0.118 ±0.004	0.165 ±0.004	0.224 ±0.006	0.292 ±0.021	0.330 ±0.007
GAR E.A	0.124 ±0.004	0.172 ±0.007	0.241 ±0.007	0.320 ±0.024	0.348 ±0.041	0.347 ±0.003
KH E.A	0.077 ±0.005	0.125 ±0.005	0.202 ±0.005	0.252 ±0.003	0.306 ±0.002	0.307 ±0.002
KRB E.A	0.107 ±0.003	0.175 ±0.007	0.283 ±0.002	0.358 ±0.003	0.426 ±0.009	0.454 ±0.009
LNL E.A	0.086 ±0.004	0.145 ±0.014	0.209 ±0.004	0.289 ±0.004	0.334 ±0.015	0.395 ±0.013
MRM E.A	0.063 ±0.004	0.122 ±0.034	0.159 ±0.021	0.193 ±0.007	0.253 ±0.012	0.332 ±0.020
RNG E.A	0.111 ±0.003	0.225 ±0.007	0.311 ±0.011	0.407 ±0.007	0.435 ±0.017	0.449 ±0.007
RTM E.A	0.039 ±0.004	0.076 ±0.004	0.136 ±0.054	0.146 ±0.004	0.178 ±0.009	0.230 ±0.014

See Table 3 for details

Table 6. Correlation coefficients (*r*) between IC_{50} values of DPPH and phenolic content

	Correlation coefficients (r)	
	Phenol	Flavonoid
DPPH (Methanol)	-0.80	-0.70
DPPH (Ethyl Acetate)	-0.62	-0.49

Aryal et al 2019). In methanol extracts, negative significant correlation was recorded between IC_{50} DPPH radical scavenging activity with both phenol and flavonoid (Table 6). In ethyl acetate extracts, the correlation of IC_{50} radical scavenging activity of DPPH with phenol and flavonoid was also negative.

CONCLUSION

The phenol and flavonoid content, as well as the DPPH radical scavenging activity and reducing power of *Phyllanthus emblica* extracts from different regions of North-East, India showed significant differences among different extracts, indicating that various factors such as genetic makeup, growing conditions, and maturity stages of plants affect the content of bioactive compounds and their bioactivities. Among the different populations of aonla, the highest values were obtained from the Garo Hills population. The DPPH scavenging activity and reducing power of the extracts also varied significantly, where the Garo Hills population showing the most activity. The study also found that the DPPH radical scavenging activity and reducing power of the extracts was concentration-dependent. The findings also suggest that the fruits of *P. emblica* have the potential to serve as natural antioxidants that can be beneficial for protecting the liver, cells, and body against the damaging effects of oxidation. Additionally, they can alleviate oxidative stress in various pathological conditions. These findings may have an impact on the development of natural antioxidant products and also serve as a basis for further research on the health benefits of *P. emblica* extracts and identify the active compounds responsible for the observed activities.

AUTHORS' CONTRIBUTION

KPR has done the research work, analyzed the data and drafted the paper. SK has supervised the work and helped in the experimentations. SBS, MMN and JJ have been involved in the experimentation and correction of the manuscript. All authors read, provided critical feedback, and approved the manuscript.

ACKNOWLEDGEMENT

The authors would like to express gratitude to the Department of Biotechnology, Ministry of Science and Technology, New Delhi, India, for their valuable support and contribution.

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Received 21 April, 2024; Accepted 15 July, 2024

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Indian Journal of Ecology (2024) 51(4): 738-743
DOI: https://doi.org/10.55362/IJE/2024/4302

Manuscript Number: 4302
NAAS Rating: 5.38

Diversity, Spatial Distribution and Biomass Patterns in Oak and Pine Forest Community along Altitudinal Gradient in Paddar Range of Kishtwar Forest Division, Northwestern Himalaya

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Abstract: This study explores the phytosociological dynamics of forest vegetation and biomass patterns in selected oak and pine forests of north-western Himalaya spanning an altitudinal range of 1650-2500 meters. The trees density varied between 126 to 214 trees/ha while the density of forest floor vegetation was 214.32 and 126.71/m^2 in oak and pine forests respectively. Herb species richness was slightly higher (23) in the oak forest compared to the pine forest (19). Asteraceae family dominated oak forest whereas Poaceae dominated pine forest stand representing 7 species at each site. The Shannon-Weiner index (H') was maximum for oak forest (3.79) and concentration of dominance (Cd) and evenness (J') were also maximum for oak forest (0.27) and pine forest (0.90) respectively. Simpson diversity was 0.86 in oak and 0.91 in pine forests. Contagious distribution patterns were observed for most species in both study sites. The forest floor biomass was 497.38 g/m^2 in oak and 412.79 g/m^2 in pine stands during the study period (2022-2023) with the rainy season contributing to the maximum biomass whereas winter season attributed to decrease in biomass at both sites.

Keywords: Biomass, Species richness, Simpson diversity index, Shannon-Weiner diversity index, Phytosociological analysis

The Himalaya stands as the World's tallest and most recently formed mountain system, serving as a repository for both biological and cultural diversity (Negi and Dhyani 2012, Chandra et al 2020). This region houses a distinctive ecosystem encompassing a diverse array of plants, animals, and other organisms contributing to its status as the most affluent biodiversity zone (Rawal et al 2018). Apart from constituting a significant portion of the Himalayan global biodiversity hotspot, this area is connected to three additional biodiversity hotspots (Dar and Sundarapandian 2016). The distribution of this region spans from subtropical to alpine zones (Singh 2008, Bhatt and Bankoti 2016). Biodiversity in the Himalayan region comprises the range and diversity of life forms, ecosystems, and ecological processes across all levels of biological organization. It serves as the fundamental basis for human survival and economic prosperity. It is imperative to consistently uphold and evaluate the various ecosystems and the entirety of biological diversity within them to ensure the enduring survival of the human species (Malik 2014, Malik et al 2014a). The altitudinal range (800-6000 meters), especially in the Himalayan region, exerts a significant influence on species distribution. Each altitude harbors distinct species, each contributing uniquely to the sustenance of associated flora and fauna (Pandey et al 2002, Kharakwal et al 2005). Within the mid montane belt (1000-2000 meters) of this geographical area, there is a prevalence of rapidly growing chir-pine (*Pinus roxburghii*) species alongside slowly developing oak species (Shreshtha et al 2007). These forests exhibit distinctions in terms of structure, functionality and the ecosystem services they provide (Joshi and Negi 2011, Bhat et al 2020). Species composition and diversity patterns is a frequently studied thematic area in ecological research as it enhances our comprehension of ecosystem conservation and management strategies (Zhang et al 2013). Abiotic environmental factors exhibit spatial and temporal variations, playing a pivotal role in determining vegetation patterns across landscapes (Kumar et al 2010, Zhang et al 2013, Kumar and Sharma 2016). Numerous studies have focused on the ecological aspects of vegetation on the forest floor. This emphasis underscores the importance of understanding the intricate dynamics and relationships within this specific ecological niche, contributing valuable insights to broader ecological investigations (Sharma et al 2009, Shaheen et al 2011, Singh et al 2016, Rawal et al 2018, Rana et al 2019, Joshi et al 2023). Despite these studies in the Western Himalaya, the database needs a continuous update by undertaking further exploration to decipher various ecosystem properties of forest stands. It is contended that additional research endeavours' are essential for a comprehensive understanding of varied forest types distributed across subtropical, temperate, and alpine environments encompassing evergreen broad-leaved, deciduous, and coniferous categories. This imperative arises due to the heightened biotic pressures exerted on the majority of Himalayan forests (Bargali et al 2013, Sharma et al 2017). The objective of this study was to characterize the species diversity, density, and distribution patterns, along with herbaceous biomass in oak and pine forest communities in the Paddar Valley to enhance existing knowledge and support sustainable forest management strategies.

MATERIAL AND METHODS

Study area: The study was conducted in the temperate and sub-alpine forest ecosystems of Paddar valley in Great Himalayan region of the Northwest Himalayas, Jammu and Kashmir (Fig. 1). This region was specifically chosen to explore and analyse the ecological dynamics and biodiversity patterns owing to limited research conducted in this specific locale thus emphasizing the need to fill this knowledge gap and enhance our understanding of the ecological complexities within these forest ecosystems. The study area is situated within the geographical coordinates of 33.10° to 33.40° N latitude and 76.10° to 76.50° E longitude, showcasing altitudinal fluctuations ranging from 1600 to 3200 m (Kumar and Sharma 2014). Renowned for its ecological diversity and topographical heterogeneity Paddar valley lies within the Kishtwar Forest Division in Jammu and Kashmir and exhibit a varied range of vegetation. This area is bordered by the Pangi Valley of Himachal Pradesh in the east, Zanskar Valley of Ladakh in north and the Marwah-Warwan valley (Kishtwar High Altitude National Park) in the west. Geologically, the region is characterized by crystalline rocks such as granites and gneiss, alongside sedimentary formations like shale, sandstone, and limestone. Moreover, the soils in the steep slopes have high carbon content whereas lower valley areas tend to be neutral to slightly alkaline, with varying degrees of carbon content ranging from medium to high. The people residing in the area are mainly agropastoral communities thus having remarkable impact on the nearby forests.

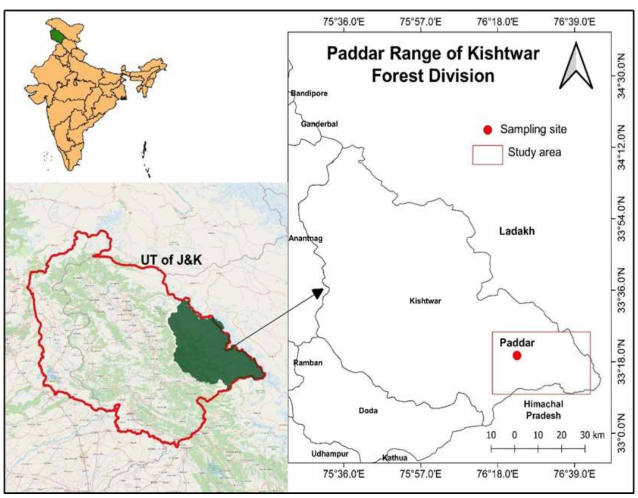

Fig. 1. Map of study area

Methodology: The study was carried out within the altitudinal range of 1650 to 2500 m in oak and pine dominated forest stands of Paddar valley, Kishtwar district, Jammu and Kashmir (Table 1). The oak forest exhibits higher levels of soil moisture, water holding capacity, organic carbon and nitrogen in its sandy clay soil compared to the pine forest with sandy loam soil. The average annual rainfall in the study area is 1200- 1440 mm which is highly variable whereas maximum and minimum temperatures were recorded as 33.15 and 6.7°C, respectively (Kumar and Sharma 2014, Ishtiyak et al 2015). For calculating the tree density, the sampling was conducted in 1 ha plots (100 m × 100 m) by laying quadrats of 5 m x 5 m in each forest stands.

The analysis of herbs and shrubs involved the systematic laying of simple random quadrats within each identified forest stand, specifically during the growing season of 2022-23. A total of 100 quadrats, each measuring 1x1 meter (with 50 in each site), were strategically positioned to examine the forest

Table 1. Attribute description of selected oak and pine forest sites

Parameter	Oak stand	Pine stand
Forest location	Kijayee	Chitoo
Altitude (m)	1750-1900	1650-2350
Latitude N	33.277130	33.221250
Longitude E	76.116738	76.217500
Dominant canopy species (Tree)	*Quercus baloot* Griff.	*Pinus wallichiana* A. B. Jacks
Dominant shrub species	*Berberis lycium* Royle	*Wikstroemia canescens* Wall.ex Meisn
Soil moisture (%)	27.43±3.31	22.13±4.31
Water holding capacity (%)	49.21±3.78	41.35±2.34
Soil Nitrogen (N%)	0.51±0.03	0.28±0.06

floor vegetation in both locations. The evaluation of forest floor vegetation parameters, including density, frequency, distribution and diversity were established using phytosociological methods (Muller-Dombois and Ellenberg 1974). The Importance Value Index (IVI) of the species was calculated by analysing value of relative density, frequency and dominance (Misra 1968). The diversity indices like Shannon and Wiener index (H'), Concentration of dominance (Cd) and Equitability or Evenness (J') were calculated following Shannon-Wiener (1963), Simpson (1949) and Pielou Index (1966) respectively. The assessment of distribution patterns (random, regular, and contagious) involved the computation of the abundance to frequency (A/F) ratio. Specifically, a regular distribution is indicated if the A/F ratio is <0.025, a random distribution is suggested for ratios between 0.025 and 0.05, and a contagious distribution is inferred for ratios >0.05 following the criteria (Curtis and Cottam 1956). For the estimation of forest floor herbaceous biomass encompassing grass and forest ground flora involved the harvesting of 1m x 1m quadrats every two months. Within each quadrat, all herbaceous vegetation was cut at a uniform height of 2 cm above the ground and subsequently sorted into live (green) biomass and standing biomass. The collected samples were then subjected to oven drying for a period of 24 to 48 hours until a constant weight was achieved (Joshi et al 2021).

RESULTS AND DISCUSSION

Species composition and diversity pattern: The oak forest encompasses a total of 27 species across 14 families, with Asteraceae being the most dominant family with 7 species and contributing to 27% of the overall forest species (Table 3). In the pine forest 29 species from 16 families were documented and Poaceae emerged as the dominant family, constituting 17% of the total species (Fig. 2). The species density in the oak forest was 214.32 individuals/m^2, whereas in the pine forest was 126.71 individuals/m^2. The species diversity (H') exhibited variation measuring 3.12 in the oak stand and 3.79 in the pine stand. The higher species diversity and richness were attributed to intensified anthropogenic stress resulting from grazing activities. This heightened competition leads to improved light interference on the forest floor vegetation as documented by Darabant et al (2007) and Harrison et al (2008). Additionally, creates habitat opportunities contributing to increased species diversity and richness. Species evenness was 0.68 for oak and 0.90 for pine forest (Table 2). Similar findings have been reported in numerous studies conducted across different regions of the Himalayas (Gupta and Kumar 2014, Kumar and Sharma 2014, Kumar and Sharma 2015, Lal and Lodhiyal 2016, Malik and Bhatt 2016, Kumar et al 2021, Joshi et al 2021, Joshi et al 2023). The highest species diversity tends to be observed in the herb layer among various forest strata. In the oak forest, Concentration of Dominance (CD) and Shannon Species Diversity (H') were 0.27 and 3.12 respectively, while in the pine forest, were 0.03 and 3.79. The diversity patterns in forest floor vegetation align with observations from previous research (Jhariyal et al 2014, Sinha et al 2015, Joshi and Chandra 2020). The species compositions in the two distinct communities differ due to local environmental conditions, with similarity of 25.13% in their composition, reflecting variations in ecological and environmental conditions.

Forest floor biomass pattern and its correlation with vegetation parameter: The annual average forest floor biomass in oak and pine stands exhibited variation ranging from 412.79 g/m^2 to 497.38 g/m^2 with the highest values during the rainy seasons in all stands. In the temperate banj-oak stand, the total forest phytomass was 411.32 grams in 2021-22, 509.13 grams in 2022-23, and an average of 460.22 grams during the years 2021-2023. The biomass reached at peak in August and reaching a minimum in the month of April. In 2022-23, it ranged from 10.35 to 93.17 grams, with the highest values observed in July and the lowest in April. The total herbaceous biomass was maximum (61%) during the rainy season, followed by 15 and 24% during winter and summer sessions respectively.

Table 2. Comparison of species diversity parameter among oak and pine forest stands

Parameter	Oak forest	Pine forest
Density (ind m^{-2})	214.32	126.71
Species richness	23.00	19.00
Shannon species diversity (H')	3.12	3.79
Concentration of dominance (CD)	0.27	0.03
Species evenness (SE)	0.68	0.90
Simpson Diversity Index (D)	0.86	0.91

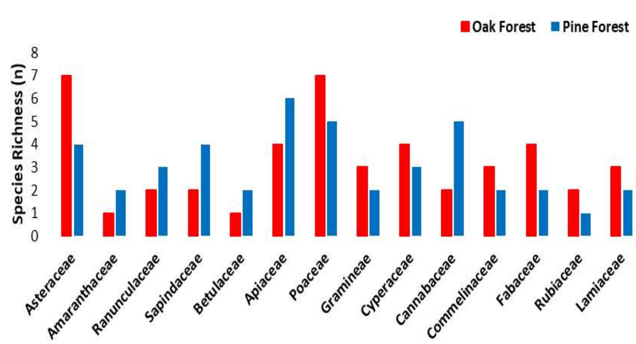

Fig. 2. Family wise distribution of species in the oak and pine forest

Table 3. Vegetation composition, relative density and distribution pattern of species in selected oak and pine forest, North-Western Himalaya

Species	Family	Oak forest		Pine forest	
		RD (%)	DP	RD (%)	DP
Achillea millefolium L.	Asteraceae	4.07	0.32*	7.28	0.97*
Achyranthes bidentata Blume	Amaranthaceae	3.61	0.27*	-	-
Aconitum heterophyllum Wall. ex Royle	Ranunculaceae	-	-	0.45	0.18*
Aesculus indica (Wall. ex Cambess.) Hook.	Sapindaceae	7.98	0.93*	-	-
Alnus nitida (Spach) Endl.	Betulaceae	0.58	0.05**	-	-
Anaphalis margaritacea (L.) Benth. & Hook.f.	Asteraceae	4.92	0.83*	-	
Angelica glauca Edgew.	Apiaceae	-	-	1.21	0.17*
Apluda mutica L.	Poaceae	27.4	1.38*	-	-
Aquilegia fragrans Benth.	Ranunculaceae	11.3	0.99*	-	-
Arisaema serratum (Thunb.) Schott	Araceae	1.0	0.06*	-	-
Artemisia vulgaris L.	Asteraceae	13.16	0.12*	27.36	1.02*
Arundinella nepalensis Trin.	Poaceae	0.86	0.31*	-	-
Arundo donax L.	Poaceae	4.21	0.14*	-	-
Aster thomsonii C.B.Clarke	Asteraceae	-	-	19.0	0.97*
Bidens pilosa L.	Asteraceae	2.11	0.3*	-	
Capillipedium parviflorum (R.Br.) Stapf	Gramineae	0.45	0.12*	1.42	0.12*
Carex nubigena D.Don.	Cyperaceae	3.11	0.58*	-	
Celtis australis L.	Cannabaceae	-	-	1.41	0.11*
Chrysopogon serrulatus Trin.	Poaceae	-	-	1.28	0.23*
Commelina caroliniana Walter	Commelinaceae	2.72	0.17*	-	-
C. paludosa Blume	Commelinaceae	3.19	0.90*	-	-
Cynodon dactylon (L.) Pers.	Poaceae	6.72	0.17*	-	-
Cyperus iria L.	Cyperaceae	4.24	0.12*	-	-
Desmodium triflorum (L.) DC.	Fabaceae	-	-	1.37	0.16*
Dioscorea deltoidea Wall. ex Griseb.	Dioscoreaceae	-	-	0.46	0.12*
Flemingia fruticulosa Wall. ex Benth.	Fabaceae	-	-	0.43	0.07*
Galium aparine Linn.	Rubiaceae	-	-	5.71	0.28*
Geranium wallichianum Oliv.	Geraniaceae	1.40	0.27*	1.36	0.15*
Hedychium spicatum Sm.	Zingiberaceae	0.98	0.11*	-	-
Imperata cylindrical (L.) P. Beauv	Poaceae	1.36	0.33*	-	-
Inula racemose Hook.f.	Asteraceae	-	-	3.22	0.18*
Justicia simplex D.Don	Acanthaceae	0.93	0.12*	-	-
Lonicera purpurascens (Royle ex Hook. fil. & Thoms.) Walp.	Caprifoliaceae	2.49	0.26*	-	-
Micromeria biflora (Buch.-Ham. ex D.Don) Benth.	Lamiaceae	3.25	0.27*	-	-
Morina longifolia Wall. ex DC.	Caprifoliaceae	-	-	2.83	0.13*
Murdannia divergens (C.B. Clarke) G. Brückn.	Commelinaceae	0.98	0.13*	-	-
Neottia listeroides Lindl.	Orchidaceae	3.52	0.04**	-	-
Oplismenus hirtellus (L.) P. Beauv.	Poaceae	-	-	1.32	0.16*
Ophiopogon intermedius D.Don	Asparagaceae	3.42	0.03**	-	-
Phlomoides umbrosa (Turcz.) Kamelin & Makhm	Lamiaceae	-	-	2.76	0.31*
Parrotiopsis jacquemontiana (Decne) Rehder	Hamamelidacea	2.34	0.11*	-	-
Persicaria capitata (Buch.-Ham. ex D. Don)	Polygonaceae	-	-	1.97	0.17*
Pilea microphylla (Linn.)	Urticaceae	-	-	0.95	0.14*
Plectranthus rugosus Wall.	Umbelliferaceae	1.83	0.37*	-	-
Pouzolzia hirta Hassk.	Urticaceae	0.73	0.13*	-	-
Robinia pseudoacacia L.	Fabaceae	0.47	0.12*	-	-
Rosa macrophylla Lindl.	Rosaceae	2.14	0.04**	2.84	0.11*
Roscoea alpina Royle	Zingiberaceae	-	-	12.91	0.93*
Rubia cordifolia L.	Rubiaceae	-	-	3.22	0.18*
Smilax parvifolia Wall	Smilacaceae	-	-	0.57	0.26*
Sorbaria tomentosa (Lindl.) Rehd.	Rosaceae	1.61	0.37*	-	-
Strobilanthes dalhousianus C.B. Clarke	Acanthaceae	0.98	0.11*	-	-
Taraxacum officinale (L.) Weber ex F.H. Wigg.	Asteraceae	-	-	3.22	0.19*
Thymus linearis Benth.	Lamiaceae	-	-	5.79	0.27*
Trifolium pratense L.	Fabaceae	-	-	1.37	0.18*
Urtica dioica L	Urticaceae	1.38	0.33*	-	-
Viburnum grandiflorum Wall. ex DC.	Adoxaceae	-	-	1.31	0.16*

RD- Relative density, DP- Distribution pattern, *Contagious distribution, **Random distribution

Table 4. Correlation among different vegetation parameter and herbaceous biomass

Parameter	Density	SR	H'	CD	SE	Biomass
Density		0.403	0.745	0.339	0.503	0.006
SR	0.805		0.3415	0.064	0.099	0.397
H'	-0.389	-0.859		0.406	0.242	0.738
CD	0.861	0.994	-0.803		0.164	0.332
Biomass	0.999	0.811	-0.398	0.866	-0.710	

SR=Species richness, H'=Species diversity, CD=Concentration of dominance, SE= Species evenness

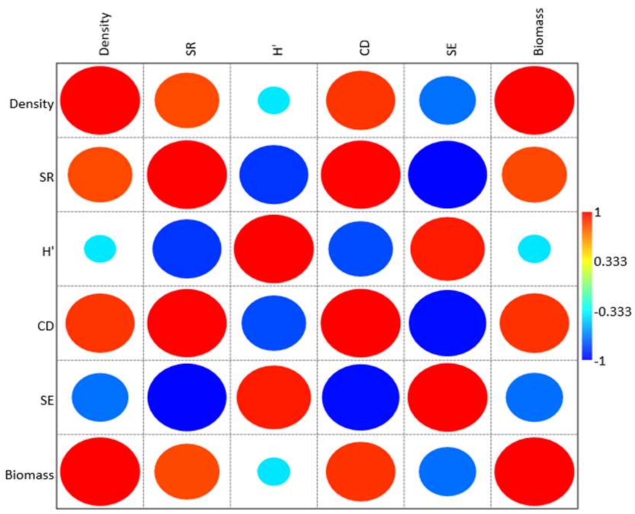

Fig. 3. Correlation matrix for biomass and vegetation factors at both forest stands

The total forest floor biomass increases with increase in density whereas it shows negative correlation with increasing species diversity, richness and evenness. The overall dry biomass of herbaceous species demonstrated a positively significant association with species density, while exhibiting a positive but not significant correlation with species richness (Fig. 3). However, a negatively significant correlation was observed with species diversity, evenness and the concentration of dominance. Species richness displayed a positive and significant correlation with species diversity, evenness and the concentration of dominance among the species (Table 4).

CONCLUSION

The herbaceous vegetation and biomass exhibited variations between the selected oak and pine forests. the pine forest demonstrated a slightly higher richness in terms of species diversity, the oak forest displayed greater potential for storing forest floor biomass. The elevated biomass observed in both forests during the rainy season suggests that the optimal growth of species is influenced by factors such as rainfall, soil properties (including moisture, texture, water holding capacity), and nutrient retention. The oak forest with its higher nutrient retention in both soil and litter, facilitated the storage of increased biomass.

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Received 15 December, 2023; Accepted 10 June, 2024

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Indian Journal of Ecology (2024) 51(4): 744-749
DOI: https://doi.org/10.55362/IJE/2024/4303

Manuscript Number: 4303
NAAS Rating: 5.38

Diversity and Economic Value Trees in Krishnagiri Taluk, Tamil Nadu, India

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Abstract: Preliminary survey on the diversity and economic values of tree species was carried out in Krishnagiri taluk, Krishnagiri District, Tamil Nadu. A total of 115 tree species belonging to 90 genera and 36 families were recorded. Fabaceae is the most dominant family (18 genera and 28 species), and *Ficus* is the dominant genus with seven species, while seventy-three genera had only one species. Among the total number of species, nineteen species were recorded as edible fruit yielding trees (19 species), avenue trees (13 species), dye plants (17 species), medicinal plants (42 species), ornamental trees (14 species), oil yielding plants (8 species), exotic trees (17 species), and timber yielding trees (30 species). Few tree species, such as *Mangifera indica*, *Cocos nucifera,* and *Tamarindus indica,* were supporting the livelihoods of local peoples. Four gymnosperm species were observed: *Cupressus sempervirens, Araucaria heterophylla, Cycas circinalis,* and *C. revolute*.

Keywords: Economical uses, Fabaceae, *Ficus,* Krishnagiri, Tamil Nadu, Tree species

Tree diversity plays a very important role in the cycle of nature and has a supreme role in maintaining balance in the ecosystem. Forests are part of the natural wealth of a country. Plants act as indicators of particular minerals and climates. More importantly, all plants, as part of the vegetation, contribute towards the stability of the environment. Rennolls and Laumonier (2000), Tchouto et al (2006), Evariste et al (2010) identified tree plant diversity as the most valuable aspect of forest ecosystem diversity and tropical forest biodiversity. Tree diversity also controls the forest ecosystem through factors like climate, stand structure, geomorphological structures, and species arrangements. The stand structure of forests was an important aspect of biodiversity and ecosystems (Ozcelik 2009). Trees also help in the interaction between the components and the ecosystem (Colding et al 2006). The diversity of trees purifies rainwater, controls pollution and soil erosion, and increases the oxygen/fresh air levels in the atmosphere. The economically valuable trees are a source of income for local people (Priya et al 2020).

Floristic survey and documentation are essential for determining the diversity status, species composition of particular districts. Only a few researchers worked and recorded the floristic diversity of the Krishnagiri (Matthew 1981-1988, Ambethkar 1992, Santhan and Rajasekarn 1993, Silambarasan and Santhan 2014). There is not a clear report on the documentation of economical valuable tree species in the present study area. Therefore, the present investigations were concerned with the documentation and also analysis economic importance of the tree species in Krishnagiri taluk, Krishnagiri district, Tamil Nadu.

MATERIAL AND METHODS

Study area and identification: Krishnagiri is a taluk in the Krishnagiri district, Tamil Nadu located between the latitudes of 12°31'57.8"N and 12°53'27.17"E and the longitudes of 78°14'51.1"E and 78°24'75'24"E. The altitude was 1,614 feet above MSL. The total area is 1,276.19 km^2. The four national highways cross in this city (NH 46, NH 66, NH 7, and NH 219) and connect the three major states such as Pondicherry, Andhra Pradesh, and Karnataka. The collected specimens were prepared for herbarium using stranded methods (Jain & Rao 1977). The prepared herbariums were deposited in the Department of Botany, Government Arts College for Men, Krishnagiri-635001 Tamil Nadu. The collected specimens were identified for tree species, taxonomic descriptions, economic values, and herbarium preparation. Each species was identified by *'The Flora of Central and North Tamil Nadu – I, II, III'* (Britto 2019) and Plants of the Western Ghats (Ganeshaiah 2012).

RESULTS AND DISCUSSION

In present investigation 115 species and 90 genera belonging to 36 families, which include 104 dicotyledons and 12 monocotyledons, were recorded from Krishnagiri taluk, Krishnagiri district (Table 1). Fabaceae is the largest family, with 18 genera and 28 species, followed by Arecaceae, which has nine genera, and ten species followed by Bignoniaceae,

Table 1. Diversity and economic value trees in Krishnagiri taluk, Tamil Nadu

Family/Botanical name	Economical values
Magnoliaceae	
Michelia champaca L.	Timber, Ornamental, Exotic
Annonaceae	
Annona reticulata L.	Fruit, Dye
A.squamosa L.	Fruit
Artabotrys hexapetalus (L. f.) Bhandari	Medicinal
Polyalthia longifolia (Sonn.) Thwaites	Timber, Exotic
Arecaceae	
Areca catechu L.	Medicinal
Borassus flabellifer L.	Fruit
Cocos nucifera L.	Fruit, Oil
Dypsis lutescens (H. Wendl.) Beentje & J. Dransf	Ornamental
Phoenix dactylifera L.	Fruit
P. sylvestris (L.) Roxb.	Exotic
Pritchardia pacifica Seem. & H. Wendl.	Ornamental
Roystonea regia (Kunth) O.F.Cook	Exotic
Washingtonia filifera (Linden ex André) H. Wendl. ex de Bary	Exotic
Wodyetia bifurcata A.K. Irvine	Exotic
Musaceae	
Musa paradisiaca L.	Fruit
Poaceae	
Bambusa arundinacea Willd.	Timber
Proteaceae	
Grevillea robusta A. Cunn. ex R. Br.	Timber
Fabaceae	
Acacia auriculiformis Benth.	Ornamental, Exotic
Acacia catechu (L.f.) Willd.	Timber, Medicinal, Dye
Acacia leucophloea (Roxb.) Willd.	Medicinal
Acacia nilotica (L.) Delile	Dye
Acacia planifrons Wight & Arn.	Medicinal
Albizia amara (Roxb.) B.Boivin	Timber
Albizia lebbeck (L.) Benth.	Timber
Bauhinia purpurea L.	Ornamental, Avenue, Dye
Bauhinia tomentosa L.	Ornamental, Dye
Calliandra inermis (L.) Druce	Exotic
Cassia fistula L.	Medicinal, Avenue
Cassia roxburghii DC.	Medicinal
Cassia siamea Lam.	Avenue
Dalbergia sissoo DC.	Timber
Delonix elata (L.) Gamble	Medicinal

Cont...

Table 1. Diversity and economic value trees in Krishnagiri taluk, Tamil Nadu

Family/Botanical name	Economical values
Delonix regia (Hook.) Raf.	Medicinal
Dichrostachys cinerea (L.) Wight & Arn.	Medicinal
Erythrina variegata L.	Medicinal
Gliricidia sepium (Jacq.) Walp.	Exotic
Lysiloma latisiliquum (L.) Benth	Timber
Peltophorum pterocarpum (DC.) Backer ex K. Heyne	Medicinal, Dye
Pithecellobium dulce (Roxb.) Benth.	Fruit
Pongamia pinnata (L.) Pierre	Avenue, Oil
Prosopis cineraria (L.) Druce	Medicinal
Prosopis juliflora (Sw.) DC.	Timber
Samanea saman (Jacq.) Merr.	Avenue
Sesbania grandiflora (L.) Pers.	Medicinal
Tamarindus indica L.	Timber, Fruit, Dye
Rhamnaceae	
Ziziphus jujuba Mill.	Fruit
Ziziphus oenoplia (L.) Mill.	Fruit
Ulmaceae	
Holoptelea integrifolia (Roxb.) Planchon.	Medicinal
Moraceae	
Ficus benghalensis L.	Avenue
Ficus benjamina L.	Medicinal
Ficus drupacea Thunb.	Medicinal
Ficus elastica Roxb. ex Hornem.	Ornamental
Ficus nitida Thunb.	Ornamental
Ficus racemosa L.	Medicinal
Ficus religiosa L.	Medicinal
Casuarinaceae	
Casuarina equisetifolia L.	Timber, Exotic
Calophyllaceae	
Calophyllum inophyllum L.	Timber, Oil
Phyllanthaceae	
Phyllanthus acidus (L.) Skeels	Fruit
Phyllanthus emblica L.	Fruit
Combretaceae	
Terminalia arjuna (Roxb. ex-DC.) Wight & Arn.	Timber, Dye
Terminalia bellirica (Gaertn.) Roxb.	Timber, Medicinal
Terminalia catappa L.	Timber, Ornamental, Dye
Lythraceae	
Lagerstroemia indica L.	Medicinal, Exotic
Myrtaceae	
Corymbia ficifolia (F. Muell.) K.D. Hill & L.A.S. Johnson	Avenue, Exotic

Cont...

Table 1. Diversity and economic value trees in Krishnagiri taluk, Tamil Nadu

Family/Botanical name	Economical values
Eucalyptus melliodora A.Cunn. ex-Schauer	Medicinal, Exotic
Melaleuca alternifolia Cheel	Medicinal
Psidium guajava L.	Fruit, Dye
Syzygium cumini (L.) Skeels	Fruit, Dye
Anacardiaceae	
Anacardium occidentale L.	Fruit
Lannea coromandelica (Houtt.) Merr.	Timber
Mangifera indica L.	Timber, Fruit, Dye
Sapindaceae	
Filicium decipiens (Wight & Arn.) Thwaites	Timber, Ornamental
Sapindus emarginatus Vahl.	Timber, Medicinal, Oil
Rutaceae	
Aegle marmelos (L.) Corrêa	Medicinal, Dye
Citrus aurantiifolia (Christm.) Swingle	Fruit
Simaroubaceae	
Ailanthus excelsa Roxb.	Medicinal
Simarouba glauca DC.	Timber
Meliaceae	
Azadirachta indica A.Juss.	Timber, Medicinal, Dye, Oil
Melia azedarach L.	Timber, Medicinal, Oil
Muntingiaceae	
Muntingia calabura L.	Avenue
Malvaceae	
Ceiba pentandra (L.) Gaertn.	Timber
Thespesia populnea (L.) Sol. ex Corrêa	Timber
Moringaceae	
Moringa oleifera Lam.	Medicinal
Caricaceae	
Carica papaya L.	Fruit
Santalaceae	
Santalum album L.	Timber
Nyctaginaceae	
Bougainvillea spectabilis Willd.	Medicinal
Pisonia grandis R. Br.	Medicinal
Cornaceae	
Alangium salviifolium (L.f.) Wangerin	Medicinal
Lecythidaceae	
Couroupita guianensis Aubl.	Medicinal
Sapotaceae	
Madhuca longifolia (J.Koenig ex L.) J.F. Macbr.	Avenue, Medicinal, Oil

Cont...

Table 1. Diversity and economic value trees in Krishnagiri taluk, Tamil Nadu

Family/Botanical name	Economical values
Manilkara zapota (L.) P. Royen	Fruit
Mimusops elengi L.	Timber, Dye
Rubiaceae	
Guettarda speciosa L.	Medicinal
Morinda tinctoria Roxb.	Dye
Neolamarckia cadamba (Roxb.) Bosser	Medicinal
Apocynaceae	
Alstonia scholaris (L.) R. Br.	Medicinal, Avenue, Oil
Plumeria obtusa L.	Ornamental
Plumeria rubra L.	Ornamental
Wrightia tinctoria R.Br.	Timber
Boraginaceae	
Cordia domestica Roth	Timber
Cordia subcordata Lam.	Avenue
Ehretia laevis Roxb.	Medicinal
Oleaceae	
Nyctanthes arbor-tristis L.	Medicinal
Bignoniaceae	
Jacaranda mimosifolia D.Don	Medicinal, Exotic
Kigelia pinnata (Jacq.) DC.	Timber, Exotic
Markhamia lutea (Benth.) K. Schum.	Avenue
Millingtonia hortensis L. f	Avenue
Spathodea campanulata P.Beauv.	Exotic
Tabebuia aurea (Silva Manso) Benth. & Hook. f.ex S. Moore	Medicinal
Tabebuia rosea (Bertol.) Bertero ex A.DC.	Timber, Exotic
Tecoma stans (L.) Juss. ex Kunth	Timber, Ornamental
Lamiaceae	
Duranta plumieri Jacq.	Ornamental
Gmelina arborea Roxb.	Medicinal
Tectona grandis L.f.	Timber, Dye

Myrtaceae, Apocynaceae. Fourteen families were monospecific, like Magnoliaceae, Musaceae, Poaceae, Proteaceae, Ulmaceae, Lythraceae, Casuarinaceae, Calophyllaceae, Muntingiaceae, Moringaceae, Caricaceae, Santalaceae, Cornaceae, and Lecythidaceae. *Ficus* is the most dominate genera with 7 species, followed by *Acacia* and, *Cassia, Terminalia* with 6 and 3 species. 12 genera were two species such as *Annona, Phoenix, Albizia, bauhinia, Delonix, Prosopis, Ziziphus, Phyllanthus, Plumeria, Cordia, Tabebuia* and 74 genera in only one species.

For analysis various aspects of economical values like medicinally plants (42 sp.), timber-yielding trees (33 sp.), oil-yielding tree (8 sp.), dye yield trees (17 sp.), edible fruit plants

(19 sp.), exotic plants (17 sp.), avenue trees (13 plants), and ornamental tree (12 sp.) were identified from the study area (Table 1). Few gymnosperm species were also recorded in the present study area, such as *Cupressus sempervirens, Araucaria heterophylla, Cycas circinalia,* and *C. revoluta*.

For their healthcare issues, the residents of Krishnagiri use a variety of morphologically beneficial parts, including leaves, flowers, bark, fruit, and stems. The various ailments that can be treated with these gathered medicinal plants include dengue fever, skin conditions, knee discomfort, kidney stones, digestive issues, hemorrhages, etc. The primary source of medicinal compounds derived from plants and the phytochemicals they contain. In the past few decades, the majority of medicinal plants' phytochemical composition and therapeutic qualities have been identified (Sayed Nudrat and Usha 2005). A small number of plants identified by earlier researchers as medicinal plants in Egalnathum village, Krishnagiri district, are also mentioned in the investigations (Silambarasan and Santhan 2014, Madhankumar and Murugesan 2016, Sivasankari et al 2013). Out of a commercial and use standpoint, oil-producing crops have been the cornerstone of the farming economy. Oil-producing medicinal herb for additional purposes, such as vitamins and supplements and cooking oil. The study's conclusions showed that the majority of the plants exploited by the study area's people produced oil in their seeds, stems,

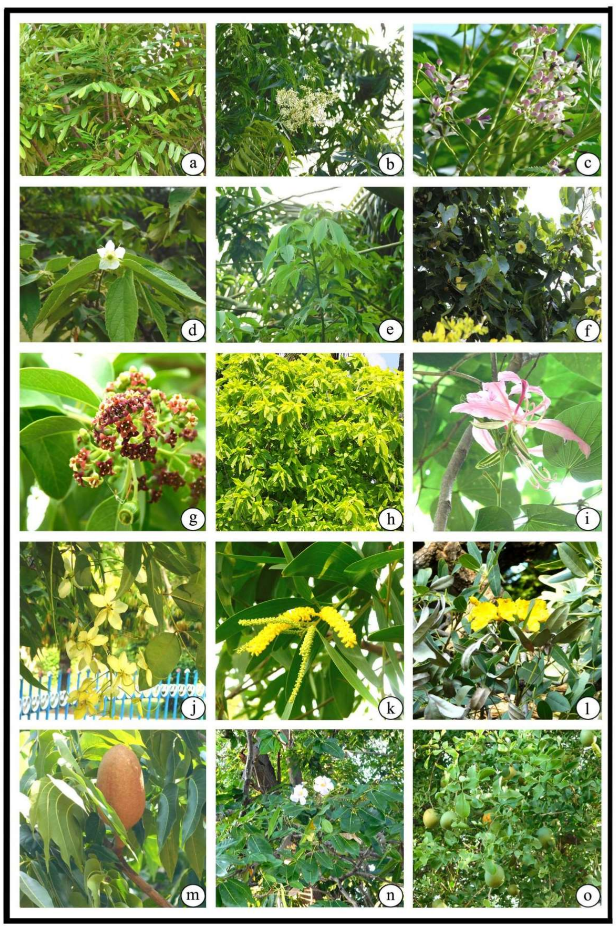

Fig. 1. a. *Simarouba glauca* DC. **b.** *Azadirachta indica* A. Juss. **c.** *Melia azedarach* L. **d.** *Muntingia calabura* L. **e.** *Ceiba pentandra* (L.) Gaertn. **f.** *Thespesia populnea* (L.) Sol. ex Corrêa **g.** *Santalum album* L. **h.** *Pisonia grandis* R. Br. **i.** *Bauhinia purpurea* L. **j.** *Cassia fistula* L. **k.** *Acacia auriculiformis* Benth. **l.** *Tabebuia aurea* (Silva Manso) Benth. & Hook. f.ex S. Moore **m.** *Spathodea campanulata* P.Beauv. **n.** *Tabebuia rosea* (Bertol.) Bertero ex A.DC. **o.** *Aegle marmelos* (L.) Corrêa

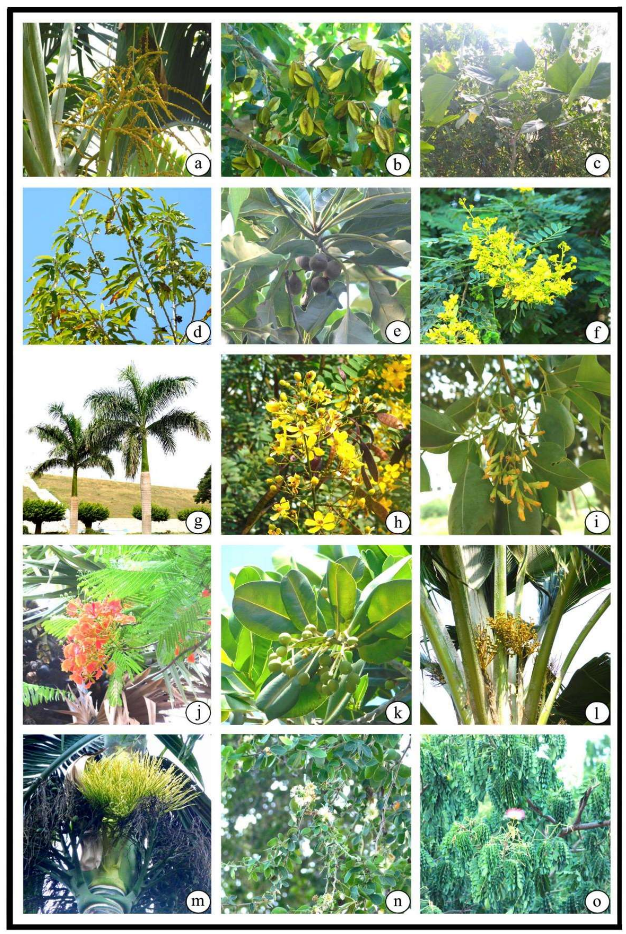

Fig. 2. a. *Dypsis lutescens* (H.Wendl.) Beentje& J. Dransf **b.** *Terminalia arjuna* (Roxb. ex-DC.) Wight & Arn. **c.** *Erythrina variegata* L. **d**. *Michelia champaca* L. **e.** *Terminalia bellirica* (Gaertn.) Roxb. **f.** *Cassia siamea* Lam. **g.** *Roystonea regia* (Kunth) O.F.Cook **h.** *Peltophorum pterocarpum* (DC.) Backer ex K. Heyne **i.** *Dalbergia sissoo* DC. **j.** *Delonix regia* (Hook.) Raf. h. **K.** *Calophyllum inophyllum* L. **l**. *Pritchardia pacifica* Seem. & H. Wendl. **m**. *Areca catechu* L. **n.** *Pithecellobium dulce* (Roxb.) Benth. **o.** *Samanea saman* (Jacq.) Merr.

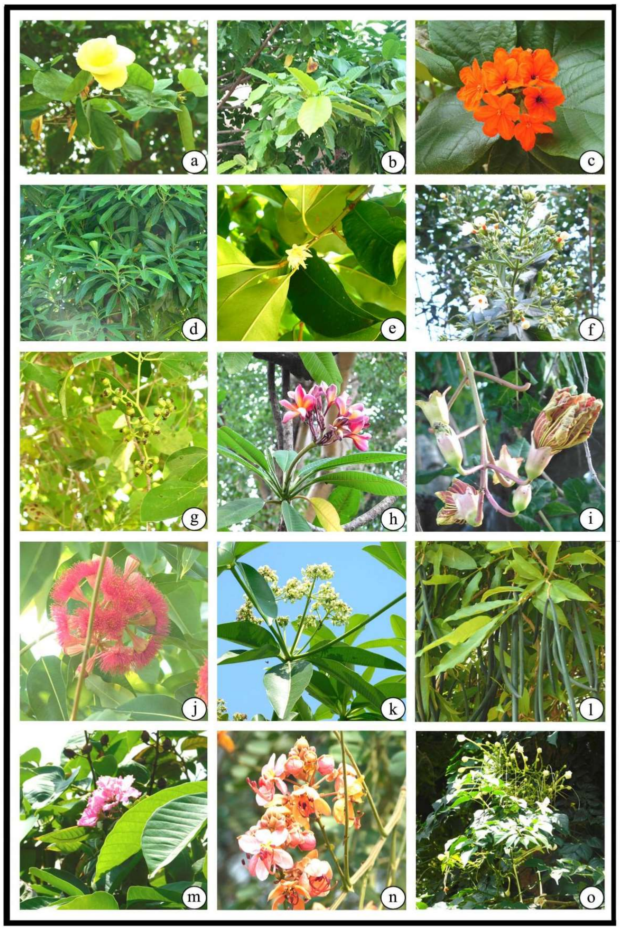

Fig. 3. a. *Bauhinia tomentosa* L. **b.** *Neolamarckia cadamba* (Roxb.) Bosser **c.** *Cordia subcordata* Lam. **d.** *Madhuca longifolia* (J.Koenig ex L.) J.F.Macbr. **f.** Nyctanthes arbor-tristis L. **g.** *Cordia domestica* Roth **h.** *Plumeria rubra* L. **i.** *Kigelia pinnata* (Jacq.) DC. **j.** *Corymbia ficifolia* (F. Muell.) K.D. Hill & L.A.S. Johnson **k.** *Alstonia scholaris* (L.) R. Br. **l.** *Wrightia tinctoria* R.Br. **m.** *Lagerstroemia indica* L. **n.** *Cassia roxburghii* DC. **o.** *Millingtonia hortensis* L. f

flowers, and leaves. The similar find out was recorded from Odisha (Nail and Mahalik 2020, Mendali and Behera 2018).

The study provides a critical overview of the species of plants that provide lumber that are currently found in Krishnagiri district, Tamil Nadu. These plant species are essential to human health and the continuation of life. The study provides a critical overview of the species of plants that provide lumber that are currently found in Tamil Nadu's Krishnagiri district. These plant species are essential to human health and the continuation of life. A small number of previously studied timber-producing species in India (Dobhal, Kumar and Bisht 2010, Sihag, Yadav and Mukundum 2022). The dye is a highly coloured material that is used to provide colour to a wide range of products, including food items, cosmetics, toothpaste, fabrics, paper, wood, varnishes, leather, ink, and fur (Siva 2007). Das and Mondal (2012) made an effort to investigate the traditional use of plants from West Bengal's lateritic zone that provide dye as well as its therapeutic potential. Garhwal Himalayan dye plants were reported by Sharma Antima et al (2012). According to Gokhale et al (2004) there are over 500 plant species from native India that produce dyes. An attempt was made at dye-producing plants in Tripura, Northeast India (Biswajit Sutradhar et al 2015). Similar findings of dye yielding plants were reported in Dharmapuri (Banu et al 2019).

Many authors reported ornamental plants in Tamil Nadu during 2014 to 2021 (Kensa et al 2014, 2018, Suba et al 2014, Sukumaran and Parthiban 2014, Neelamegam et al 2015a, 2015b, 2016, Parthiban et al 2016, Sukumaran and Jeeva 2017, Kensa 2018, Rejitha and Brintha 2019, Rejitha and Uma Devi 2021). Based on the present studies around 48.52% tree species available in Krishnagiri taluk, compared with the flora diversity in Krishnagiri and Dharmapuri district (Ramasamy, Manikandan and Ponnurangam, 2020). A variety of fruit-bearing trees have been reported to be an appropriate and valuable food supply for urban societies (Clark and Nicholas 2013, Kohli et al 1996).

CONCLUSION

Krishnagiri taluk has more exotic, fruit-yielding, dye-yielding, and medicinal tree species. The diversity richness of indigenous areas demonstrates the significant variance in species occurrence between various locations. The majority of the tree species under investigation are significant from both a socioeconomic and medical aspect. The details required to decide with confidence on both the economic and ecological advantages of planting trees in towns and cities. The growth of cities and anthropogenic influence are making certain indigenous species scarce. The town's old trees should be preserved since they offer a look at native plants and serve as a suitable home for a number of animal and bird species. Given that trees provide refuge to numerous different species, more research is required to determine the Keystone value of trees.

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Received 02 March, 2024; Accepted 10 June, 2024

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Indian Journal of Ecology (2024) 51(4): 750-755
DOI: https://doi.org/10.55362/IJE/2024/4304

Manuscript Number: 4304
NAAS Rating: 5.38

Participation, Hindrances and Contributing Factors of Tribal Women in Millet Cultivation: Case of Eastern Plateau and Hill Region Climatic Zone

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Abstract: Millet cultivation is integral to the socio-cultural and economic framework of tribal societies, serving as a cornerstone for their sustenance and identity preservation. Despite its critical importance, the role of tribal women in millet farming remains under explored and insufficiently recognized. This study examines the extent of tribal women's participation, the challenges they face, and contributing factors in millet cultivation through tabular analysis, statistical methods, binomial logistic regression, and Garrett ranking. The participation is negatively correlated with age, education, social motivation, and annual agricultural income, while economic motivation has a positive correlation. Lack of education is identified as the primary constraint, with the highest mean score of 72.70, followed by inadequate knowledge dissemination from developmental programs. Policy recommendations include targeted awareness campaigns on millet's nutritional benefits and culturally sensitive policies to empower tribal women in millet farming.

Keywords: Millets, Tribals woman, Participation, Binomial Logistic, Factors, Hinderances

The pivotal role of women in agriculture has been recognized throughout history, encompassing a diverse range of activities vital to agricultural production and household welfare. Highlighted by the Food and Agriculture Organization (FAO) in 2011, women's contributions in crop cultivation, animal husbandry, processing, and marketing of agricultural produce are indispensable for ensuring food security and overall well-being within households (FAO 2011). However, despite their significant contributions, women have faced systemic disparities rooted in gender-based discrimination, limiting their access to essential resources (Doss in 2018). These disparities have profound implications for food security and nutrition, underscoring the intricate link between women's roles in agriculture and household welfare (FAO 2011). Addressing and rectifying these inequalities is not only crucial for promoting gender equality but also imperative for advancing broader sustainable development goals, as emphasized by the FAO in 2020.Major millets such as sorghum and pearl millet, along with smaller grain millets like finger millet (Ragi), foxtail millet (Kangni), kodo millet (Kodo), proso millet (Cheena), barnyard millet (Sawan), and little millet (Kutki), offer numerous advantages. Additionally, millet cultivation serves as the cornerstone of rain-fed agriculture, upon which 60% of Indian farmers rely.

In Jharkhand, India, home to 32 distinct tribes, tribal communities are categorized into Hunter-Gatherer Types, Shifting Agriculturists, Simple Artisans, and Settled Agriculturists, each contributing to the rich diversity of tribal life. Agriculture in Hazaribagh is predominantly rainfed, with the kharif season (June–September) being the primary cropping period. Sorghum, bajra and finger millet are significant staple food crops, particularly among subsistence farming households in the rainfed uplands. These millets, alongside paddy, form the backbone of agricultural activities in the district. Tribal communities in the region predominantly cultivate local landraces of finger millet, including Birhor, Korwa, Hill Kharia, Sauria Paharia, Mahli, Lohra, Karmali, and Chik Baraik, among others. Traditional agronomic practices are employed for millet cultivation, primarily during the *kharif* season on marginal lands in upland and hilly regions. Millets are often grown in mixed cropping systems alongside pulses, legumes, and oilseeds, requiring minimal external inputs. In addition to serving as a nutritious food crop, finger millet significantly contributes to the income of rural households. The participation of tribal women in millet cultivation is a vital yet often underexplored aspect of agricultural practices. Factors such as socio-cultural norms, land rights, access to resources, and the presence of support systems influence the involvement of tribal women in millet farming operations (Haque and Belwal 2017). The deeper examination of these factors is essential, as affect not only millet production but also gender equality and sustainable agriculture in India, as highlighted by Gupta et al (2017). This research aims to address this gap by investigating the extent of tribal women's involvement and factors affecting in various aspects of millet cultivation and identifying the constraints they face.

MATERIAL AND METHODS

The study centred on the Jharkhand state in India, located in the northeastern region of the country, within Zone VII of the country, recognized as the Eastern Plateau and Hill Region (cite). Jharkhand shares its boundaries with Bihar to the north, West Bengal to the east, Odisha to the south, Chhattisgarh to the west, and Uttar Pradesh to the northwest. The capital city of Jharkhand is Ranchi. Agriculture stands as the primary economic activity, engaging approximately 63% of the rural population in the state.

For our research, because if tribal dominated state, study selected randomly North Chhota Nagpur division. From this region, we have purposively chosen the villages of Kundwa and Jitpur in the Barhi block of Hazaribagh district. A total of 60 households were selected from each villages using an unplanned approach to attain a total sample size of 120. A multistage sampling approach were utilized, encompassing both random and purposive selection of districts, blocks, and villages, to form the foundation for data collection in the state of Jharkhand. The specific focus of this research was on "Participation and the factors influencing tribal women's participation as well as what kinds of hindrances facing during the cultivation of millet cultivation in study area during the agriculture year 2022-23. Data collection was conducted through personal structured interviews with a carefully selected group of farmers. To identify suitable respondents for the study, a snowball sampling technique was employed.

Questionnaire design: Survey was designed to assess the knowledge levels about the nutritional aspects of millets among the local tribal population The preliminary study involving 30 participants was conducted to evaluate the questionnaire's reliability and validity. Out of the eight items in the satisfaction questionnaire, strong validity was observed, with values ranging from 0.632 to 0.824. The construct validity analysis, including Cronbach's alpha (CA) of 0.802, composite reliability (CR) of 0.923, and average variance extracted (AVE) of 0.862, met the established criteria of CA and CR ≥ 0.800 and AVE > 0.500 and CR > AVE, confirming the questionnaire's credibility. The questionnaire encompassed four demographic variables and the factors influencing the subsequently formulated through logical reasoning. Prior consent from participants was obtained by transparently stating the study's purpose. The questionnaire was supplemented with images of millets to facilitate easy identification and ensure unbiased responses.

Statistical analysis: The study employs a mixed-methods approach, combining qualitative and quantitative techniques to gather comprehensive data. Tabular analysis, totals and mean methods were employed to assess the extent of tribal women involvement and their contribution in various activities related to millet cultivation. The analysis focused on determining the number of days worked by individuals (where a work-day represents the productive work completed by a worker within an eight-hour day). Descriptive and inferential Analytical tools were used to analyse the data using Stata and SPSS Software. The binomial logistic regression method was employed to examine the determinants behind farmers' decisions regarding their involvement in different operations of millet cultivation. This statistical analysis was used to identify and understand the various factors that played a role in shaping these decisions.

The logistic regression model used typically follows this form:

$$\ln(p/1-p) = \beta_0+\beta_1x_1+\beta_2x_2+\ldots+\beta_px_p + u_i$$

where, p represents the probability of the dependent variable being 1 i.e., participation in different operations of millet cultivation

1-p represents the probability of the dependent variable being 0 i.e., non-participation in different operations of millet cultivation

β_0 is the intercept coefficient

β_1, β_2,…….. β_p are the coefficients of the independent variables x_1, x_2, x_3…..x_p

β_0= intercept coefficient

β_1…..β_p = coefficients of independent variables

x_1= Age (In years)

x_2= Education (Years of schooling)

x_3 = Economic motivation (Yes = 1, No = 0)

x_4 = Social Motivation (Yes = 1, No = 0)

x_5 = Farming Experience (in years)

x_6 = Area (ha)

x_7 = Annual income from agriculture (Rs/annum)

x_8 = Surplus family labour (Yes=1, No = 0)

u_i = Random Error Term

In a binomial logistic regression model, the odds ratio is a measure that quantifies how the odds of an event occurring change with a one-unit change in an independent variable while holding all other variables constant. It provides insight into the relationship between a specific predictor variable and the probability of the binary outcome (typically coded as 1 or 0) happening. Mathematically, the odds ratio for a predictor variable xi in a logistic regression model is calculated as follows:

Odds Ratio = $e^{\wedge}\beta_i$

where, β_i is the coefficient associated with the predictor variable xi in the logistic regression model.

e represents Euler's number, approximately equal to 2.71828

Study focused on assessing the limitations experienced by tribal women in the research area, and this was accomplished using the Garrett Ranking method. The major advantage of this technique as compared to simple frequency distribution is that the constraints and advantages are arranged based on their importance from the point of view of respondents. Hence, the same number of respondents on two or more constraints may have been given different ranks.

By applying a specific formula, the factors were ordered and assigned ranks, allowing for a systematic evaluation of their significance.

Per cent position = $100(R_{ij}-0.50)/N_j$

where, R_{ij} = Rank given for the i^{th} reason by j^{th} respondent

N_j = Number of factors ranked by j^{th} respondent

This involves converting the percentile position of each factor into scores using Garrett's Ranking table. The scores for each labourer across the 10 factors are then aggregated and divided by the total number of respondents. The mean score obtained is used to rank the sources of problems in descending order of importance.

RESULTS AND DISCUSSION

Participation: Tribal women exhibited significant involvement in transplanting activities, with an average time spent per individual reaching 4.85 hours (Table 1). Chauhan et al (2006) also highlighted transplanting as a task garnering high participation from farm women. The prominence of women in transplanting tasks can be attributed to the meticulous attention and care required, where their patience and precision play pivotal roles, thereby underscoring their substantial contribution to this aspect of agricultural practice. Following transplanting, harvesting emerged as another operation where tribal women demonstrated participation, with an average time of 4.66 hours per individual. This finding underscores the integral role played by women in harvesting activities, reflecting their contribution to the successful culmination of the cultivation process. Furthermore, the study revealed that weeding, harvesting, and transplanting tasks were exclusively performed by females, highlighting their central role in these essential agricultural activities. Conversely, field preparation, a task characterized by its strenuous nature, was predominantly carried out by men, resulting in negligible participation from tribal women and restricting their involvement to seedbed preparation alone. Hussain et al (2011) and Kumari et al (2016), emphasized the division of labour based on gender roles in agricultural practices of work-days.

Constraints faced by women workers: The lack of education emerged as the foremost constraint, garnering the highest mean score of 72.70 (Table 2). This finding underscores the critical need for educational interventions targeting tribal women, as education serves as a foundational tool for enhancing their capacity, agency, and opportunities for socio-economic advancement. Slathia (2015) and Jaiswal (2018) also identified low levels of education as a primary obstacle hindering the empowerment and well-being of tribal women. Insufficient knowledge dissemination by developmental programs emerged as the second-highest constraint, reflecting the need for more effective communication and outreach strategies to ensure the accessibility and relevance of development initiatives for tribal women. Mareeswaran et al (2017), Jaiswal (2018) and

Table 1. Tribal women participation in different operations of millet cultivation in terms of work-days

Operations	Total hours	Total works-days	Total time spent by an individual farmer
Field preparation	287.5	35.4	0.3
Sowing	526.0	65.75	0.55
Transplanting	4654.0	581.75	4.85
Irrigation	231.5	28.94	0.24
Weeding	2690.5	336.31	2.8
Fertilizer application	477.2	59.65	0.5
Harvesting	4469.0	558.63	4.66
Threshing	697.0	87.13	0.73
Winnowing	348.5	43.56	0.36
Grading and packaging	161.5	20.19	0.17
Transportation and marketing	532.0	66.5	0.55
Total	15074.7	1883.81	15.71

Table 2. Constraints faced by tribal women

Constraints	Mean score	Rank
Lack of education	72.7	1
Insufficient knowledge about development programs	72.05	2
Less numeration	71.98	3
Lack of training	70.32	4
Lack of alternate employment	63.64	5
Health issue	62.24	6
Priority to male worker	61.1	7
Insufficient credit facility	48.73	8
Family restriction	44.53	9
Lack of freedom to take decision	34.96	10

Shamna et al (2018) underscored the importance of targeted interventions and capacity-building efforts to address knowledge gaps and enhance the effectiveness of developmental programs in empowering tribal women. Furthermore, the analysis identified several other notable constraints, including inadequate remuneration, lack of training opportunities, limited access to alternative employment, insufficient credit facilities, family restrictions, and health issues. These findings highlight the multifaceted nature of the challenges faced by tribal women, encompassing economic, social, and health-related dimensions. The recognition of these constraints underscores the urgency of adopting holistic approaches that address intersecting needs and vulnerabilities of tribal women, while also promoting their agency, autonomy, and well-being.

Factors influencing the participation: The logistic regression analysis revealed significant associations between several predictor variables and the odds ratio of a particular outcome (Table 4) by the p-values. Age (p = 0.03116) and economic motivation (p = 0.02481) were negatively and positively correlated with the participation of tribal women, respectively, with odds ratios of 0.96664 and 1.22646, suggesting that for each year increase in age, the odds of the participation of tribal women in different operations of millet decrease by 0.96664 times, and each unit increase in economic motivation results in 1.22646 times increase in the odds. Furthermore, social motivation (p = 0.04256) was also negatively associated with the participation, with an odds ratio of 0.9522, implying that increased social motivation is associated with 0.9522 times decrease in the odds of participation. These findings suggest that age, education, economic motivation, and social motivation have significant impacts on the outcome. However, other variables like farming experience, area, and surplus family labour, did not show significant associations with the outcome. The Cox and Snell R-squared value of 0.713 (Table 3) indicates that the model explains a substantial portion of the variance in the data. The variable 'age' exhibited a negative and significant relationship with participation, indicating that older tribal women tended to allocate less time to agricultural activities compared to their younger counterparts. Younger women in farming displayed a higher inclination towards embracing change, likely attributed to their greater physical strength, which enables them to engage in a wider range of agricultural tasks. This observation aligns with the research conducted by Choudhary and Singh (2003). However, it contradicts the

Table 3. Policy measures and suggestions to address the constraints faced by tribal women

Livelihood diversification	Introduce and support livelihood diversification programs that align with the local ecosystem and resources. This might involve promoting sustainable agriculture, non-timber forest products, and cottage industries to increase income opportunities.
Community-based training	Establish community-based training centres that offer practical skills relevant to the local economy. These centres can focus on agriculture, traditional crafts, and small-scale enterprises to enhance employability.
Health camps	Organize regular health camps within tribal communities, offering basic healthcare services and awareness programs on nutrition, hygiene, and preventive healthcare. Collaborate with local healthcare providers to ensure accessibility.
Microfinance initiatives	Facilitate the formation of women's self-help groups and provide them with access to microfinance services. This empowers women to start small businesses or invest in income-generating activities.
Tailored educational programs	Develop customized educational programs that consider the unique needs of tribal women. Ensure schools are located nearby, provide scholarships, and offer flexible timings to accommodate their responsibilities.
Women's cooperatives	Encourage the formation of women's cooperatives to collectively address issues and access resources. These cooperatives can engage in joint ventures, marketing, and advocacy.
Mobile information centres:	Establish mobile information centres that visit remote tribal areas regularly to disseminate information about government schemes, entitlements, and services available to them.
Inclusive governance	Promote the inclusion of tribal women in local governance structures and decision-making bodies. Ensure their voices are heard in matters affecting their communities.
Cultural sensitivity	Design policies and programs that respect and incorporate the cultural values and practices of tribal communities. This ensures greater acceptance and participation.
Monitoring and evaluation	Implement robust monitoring and evaluation mechanisms to assess the effectiveness of policies and programs. Adapt strategies based on real-time feedback and experiences on the ground.
Collaborative approach	Foster partnerships between government agencies, non-governmental organizations (NGOs), and local community leaders to jointly address the multifaceted challenges faced by tribal women.
Legal support	Establish legal aid centres in proximity to tribal communities, providing guidance and support to women dealing with legal issues, including family restrictions and property rights.
Infrastructure development	Prioritize infrastructure development in tribal areas, including road connectivity, electricity, and clean water supply, to improve accessibility and quality of life.

Table 4. Binary logistic results for analysis of factors influencing participation of tribal women in different operation of Millet production for whole sample

Variables	B	Standard error	*p*-Value	Exp(B)/ Odds Ratio
Intercept	4.338	1.27023	0.00013	-
Age	-0.03451	0.01384	0.03116	0.96664
Education	-0.002421	0.00243	0.00245	0.99758
Farming experience	0.50632	2.47245	0.8941	1.66058
Social motivation	-0.04861	0.59341	0.04256	0.9522
Economic motivation	0.20432	0.82457	0.02481	1.22646
Annual Income from agriculture	-0.01321	0.54839	0.00613	0.98694
Area	-0.12451	0.86986	0.89412	0.88245
Surplus family labour	0.00647	2.17485	0.91347	1.00647
Cox and Snell R-squared	0.713			

results reported by Fami (2006) and Chauhan (2011). The 'education' variable demonstrated a negative and significant relationship with the participation of tribal women in farming.

These findings are not consistent with the results of studies conducted by Singh et al (2015) and Chauhan (2011). The 'social participation' variable exhibited a notable negative and statistically significant relationship with the participation of tribal women in farming. This was attributed to their active involvement in community activities, which resulted in less time being allocated to farming. These findings are in contrast to those of Singotia (2014) and Patel et al (2016). On the other hand, 'economic motivation' displayed a positive and significant relationship with the participation of farm women in agricultural activities. Many tribal women want to assist the head of the family in income generation to meet the daily needs. Sharma (2008) and Bhairve (2013) reported similar findings. Annual income from agriculture has a negative and significant relationship with the participation index as millet cultivation is a minor crop which is basically done in the study area for their own consumption. Therefore, as their income increases from other major crops participation in millet cultivation decreases.

CONCLUSION

The transplanting is the most labour-intensive operation in millet cultivation, primarily undertaken by tribal women who also handle weeding and harvesting tasks. However, their involvement in field preparation is limited due to the physical demands of the work. The main challenges faced by tribal women include a lack of education and insufficient knowledge from developmental programs, which significantly impact their participation in millet farming. Factors such as age, education, social motivation, and agricultural income further influence their engagement negatively. Based on these findings, the study suggests several policy measures, including the creation of nutritional awareness campaigns, the implementation of culturally-sensitive policies, the establishment of proper market facilities for output procurement, and the promotion of community-based organizations or cooperatives among tribal women.

AUTHOR CONTRIBUTION

The conceptualization of the paper, supervision of field research, and data collection were overseen by P.S. Badal. Kumari Megha contributed to data collection and entry. Sachin Rathour conducted data analysis and interpreted the findings.

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Received 13 March, 2024; Accepted 10 June, 2024

Indian Journal of Ecology (2024) 51(4): 756-760
DOI: https://doi.org/10.55362/IJE/2024/4305

Manuscript Number: 4305
NAAS Rating: 5.38

Variation in Fruit, Seed and Germination Traits in *Sterculia urens* Roxb.

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Abstract: *Sterculia urens* Roxb., commonly known as Gum Karaya or Indian-tragacanth, is one of India's commercial non-timber forest genetic resources. Many tribal communities depend upon various NTFPs, including *Sterculia* Gum, for their routine life and livelihood security. The present study recorded variation in fruit, seed and germination traits among selected accessions from the Vansda forest of South Gujarat. The result showed that there was a significant variation among 14 accessions for fruit length (29.30-43.29 mm), fruit thickness (14.60-19.70 mm) and fruit weight (1.05-2.56 g), seed length (8.57-11.56 mm), seed thickness (5.33-6.91 mm) and single seed weight (0.12-0.29 g). The significant variation was recorded for seed germination, which ranged from 53 to 100 percent. Six out of fourteen accessions produced > 90% seed germination. Seed length (86%) and seed weight (81%) recorded maximum heritability values. The overall genetic gain among fruit and seed traits was less; however, seed weight (38.50%) and germination (30.86%) recorded comparatively higher gain than other traits. It is revealed that seed lots collected from the Vansda forest exhibited variability in fruit & seed biometry and germination percentage. Hence, there is a scope to select and improve the species.

Keywords: *Sterculia urens,* Gum Karaya, Seed variability, Germination, Heritability

Sterculia urens Roxb. (Gum Karaya, Family: Malvaceae-Sterculioideae) is one of the commercial important NTFP tree species distributed in the tropical deciduous forests of dry rocky hill lands. Globally, this species is distributed in India, Sri Lanka and Malaysia; however, also grown in Australia, Pakistan, Panama, Philippines, Indonesia, Senegal, Sudan and Vietnam (Rao 2015, Gautami and Bhat 1992). In India, the species of *Sterculia* are found in the tropical Himalayas, Western and Central India, and the Eastern and Western Ghats. In Gujarat, this species is found throughout deciduous and scrub forests of Panchmahals, Dangs, Khatana, Barda Wildlife Sanctuary, Girnar (Junagadh), Ramapara Wildlife Sanctuary, Vyara and Chhotauadepur (Anon 2008). Tribal communities/ forest dwellers use to collect gums and resins from standing trees, including *Sterculia urens*, in the natural forests. Gums extracted from this species are called Karaya gum (or Indian-tragacanth). The pure form of gum is used in foodstuffs as emulsifiers/stabilizers, as thickeners in cosmetics and medications, and as an adhesive for dentures (Coppen 1995, Orwa et al 2009). Due to its natural source and various end uses, the industrial demand is increasing day by day in the international market. It is reported that the compound annual growth rate (CAGR) of global market for gum karaya is about 5.4% from 2016 to 2021; however, for coming 10 years, the Indian market for gum karaya is expected to grow upto 3.7% CAGR (https://www.futuremarketinsights.com/ reports/karaya-gum-market).

Domestication is an important step toward bringing such commercial plants from wild into cultivated condition for its sustainable utilization of gums and its value-added products to meet the industrial demand; meanwhile, it also helps in conservation of species and its natural habitat. Understanding variability for fruit/seed attributes and other economic traits is one of the parts of domestication; however, such information on this species is scanty (Bhuva 2016). Therefore, a study was undertaken to document the variability in fruit, seed and germination among fourteen accessions of *S. urens*.

MATERIAL AND METHODS

To understand the tree to tree variation within a population of *S. urens* for fruit, seed and germination traits, 14 good bearing accessions were selected in the tropical dry deciduous forest of the Vansda forest (Latitude of 20° 45' N and Longitude of 73° 28' E), South Gujarat, India. Laboratory and nursery trials were conducted in the College of Forestry, Navsari Agricultural University, Navsari. Bio-metric parameters of these 14 trees are given in Table 1. Fruit maturity occurs from April to May. Individual tree-wise fruits were collected, labelled and packed separately. Fruit traits such as length, thickness, weight, seeds per fruit, seed length, seed thickness, single seed weight and fruit/seed weight were measured as per standard procedure (Bhuva 2016). Total sixty seeds of three samples containing 20 seeds each were used for seed trait assessment. The seed germination trial was conducted in the forest nursery using the germination tray filled with sterile sand. These trays were arranged randomly following completely randomized design by maintaining uniformity growing conditions under shade-net areas. Pre-sowing treatment of soaking seeds in normal water for 12 hrs. was commonly given to all the 14 seed lots, separately. The number of seeds germinated for each day was counted up to 21 days from the date of sowing. The emergence of plumule above the sand was taken to count germination. Data were subjected to statistical analysis following Panse and Sukhatme (1967) with statistical software.

RESULTS AND DISCUSSION

The seed samples collected from fourteen accessions of *Sterculia urens* from the Vansda forest showed greater variation for fruit, seed and germination traits. Number of fruits per inflorescence varied from 3.22 to 5.56 with overall mean of 4.42 among nine individuals (Fig. 1). Trees such as VNP-03, VNP-01 and VNP-05 recorded more than 5 fruits per inflorescence. Table 2 and 3 presenting variability within individuals as well as between trees/accessions for fruit and seed traits. There was significant variation among different individuals for fruit length (29.30 to 43.29 mm), fruit thickness (14.60 to 19.70 mm) and fruit weight (1.05 to 2.56 g) (Table 2). The number of seeds per fruit ranged between 3.40 (VNP-05) and 4.77 (VNP-03; Fig. 1). Similarly, all the seed traits such as seed length (8.57 to 11.56 mm), seed thickness (5.33 to 6.91 mm) and single seed weight (0.12-0.29 g) also varied significantly among individuals of *Sterculia urens* (P <0.05; Table 3). Seeds collected from VNP-05>VNP-06>VNP-03>VNP-07>VNP-04>VNP-10 showed bigger and bolder seeds than other accessions. Seed germination significantly varied from 53 to 100 per cent with overall mean of 81.43 per cent (Fig. 2). Accessions such as VNP-02>VNP-06>VNP-10>VNP-11>VNP-12>VNP-14 recorded more than 90 per cent germination within 9 days from sowing date.

The seed length associated positively with seed weight (r=0.769); while, seed thickness also correlated significantly with seed weight (r=0.843) (Table 4). However, germination

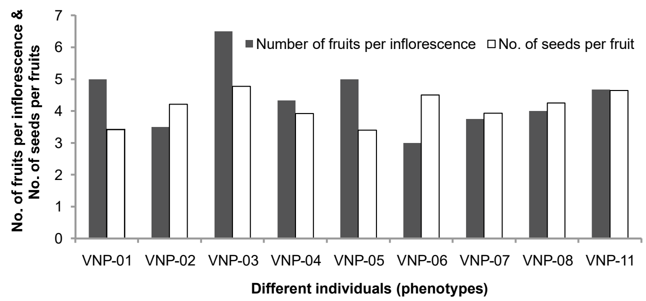

Fig. 1. Variation among different accessions for fruit traits of *S. urens*

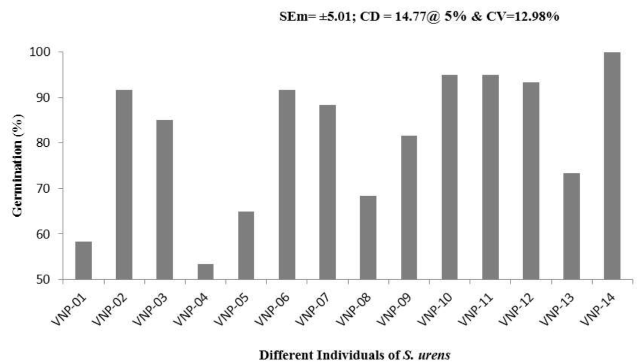

Fig. 2. Variation in seed germination among different accessions of *S. urens*

Table 1. Details of biometric information of 14 selected accessions of *S. urens*

Accession code	Tree height (m)	Girth at breast height (GBH) (cm)	Clear bole height (m)	Crown diameter (m)
VNP-01	11.20	131.00	3.10	8.35
VNP-02	6.30	39.00	4.00	3.30
VNP-03	9.70	46.00	8.30	4.55
VNP-04	12.80	95.00	10.30	8.75
VNP-05	14.50	159.00	9.50	8.05
VNP-06	14.00	109.00	9.00	9.00
VNP-07	16.00	122.00	11.00	9.60
VNP-08	5.80	56.00	1.80	3.30
VNP-09	10.80	50.00	7.00	5.50
VNP-10	10.80	69.00	6.90	3.80
VNP-11	10.50	62.00	7.80	3.85
VNP-12	15.20	129.00	11.30	7.75
VNP-13	17.20	137.00	13.10	7.40
VNP-14	8.00	76.00	6.00	4.75

does not show significant correlation with seed length, seed thickness and seed weight. Genetic parameters are also worked out for seed traits and germination . The phenotypic co-efficient of variation (PCV) showed a great difference among studied parameters and they varied from 7.09 (seed thickness) to 22.86 per cent (seed weight), whereas for

Table 2. Variation in fruit and seed traits among different accessions of *S. urens* in Vansda tropical forest

Accession code	Fruit length (mm)			Fruit thickness (mm)			Fruit weight (g)		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean
VNP-01	28.7	49.9	38.11	13.5	24.8	18.17	1.2	2.7	1.87
VNP-02	23.5	41.1	35.34	12.6	18.9	16.30	0.8	2.5	1.98
VNP-03	35.2	48.3	41.84	15.8	21.9	18.53	2.2	3.1	2.56
VNP-04	28.4	45.9	39.67	12.4	19.8	17.53	1.1	3.1	2.24
VNP-05	26.2	46.4	37.16	13.4	20.2	16.26	0.8	2.8	1.84
VNP-06	20.2	36.7	29.30	17.5	20.3	18.68	1.7	3.1	2.31
VNP-07	35.0	49.5	43.29	15.1	24.0	19.53	1.8	3.2	2.48
VNP-08	34.0	37.6	36.66	13.2	15.4	14.60	0.9	1.3	1.05
VNP-09	-	-	-	-	-	-	-	-	-
VNP-10	-	-	-	-	-	-	-	-	-
VNP-11	24.6	42.2	30.79	16.2	23.7	19.70	1.4	3.3	2.13
VNP-12	-	-	-	-	-	-	-	-	-
VNP-13	-	-	-	-	-	-	-	-	-
VNP-14	-	-	-	-	-	-	-	-	-
Overall values	20.2	49.9	36.91	12.4	24.8	17.70	0.8	3.3	2.05
SEm (±)			2.6			0.77			0.18
CD @ 5%			7.71			2.29			0.53

Note: Data is not given in five trees due to insufficient collection

Table 3. Variation in fruit and seed traits among different accessions of *S. urens* in Vansda tropical forest

Accession code	Seed length (mm)			Seed thickness (mm)			Seed weight (g)		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean
VNP-01	7.92	10.44	9.58	5.13	7.03	6.05	0.10	0.29	0.19
VNP-02	8.42	10.13	9.35	5.51	6.77	6.32	0.18	0.29	0.24
VNP-03	9.37	11.83	10.81	6.03	7.01	6.57	0.22	0.33	0.29
VNP-04	6.07	11.58	10.52	4.06	7.51	6.91	0.03	0.34	0.28
VNP-05	9.77	12.85	11.56	4.85	6.94	6.15	0.19	0.36	0.29
VNP-06	9.79	12.08	11.01	5.97	7.35	6.73	0.16	0.35	0.29
VNP-07	8.72	11.89	10.66	5.58	7.20	6.47	0.07	0.33	0.27
VNP-08	7.71	10.41	9.26	4.82	5.86	5.33	0.07	0.17	0.12
VNP-09	8.39	11.26	9.82	5.62	7.10	6.39	0.12	0.28	0.23
VNP-10	8.37	12.47	10.49	5.53	7.66	6.46	0.02	0.40	0.29
VNP-11	8.62	12.33	10.05	4.42	7.24	6.35	0.09	0.31	0.24
VNP-12	7.61	9.71	8.57	5.64	7.31	6.53	0.03	0.29	0.22
VNP-13	7.72	10.65	9.41	4.85	6.36	5.81	0.06	0.25	0.18
VNP-14	8.58	11.11	9.70	5.22	7.43	5.98	0.15	0.30	0.21
Overall values	6.07	12.85	10.06	4.06	7.66	6.29	0.02	0.4	0.24
SEm (±)			0.13			0.08			0.01
CD @5%			0.37			0.23			0.03

Table 4. Correlation between seed traits and germination in *S. urens*

Parameters	Seed length (mm)	Seed thickness (mm)	Seed weight (g)
Seed thickness	0.417	-	
Seed weight	0.769*	0.843**	-
Germination	-0.126	0.180	0.203

Note: *Significant at 5% P; ** Significant at 0.1% P

Table 5. Estimation of genetic parameters for seed traits and germination in *S. urens*

Parameters	PCV (%)	GCV (%)	ECV (%)	$H^2_{b.s}$	GA	GG (%)
Seed length (mm)	8.71	8.09	3.22	86.0%	1.56	15.49
Seed thickness (mm)	7.09	6.22	3.37	77.0%	0.70	11.26
Seed weight (g)	22.86	20.67	9.76	81.0%	11.26	38.50
Germination (%)	20.41	17.48	10.52	73.0%	25.13	30.86

PCV= Phenotypic co-efficient of variation; GCV= Genotypic co-efficient of variation; ECV= Environmental co-efficient of variation; $H^2_{b.s}$ = Broad sense heritability; GA= Genetic advance; GG= Genetic gain

genotypic co-efficient of variation (GCV), values ranged from 6.22 (seed thickness) to 20.67 per cent (seed weight). Environmental co-efficient of variation (ECV) values ranged from 3.22 (seed length) to 10.52 per cent (germination). All the parameters such as seed length, seed weight, seed thickness and germination showed highest (> 73%) heritability values (Table 5). Germination per cent showed the highest genetic advance of 25.13 and genetic gain of 30.86% than rest of the parameters, except seed weight, which has 38.50% genetic gain.

Selected accessions of *Sterculia urens* from Vansda forest showed greater variability for fruit, seed and germination traits. Thus, there is a scope and potential for selection and improvement of this species. Even seed traits and germination recorded higher heritability values; hence, such parameters can be considered while selection of superior trees in *S. urens*. Similar kind of observation was also recorded among different forest tree species *viz., Dysoxylum binectariferum* (Gunaga et al 2015), *Mammea suriga* (Gunaga and Vasudeva 2009), *Pongamia pinnata* (Raut et al 2010), *Garcinia talbotii* (Bansude et al 2013), *Sterculia urens* (Bhuva et al 2019), *Madhuca longifolia* (Hegde et al 2018) and other forest species. Generating such baseline data/information provide a quick guide for further selection and improvement of forest tree species and its conservation management.

CONCLUSION

Study shows that fruit traits, seed traits and germination per cent varied among accessions of *Sterculia urens*. Fruits collected from some of the accessions recorded bolder seeds and yielded higher germination. It is indicated that there is further scope for superior tree selection in order to raise good quality planting materials for raising plantations.

ACKNOWLEDGMENTS

We thank the University Officers for their support and cooperation. We acknowledge the Gujarat Forest Department for their help during this study.

AUTHORS CONTRIBUTION

Dr. Gunaga designed the experiment and analyzed the data, Dr. Thakur and Dr. M.J. Dobriyal helped in laboratory/nursery experiments, Dr. D. Nayak helped in revising Manuscript and Dr. H.T. Hegde involved in the field studies.

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Received 12 February, 2024; Accepted 30 June, 2024

Indian Journal of Ecology (2024) 51(4): 761-764
DOI: https://doi.org/10.55362/IJE/2024/4306

Manuscript Number: 4306
NAAS Rating: 5.38

Wild Food Resource Utilization in Tribal Communities of South Gujarat

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Abstract: The southern part of Gujarat is rich in terms of forest resources and home for many ethnic communities. Present study was conducted to document the collective knowledge of wild edibles possessed by selected ethnic communities of south Gujarat. Information on use of wild edibles were collected mainly from Dhodia, Kukna, Varli, Gamit and Naika communities South Gujarat. The 40 wild food plant species of 21 families are commonly consumed by these communities. Study helped to document the various wild food sources like tree-based food, tuber, leafy vegetables, fruits, bulb, pods, seeds, nuts, mushroom and young shoots. The Varli, Kukna and Gamit communities have adequate knowledge of wild plants and making maximum utilization. The generated baseline data through present study will be helpful for prioritization of conservation through sustainable use and management of the resources. Community based conservation efforts will be more effective way for resource management and maintaining the ethnic food culture of the communities in long run.

Keywords: Ethnic food, South Gujarat, Tribal communities, Wild edibles

Food scarcity, nutrition crisis, pesticide residue, drought are some serious problems of this twenty first century. In the changing scenario, it is difficult to fulfil the food demand of all in present rate of agricultural production. There is an urgent need to search for alternative sources which can fulfil the human needs of nutrition and health. In these circumstances wild edible species are the better source to meet the food demand and are good source of vitamins and minerals. In recent days, ethnic food culture is declining due to many reasons like deforestation, over-harvesting, indiscriminate way of utilization, change in food preference and due to modern lifestyle, the knowledge of this wild treasure remains in the memory of elderly people. These factors eventually leading to resource degradation and this decline affect the food security of rural people directly (e.g., availability and accessibility to food) and indirectly (modifying the ecological habitat where species grow) (Van Noordwijk et al 2014, Agarwal et al 2015).

Wild plants are important source of food, healthcare and material subsistence in much of the developing world and carry a strong association with human livelihood (Sundriyal et al 2004, Misra et al 2008, Mavengahama et al 2013, Ojelel et al 2015). The word 'wild' in this context refers to species that are not intentionally grown and managed by humans, including those minimally managed to prevent overgrowth or overharvest. This includes both native and alien plants, regardless of the preservation level of the habitats (Menendez et al 2012). Since ancient times, wild food supplements are helpful in maintaining the dietary balance of the tribal communities. Aborigines consume a main staple diet and it is supported with supplementary wild foods. These species are consumed by various communities depending on the local availability. The knowledge of traditional food associated with farmers, hunters and nomadic tribes is of great importance. These people had survived in extreme food scarcity periods from time immemorial. Numerous preparations of plant species are also in practice and sold in tribal markets. Tribal and local communities have traditional knowledge of wild food resources due to their long association with nature (Chauhan et al 2018). In recent years, there has been a growing interest in exploring the traditions of using wild plants and consensus has been formed that information on wild edibles is a vital part of ethnobotanical knowledge. Many previous ethnobotanical works have listed useful plants with a strong tendency to focus on the scouting of new drug sources and new non-wood forest products (NWFP), both of which can be economically lucrative. Nene (2004) recorded 300 diverse plant species belonging to 90 families utilized as food resources during famine. It includes herbs, flowering stalks, leaves, seeds, kernels, fruits, tubers, etc. Usually, these wild species are not in cultivation. The survey of wild edibles from Orissa state reported 144 non-conventional food resources consumed by five tribal groups which are playing major role in nutritional point of view (Kulkarni 2006). Studies on wild edibles from Gujarat region were carried out by many researchers (Bhattacharjee et al 2009, Shalini Dhyani 2016, Chauhan et al 2018). However, there is lack of information on ethnic food culture of Dhodia, Kukna, Varli, Gamit and Naika communities in particular. With this background, present investigation was undertaken to explore the collective knowledge of wild edibles possessed by selected ethnic communities of south Gujarat.

MATERIAL AND METHODS

Study area: Biogeographically, the south Gujarat (latitude 21°14'-22°49' N and longitude 72° 22' - 74°15' E) consists of seven districts *viz.,* Bharuch, Dangs, Narmada, Navsari, Surat, Tapi and Valsad covering a geographical area of 31,495 km^2. The plains of south Gujarat are watered by Purna, Par, Damanganga, Auranga, Kolak, Ambica, Darota, Narmada and Tapi rivers. The region shows a typical sub-humid to humid climate (Anonymoius 2006). The mean annual temperature is about 26 °C and average annual rainfall varies from 1300 to 2200 mm. The major forest types in the south Gujarat are moist deciduous forest and dry deciduous forest. (Bhatt et al 2013).

Methodology: The study was conducted in selected tribal pockets of south Gujarat. Information on wild edibles was collected through Participatory Rural Appraisal (PRA) method (Chambers 1995). Data was collected from 100 respondents from Dhodia, Kukna, Varli, Gamit and Naika communities. Expert interviews with key informant were also conducted to quantify past and present consumption trends. The diverse information about local names, plant part and usages *etc.* was also sought from the local people. Wild food plants identified during the field visits were cross checked against different informants to validate the information. The details on utilization of wild food plants were prepared by referring the earlier studies of Bhattacharjee et al (2009), Chauhan et al (2018) and Kokni & Solanki (2022) for authentication.

RESULTS AND DISCUSSION

The 40 wild food plant species of 21 families are being commonly consumed by Dhodia, Kukna, Varli, Gamit and Naika communities (Table 1). The higher number of wild food yielding plants were reported from families namely, Fabaceae (06 species) followed by Amaranthaceae (03 species) and Lyophyllaceae (03 species). Plant species from Fabaceae family were collected mainly for leaves and some for fruits, while species from Amaranthaceae family were collected for their leaves . The various wild food sources recorded were 23 fruit trees, 01 tuber crop, 09 green leafy vegetables etc. (Table 2). Some of these were used for direct consumption, garnish or complement other food items. Mainly wild fruits and) green leafy vegetables are utilized by the communities in different season. Varli, Kukna and Gamit communities have adequate knowledge of wild plants and reported maximum utilization of wild plants along with their staple diet (Fig. 1). Tree-based food sources and herbs were highly utilized by the communities. The majority of fruits in the diet of communities were mainly contributed by tree species, while leafy vegetables were mostly sourced from herbs species. Trees and shrubs were the main source of edible fruits and flowers and herbs for leaves. The main sources of tubers and pods were from twiners and climbers. In case of young shoot, they are collecting from herb and grass species. Bhattacharjee et al (2009) recorded out of 31 wild food plants gathered by Bhil tribe of Dang district for consumption 18 were fruits, nuts and seeds from trees and 13 green leafy vegetables. Chauhan et al (2018) reported about the utilization of 90 species of wild edibles by the Vasavas in Dediapada Taluka which shows the dependency of those communities on wild food resources. Some of the studies previously undertaken in India also highlighted about the usage of wild resources as a food sources. There are 22 species of edible plants used by major ethnic groups such as Gond, Majhwar and Baiga reported from the deciduous forests of Chhattisgarh in Central India (Kala 2009). Utilization of 32 wild edibles in Manipur was documented by Pfoze et al (2012) through market and house hold survey in the villages of Mao community. In present study, use of wild mushrooms were rare by the communities. Similar observations were also made about the mashroom usage in different parts of South Gujarat by various tribal people (Kokni & Solanki 2022) and Mahadeo Koli tribe in Western Maharashtra (Kulkarni and Kumbhojkar 1992).

Community based conservation efforts will be more effective way for resource management and maintaining the ethic food culture of the communities in long run. Cultural values associated with the wild edible plants may enrich the efforts of bio-resources conservation. The study and documentation of local wild edible plants can also be used in development of domestication programme. Processing, preparation of food items from the wild species and their marketing will give rise to small scale food web which can providing job opportunities to many people in rural areas.

Table 1. Wild food plant species utilized by the communities

Plant species and scientific name	Local name	Family	Use
Trees			
Aegle marmelos	Bili	Rutaceae	Fruits used as a pickle
Bauhinia purpurea	Kuhrul, Kuralo	Fabaceae	Young leaves used as a stir-fried vegetable
Bauhinia racemosa	Katmauli	Fabaceae	Young leaves used as a stir-fried vegetable
Bombax ceiba	Savar	Bombacaceae	Flowers used as a vegetable
Borassus flabellifer	Tad	Arecaceae	Ripen fruit use for consumption
Cordia gharaf	Gundi	Boraginaceae	The ripe fruit is consumed, and unripe fruit is pickled
Cordia dichotoma	Gunda	Boraginaceae	Green Fruits and Inflorescence used as a stir-fried vegetable & also used for pickle & ripen fruits used for raw consumption
Diospyros melanoxylon	Timru	Ebenaceae	Ripen fruit used for consumption
Garuga pinnata	Kakad	Burseraceae	Fruits used as a pickle.
Grewia tiliaefolia	Dhamna	Malvaceae	Ripen fruit use for consumption
Limonia acidissima	Kotha	Rutaceae	The fruit pulp is edible after adding some spices. It is usually made into a chutney
Madhuca longifolia	Mahudo	Sapotaceae	Oil from Seeds and flowers use for alcohol preparation and dry flowers also edible
Manilkara hexandra	Rayan	Sapotaceae	Ripen fruits used for consumption
Meyna laxiflora	Alva	Rubiaceae	Fruits are edible
Moringa oleifera	Sektho, Saragvo	Moringaceae	Fruits used as a vegetable
Pithocellobium dulse	Vilayati amli	Fabaceae	Ripen fruits for direct consumption and it also used as vegetable
Phoenix sylvestris	Khajur	Arecaceae	Ripen fruits used for consumption
Spondias pinnata	Khato ambado	Anacardiaceae	Green fruit in the form of Chutany
Tamarindus indica	Khati amli	Fabaceae	Ripen fruits use for consumption and Chutney preparation
Terminalia bellirica	Baheda	Combretaceae	Fruits are edible and having medicinal importance also
Terminalia chebula	Harde	Combretaceae	Fruits are edible and having medicinal importance also
Wrightia tinctoria	Kudi	Apocynaceae	Leaf and flowers are used as a vegetable
Ziziphus mauritiana	Bor	Rhamnaceae	Ripen fruits use for consumption
Ziziphus oenoplia	Chini bor	Rhamnaceae	Ripen fruits use for consumption
Shrubs			
Carrisa carandas	Karamda	Apocynaceae	Ripen fruits use for consumption
Herbs			
Abelmoschus esculentus	Jungli bhindi	Malvaceae	Fruits used as a vegetable
Achyranthes aspera	Aghedo	Amaranthaceae	The leaves are consumed as leafy vegetables
Amaranthus virdis	Tandaljo, Lal bhaji	Amaranthaceae	Leaves used as a vegetable
Amorphophallus commutatus	Shevla	Araceae	Young shoot used as a Vegetable with *Largestroemia speciosa* leaves for removing it's pruritic property
Celosia argentia	Lemdi bhaji	Amaranthaceae	Young leaves of plant used as a vegetable
Chlorophytum borivilienum	Kavli	Asparagaceae	Young leaves used as a vegetable
Hibiscus sabdariffa	Khati bhaji	Malvaceae	Leaves are used as a vegetable
Climbers			
Bauhinia vahlii	-	Fabaceae	Young leaves used as a vegetable
Canavalia gladiata	Abai	Fabaceae	Fruits used as a pickle
Mushroom			
Termitomyces globulous	Alim	Lyophyllaceae	Used as a vegetable stir fried with spices and dry mushroom also used for consumption
Termitomyces microcarpus	Alim	Lyophyllaceae	Used as a vegetable stir fried with spices and dry mushroom also used for consumption
Termitomyces albuminous	Alim	Lyophyllaceae	Used as a vegetable stir fried with spices and dry mushroom also used for consumption
Grass			
Dendrocalamus strictus	Vans	Poaceae	Young shoot used as a vegetable and pickle is also prepared from it

Table 2. Wild food sources utilized by the communities

Type of food resources	Number of species
Fruit trees	23
Green leafy vegetables	09
Wild flowers	03
Bulb	01
Tubers	01
Tree Seeds	01
Mushroom	03
Young shoot	02

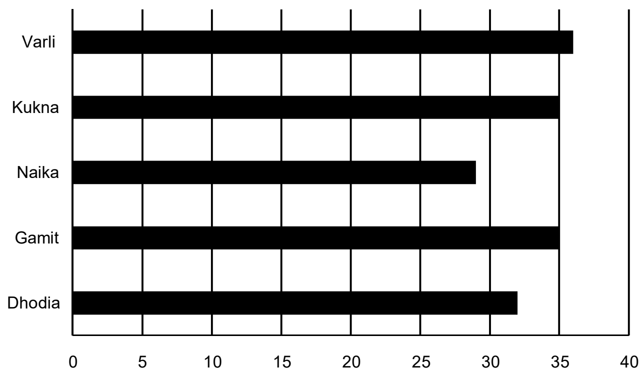

Fig. 1. Wild plants utilized by the tribal communities

CONCLUSIONS

Total 40 species of wild food plants of 21 families commonly consumed by the communities namely, Dhodia, Kukna, Varli, Gamit and Naika. Among all families Fabaceae family represented high number of plants. The various wild food sources recorded are fruit trees, tuber crops, green leafy vegetables, bulb, pods, seeds, nuts and mushroom. Among these, green leafy vegetables and fruits are widely consumed by the tribal communities, but the consumption pattern vary according to the season and availability. These ethnic foods are functional ingredients and lead to improve the health in a holistic way. This study generated the baseline data helpful for prioritization of conservation strategies through sustainable use and management of the resources.

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Received 15 February, 2024; Accepted 15 July, 2024

Indian Journal of Ecology (2024) 51(4): 765-771
DOI: https://doi.org/10.55362/IJE/2024/4307

Manuscript Number:4307
NAAS Rating: 5.38

Pattern of Species Diversity and Carbon Stocks along the Intertidal Zones of Protected Mangrove Forest in Southern Philippines

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Abstract: This study examined the composition, structure, and carbon storage of the Pangasihan Mangrove Forest Reserve in the Philippines. The reserve, spanning 64 hectares, was established in the 1990s and comprises natural and planted mangrove species dominated by *Sonneratia alba, Avicennia marina* var. *rumphiana*, and *Rhizophora apiculata*. Sampling was conducted along three transects covering the tidal gradient, with three sampling plots established along each transect. Trees with a diameter at breast height (DBH) ≥ 5cm were inventoried, and vegetation analysis was performed to determine species importance value, species richness, and diversity indices. Biomass estimation for carbon stock utilized published allometric equations and specific wood density values were applied. Carbon stock estimates were converted to CO_2 equivalents. Based on the result, the richness and abundance of mangrove species in the different intertidal zones is higher in the landward zone than in the seaward and middle ward zones. Species richness indices were 1.58, 1.00, and 3.37, while the diversity index is generally low at 1.57, 1.53, and 2.25 for seaward, middle ward, and landward, respectively. The carbon stocks from mangrove tree biomass in different intertidal zones were higher in the seaward region with computed values of 777, 422, and 488 t ha^{-1} and carbon stock densities of 350, 190, and 219 t C ha^{-1} for seaward, middle ward, and landward, respectively. This study generated valuable insights on which zone has higher species diversity and carbon stock, which could be helpful in the planning and management of the study area.

Keywords: Mangrove forest, Species richness and diversity, Carbon, Intertidal zones

The Philippines boasts a rich diversity of mangrove species, with around 42 species from 18 families, making it one of the most diverse in the world (Samson and Rollon 2011). This starkly contrasts North and Central America, which have a mere ten species (Abantao et al 2015). Most mangrove areas are situated in the southern part of the archipelago, particularly in Mindanao, Samar, and Palawan to the west. In 1918, the Philippines had an estimated 500,000 hectares of mangrove forest, but by 1994-1995, this had dwindled to 100,000 hectares (Primavera 2000). However, according to the 2011 Philippine Forestry Statistics, citing 2003 data, the total mangrove area was reported at 247,362 hectares, showing an increase since 1995 (DENR-FMB 2011).

Mangroves play a crucial role in coastal ecosystems, providing essential nursery habitat for numerous species and acting as natural barriers against storm damage and coastal erosion. In addition to their well-known ecological and economic benefits, coastal ecosystems are increasingly valued for their ability to store and sequester carbon. Blue carbon refers to the carbon stored in coastal systems such as mangroves, seagrasses, and salt marshes, with the majority found in the tropics (Siikamäki et al 2013). According to Donato et al (2011), cited by Castillo et al (2018), mangroves are among the most carbon-dense tropical forests, storing three to five times more carbon than terrestrial forests. Their ability to trap suspended matter and associated organic carbon during tidal inundation further enhances their contribution to long-term carbon sequestration (Mcleod et al 2011). Despite their significant ecological importance, mangrove forests face a severe threat from deforestation. In Southeast Asia and the Philippines, the rapid expansion of aquaculture development is the leading cause of mangrove forest loss (Cañizares and Seronay 2016). In the Philippines, brackish-water pond development alone accounts for approximately 50% of estimated mangrove deforestation. This loss of mangrove forests contributes to a substantial reduction in forest biomass and significantly adds to the alarming concentration of CO_2 in the atmosphere (Abino et al 2014).

Several studies from different parts of the world have highlighted the ecological significance of mangrove forests and their role in carbon sequestration. A survey conducted in the Labuhan mangrove forest in Indonesia by Asadi et al (2018) revealed a substantial carbon storage capacity of 74.70 t C ha^{-1}, with an equivalent CO_2 sequestration potential of 274.15 t ha^{-1}. The dominance of *R. apiculata* underscores its ecological importance in carbon sequestration. Similarly, a study in the Kanhlyashay natural mangrove forest in

Myanmar found that the mean biomass of the mangrove stand was 335.55 t ha^{-1}, with aboveground biomass (AGB) at 241.37 t ha^{-1} and below-ground biomass (BGB) at 94.17 t ha^{-1} while the mean carbon stock was 150.25 t C ha^{-1}. This underscores the significant carbon storage potential of the forest, emphasizing the importance of sustainable management to maintain and enhance carbon storage. Despite the low species diversity, *Avicennia officinalis* is dominant and displays high adaptive abilities, suggesting its suitability for afforestation efforts on mudflats due to its tolerance to increased salinity. Proper forest management is essential for preserving carbon sequestration capacity (Cañizares and Seronay 2016).

Despite the numerous studies conducted worldwide on mangrove identification and diversity, more information on species composition and diversity studies of mangroves from various parts of the Philippines is needed. Understanding the mangrove species is crucial for ecological assessment and matching sites with suitable species for reforestation and forest protection. This approach can enhance survival rates, unlike past efforts where success was limited due to incorrect site or species selection (Baleta and Casalamitao 2016). Therefore, assessing the remaining mangrove forest is essential for preserving and protecting the ecosystem in the Philippines (Cañizares and Seronay 2016). Despite their ecological significance, mangrove forests are threatened by deforestation driven by aquaculture development, resulting in substantial loss of forest biomass and exacerbating atmospheric CO_2 concentrations. This study is crucial for informed conservation and management efforts, providing valuable insights to guide strategies for preserving and protecting mangrove forests and upholding their ecological functions and benefits. Meanwhile, there is little precise knowledge about the amount of biomass and carbon sequestration and storage in this coastal vegetation (Abino et al 2014). Therefore, this study aims to assess species diversity and biomass and estimate the carbon sequestration potential of a natural mangrove stand in Pangasihan, Gingoog City, Misamis Oriental, Philippines.

MATERIAL AND METHODS

Study area: The Pangasihan Mangrove Forest Reserve, located at the geographic coordinates between 125°10' longitude and 8°51' latitude, falls within climatic type III. The area experiences distinct wet and dry seasons, with the dry period from November to April and higher rainfall from May to October, averaging 1,500 to 2,500 millimeters annually. The temperatures range from 25°C to 32°C throughout the year, with occasional tropical cyclones during the wet season bringing heavy rain and strong winds (DENR 2019). This 64-hectare mangrove reforestation was initiated in the 1990s, combining natural and planted mangrove species, mainly *Sonneratia alba*, *Avicennia marina* var. rumphiana, and *Rhizophora apiculata*. The soil in the area is hydrosol, which is ideal for fishpond and mangrove development. Nipa and mangrove forests dominate this area, characterized by rocky, muddy, and sandy substrate. The site can be categorized into closed and open canopy mangrove forests. The closed canopy ones are dense and intact, located far from human developments, while the open canopy features more dispersed vegetation, creating varied microclimates and essential roles in coastal ecosystems.

Sampling procedure: In setting up sampling plots in the study, three transects were established to cover the natural tidal gradient: near the sea (seaward), in the middle/middle ward, and near the land/upstream (landward) (Kauffman and Donato 2012; Castillo et al 2018). The seaward transects began approximately 15m - 20m from the interface between the mangroves and the sea. Three 10m x 20m (200m²) sampling plots were established for each transect, spaced 50m apart. Geographic coordinates were recorded for each plot. In each plot, the species name of each tree was recorded, and the diameter at breast height (DBH) was measured 1.3 m from the ground or 30 cm above the highest prop root for stilt-rooted species. All mangroves within the plots with a DBH of ≥ 5cm were inventoried, while vegetation with less than 5cm was not included in the sampling. This measurement standard is used for assessing species diversity and carbon stock, ensuring consistency, precise above-ground biomass estimation, and minimal ecosystem disturbance (Abino et al 2014). This approach aligns with established protocols for accurate and comparable research findings, as Aye et al (2022) and Abino et al (2014) suggested. An inventory form was completed, including the species name (common, scientific, and family name) and the DBH of each tree. The species were identified by CENRO Gingoog City personnel and further verified through intensive reviews of relevant field guides.

Estimation of importance value: Vegetation analysis employing various ecological parameters was utilized to ascertain the density (D), relative density (RD), frequency (F), relative frequency (RF), dominance (D), relative dominance (RD), and the species importance value (SIV) within the area. The computed importance value aided in identifying the dominant species within the area (Table 1).

Species richness and diversity: Four distinct diversity indices-Margalef's, Shannon H's, Pielou's J, and Jaccard's-were calculated using a custom Microsoft Excel template designed for this specific purpose. The template efficiently computed the desired output values (Table 2).

Estimation of carbon stock in tree biomass: Survey was conducted to assess species richness and estimate biomass. Since specific allometric equations for the study site or Philippine mangroves were unavailable, we utilized published allometric equations to calculate each tree's aboveground and belowground biomass. For aboveground biomass (AGB) and belowground biomass (BGB) of mangroves, we used species/genus-specific equations; otherwise, we used the ordinary allometric equation developed by Komiyama et al (2005). The species-specific wood density values for some mangrove species and genera in the Philippines were used. Species without available wood density data relied on information from published literature, such as the compilation by Howard et al (2014). The biomass allometric equations and their corresponding wood density values (Table 3).

The quantitative carbon stock estimates in mangrove forests were derived from aboveground biomass (AGB) and belowground biomass (BGB). The biomass content was determined using a standard value of 45%, representing the average carbon content found in tree biomass and root biomass density of tree species in forests (Lasco and Pulhin 2000). To convert AGB and BGB data to their respective carbon (C) stock equivalents, the values were multiplied by 48% and 39%, as recommended by Kauffman and Donato (2012) as cited by Castillo et al (2018). The combined C stocks of AGB and BGB, referred to as tree C stock, were calculated to assess the tree C stock per plot, then averaged per site and zone to obtain the mean tree C stock. These generated values were then transformed into CO_2-equivalents (CO2) by multiplying the C stocks by 3.67, based on the methods of Pendleton et al (2012) and Castillo et al (2018). Additionally, the basal area of each tree was computed using the formula 0.7854 * $(dbh)^2$, and the results were summed together per plot.

RESULTS AND DISCUSSION

Species composition, importance value, and ecological status: The study area was home to 420 individual trees and 20 mangrove species from ten genera and eight families (Table 4). Compared to the other two zones, the landward zone exhibited a higher diversity of families, genera, and species. Interestingly, despite the

Table 2. Different species diversity indices used in the study (Magurran 2004)

Index	Measures of diversity	Equation
Margalef's	Species richness	$Da = \left[\frac{(S-1)}{(\ln N)}\right]$
Shannon H'	Species diversity-evenness	$H' = \left[-\sum(Pi \times \ln Pi)\right]$
Pielou's J	Species diversity-evenness	$J' = \left[\frac{H'}{\ln(S)}\right]$
Jaccard	Community similarity/dissimilarity	$SJ = \left[\frac{a}{(a+b+c)}\right]$

Table 1. Vegetative analysis formula used in the study

Parameter	Formula	Description
Density $\left(\frac{tress}{ha}\right)$	$D = \frac{total\ no.of\ individuals\ of\ a\ species}{total\ area\ sampled\ in\ m^2 x\ \frac{1\ ha}{10000 m^2}}$	These were used to determine the number of individual trees per unit area.
Relative Density	$RD = \frac{density\ of\ a\ species}{total\ density\ of\ all\ species} \times 100$	These were used to compute the number of trees between two areas of equal size.
Frequency	$F = \frac{no.of\ quadrant\ in\ which\ species\ A\ occurs}{total\ no.of\ quadrant\ examined}$	These were used to determine the probability of finding the species in any quadrant.
Relative Frequency	$RF = (\frac{frequency\ value\ of\ species\ A}{total\ frequency\ value\ of\ all\ species}) \times 100$	These were used to compare the numerical frequency of one species to the total frequency of all species.
Dominance $\left(\frac{m^2}{ha}\right)$	$C = \frac{area\ covered\ by\ a\ species}{sum\ of\ all\ plot\ areas}$	These were used to determine the species that exert a major controlling influence on the community by virtue of size or number.
Relative Dominance	$RC = \frac{dominance\ value\ of\ species}{total\ dominance\ value\ of\ species} \times 100$	The data on the number of individuals per species and the total number of all species were used.
Species Importance Value (SIV)	SIV = $\left(\frac{RD + RF + RC}{3}\right)$	Were used to reveal what species are dominant in the area.

greater diversity, the landward zone had fewer trees and a smaller basal area. This suggests that human activities may have led to greater disturbance in the landward zone.

Rhizophora apiculata (Rhizophoraceae) was the most common tree species across the three zones, with 116 out of 420 (28%) individual trees sampled. The greatest SIV value (22.96), indicative of its high importance as a component species in the study, was also observed in the study area. The top three most common tree species across the zonation are *R. apiculata, Sonneratia alba*, and *R. stylosa*, respectively. These three species are the only four, including R. mucronata, which appeared in each zone. Meanwhile, *Excoecaria agallocha, Heritiera littoralis, Hibiscus tiliaceus, Bruguiera cylindrica,* and *Xylocarpus moluccensis* were the

Table 3. Biomass allometric equations and wood density values used by Komiyama et al (2005)

Species	Above ground	Below ground	Source	Wood density ($g\ cm^{-3}$)
Avicennia marina	Biomass (kg) = 0.251*ρ*$D^{2.46}$	Biomass (kg) = 0.199*$ρ^{0.899}D^{2.22}$	Komiyama et al (2005)	0.71^a
A.officinalis	Biomass (kg) = 0.251*ρ*$D^{2.46}$	Biomass (kg) = 0.199*$ρ^{0.899}D^{2.22}$	Komiyama et al (2005)	0.71^a
Bruguiera cylindrica	Biomass (kg) = 0.186*ρ*$D^{2.31}$	Biomass (kg) = 0.199*$ρ^{0.899}D^{2.22}$	Clough and Scott (1989)	0.85^b
B. gymnorrhiza	Biomass (kg) = 0.186*ρ*$D^{2.31}$	Biomass (kg) = 0.199*$ρ^{0.899}D^{2.22}$	Clough and Scott (1989)	0.85^b
B. parviflora	Biomass (kg) = 0.168*ρ*$D^{2.42}$	Biomass (kg) = 0.199*$ρ^{0.899}D^{2.22}$	Clough and Scott (1989)	0.89^b
B. sexangula	Biomass (kg) = 0.168*ρ*$D^{2.42}$	Biomass (kg) = 0.199*$ρ^{0.899}D^{2.22}$	Clough and Scott (1989)	0.87^b
Ceriops decandra	Biomass (kg) = 0.251*ρ*$D^{2.46}$	Biomass (kg) = 0.199*$ρ^{0.899}D^{2.22}$	Komiyama et al (2005)	0.89^b
C. tagal	Biomass (kg) = 0.251*ρ*$D^{2.46}$	Biomass (kg) = 0.199*$ρ^{0.899}D^{2.22}$	Komiyama et al (2005)	0.89^b
Excoecaria agallocha	Biomass (kg) = 0.251*ρ*$D^{2.46}$	Biomass (kg) = 0.199*$ρ^{0.899}D^{2.22}$	Komiyama et al (2005)	0.71^a
Heritiera littoralis	Biomass (kg) = 0.251*ρ*$D^{2.46}$	Biomass (kg) = 0.199*$ρ^{0.899}D^{2.22}$	Komiyama et al (2005)	0.84^a
Hibiscus tiliaceus	Biomass (kg) = 0.251*ρ*$D^{2.46}$	Biomass (kg) = 0.199*$ρ^{0.899}D^{2.22}$	Komiyama et al (2005)	0.71^a
Lumnitzera littorea	Biomass (kg) = 0.251*ρ*$D^{2.46}$	Biomass (kg) = 0.199*$ρ^{0.899}D^{2.22}$	Komiyama et al (2005)	0.71^a
L. racemosa	Biomass (kg) = 0.251*ρ*$D^{2.46}$	Biomass (kg) = 0.199*$ρ^{0.899}D^{2.22}$	Komiyama et al (2005)	0.71^a
Rhizophora apiculata	Biomass (kg) = 0.235*ρ*$D^{2.42}$	Biomass (kg) = 0.199*$ρ^{0.899}D^{2.22}$	Ong et al (2004)	1.04^a
R. mucronata	Biomass (kg) = 0.235*ρ*$D^{2.42}$	Biomass (kg) = 0.199*$ρ^{0.899}D^{2.22}$	Ong et al (2004)	0.98^b
R. stylosa	Biomass (kg) = 0.235*ρ*$D^{2.42}$	Biomass (kg) = 0.199*$ρ^{0.899}D^{2.22}$	Ong et al (2004)	0.98^b
Sonneratia alba	Biomass (kg) = 0.251*ρ*$D^{2.46}$	Biomass (kg) = 0.199*$ρ^{0.899}D^{2.22}$	Komiyama et al (2005)	0.83^b
S. caseolaris	Biomass (kg) = 0.251*ρ*$D^{2.46}$	Biomass (kg) = 0.199*$ρ^{0.899}D^{2.22}$	Komiyama et al (2005)	0.83^b
Xylocarpus moluccensis	Biomass (kg) = 0.251*ρ*$D^{2.46}$	Biomass (kg) = 0.199*$ρ^{0.899}D^{2.22}$	Komiyama et al (2005)	0.66^b
X. granatum	Biomass (kg) = 0.251*ρ*$D^{2.46}$	Biomass (kg) = 0.199*$ρ^{0.899}D^{2.22}$	Komiyama et al (2005)	0.66^b

Table 4. Dendrological characteristics of the site

Zone	No. of family	No. of genera	No. of species	No. of trees	Mean DBH (cm)	Basal area (m^2/ha)
Seaward	4	5	9	157	16.39	77.27
Middleward	3	4	6	148	11.19	67.44
Landward	8	10	17	115	13.86	30.75
Mean	5	6	11	140	13.81	58.49
Total	8	10	20	420	41.44	175.46

least frequent species with only one individual tree in the entire area. The mangrove forests at the study site are dominated by *Rhizophora spp*. This is comparable to the study by Castillo et al (2018) in Honda Bay, Palawan, and that of Cañizares and Seronay (2016) in Barangay Imelda, Dinagat Island, Philippines. *Avicennia marina* is also the top species found in the area, comparable to the study by Pototan et al (2017) of the three municipalities in Davao del Norte. In terms of conservation status, most of the species collected were classified as "least concern" except *Ceriops decandra*, which has been categorized as near-threatened, and *Bruguiera gymnorrhiza, Hibiscus tiliaceus, Bruguiera sexangula* as not assessed by IUCN (Table 5).

Species richness, diversity, and evenness: The landward zone exhibited the highest species richness index value (3.37) among the three zones (Fig. 1). Seventeen mangrove species were documented in the landward zone, surpassing the 1.58 and 1.0 recorded for the seaward and middle ward zones, respectively. The richness index is higher in the landward zone due to the more significant number of species. Despite having fewer individuals than the seaward zone, the landward zone also achieved the highest diversity index value. This highlights that, although the zones are relatively similar in abundance, the landward zone's more significant variety of species results in higher diversity. Richness measures do not differentiate among species and account for all species equally, including the rare ones (Magurran 2004).

The diversity and prevalence of mangrove species in intertidal zones are believed to be shaped by factors like tides, salinity levels, and human impact. The distribution and zonation pattern of mangroves is primarily influenced by the geographical location, tidal flooding, and freshwater inflow (Sreelekshmi et al 2018). Coastal areas closer to the sea are subject to more frequent tidal inundation, leading to the prevalence of species that can endure saltwater submersion. The genus *Rhizophora*, in particular, demonstrates a relatively high tolerance to salt (Hogarth 2015), which accounts for its widespread presence in these areas. On the other hand, areas further inland may experience less frequent saltwater inundation, allowing for a greater diversity of species, particularly those with lower salt tolerance, such as those belonging to the genus *Bruguiera* and *Sonneratia* (Hogarth 2015). Kodikara et al (2017) also revealed that *R. mucronata* exhibited the highest survival rate among tested mangrove species under varying salinity levels. This finding supports the widespread occurrence of this species across the three zones studied.

Biomass and carbon stock: The biomass density of the

Table 5. SIV and ecological status of species

Species	Seaward	Middleward	Landward	SIV	Ecological status
Rhizophora apiculata	/	/	/	22.96	LC
Sonneratia alba	/	/	/	21.62	LC
Avicennia marina	/	/	/	12.49	NT
Rhizophora stylosa	/			11.65	LC
Avicennia officinalis		/	/	7.29	LC
Rhizophora mucronata	/	/	/	7.09	LC
Lumnitzera littorea	/		/	4.15	LC
Ceriops decandra		/	/	2.11	LC
Bruguiera parviflora	/			1.69	LC
Bruguiera gymnorrhiza	/			1.51	NA
Lumnitzera racemosa	/		/	1.44	LC
Ceriops tagal			/	1.13	LC
Xylocarpus granatum			/	1.06	LC
Sonneratia caseolaris			/	0.64	LC
Bruguiera sexangula			/	0.61	NA
Hibiscus tiliaceus			/	0.52	NA
Excoecaria agallocha			/	0.52	LC
Xylocarpus moluccensis			/	0.52	LC
Bruguiera cylindrica			/	0.51	LC
Heritiera littoralis			/	0.51	LC

Legend: / - Presence in zone NT- Near-threatened, LC – Least concern, NA- Not assessed

Table 6. Biomass and C stock of different zones

Zone	Tree biomass density	ABG C stock density	BGB C stock density	Tree C stock density
Seaward	777	673	104	350
Middleward	422	359	63	190
Landward	488	418	70	219
Mean	488	483	79	253

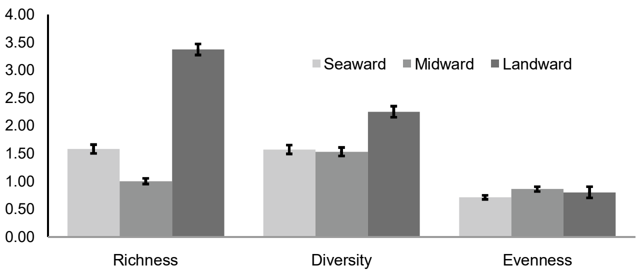

Fig. 2. Variation in species richness, diversity, and evenness indices among zones

computed tree for seaward, middle ward, and landward areas were 777 t ha⁻¹, 422 t ha⁻¹, and 488 t ha⁻¹, respectively. In addition, the carbon stock density for seaward, middle ward, and landward areas were 350 t C ha⁻¹, 190 t C ha⁻¹, and 219 t C ha⁻¹ (Table 6).

The findings indicate that the natural mangrove forest in Pangasihan, Gingoog City, and the mangrove forest in Botoc, Pinabacdao, Samar, are comparable and have the potential to store as much as 350 tons of carbon per hectare, despite having lower species diversity. This estimated value is similar to the average carbon storage of Philippine mangroves, as Lasco and Pulhin (2004) reported. The Seaward zone showed higher carbon stock despite its lower diversity. This demonstrates that carbon storage varies significantly within different areas of the forest. Consequently, there are cases where forests with high species diversity may not be rich in carbon, and vice versa. This suggests there may be trade-offs between carbon and biodiversity conservation (Lawton et al 1998, Heino et al 2009).

Mangrove forests face a critical threat from climate change, particularly sea-level rise. Therefore, it is crucial to develop sustainable funding and effective incentive systems that support mangrove conservation and coastal communities' well-being. Promising options for achieving this balance include Payments for Ecosystem Services (PES) and the Blue Carbon Fund, similar to REDD (Reducing Emissions from Deforestation and Forest Degradation) but focusing on carbon sequestration in coastal areas. Additionally, it is essential to conduct further research to develop a biomass equation applicable to different Philippine mangrove species and wide diameter at breast height (DBH) classes. Having site- and species-specific allometric equations will improve the accuracy of current biomass estimates for mangroves, which is crucial for initiatives like carbon trading. This aligns with the study conducted by Abino et al (2014) and is consistent with the average carbon storage of Philippine mangroves as determined by Lasco and Pulhin (2004).

CONCLUSION

The study revealed that the richness and abundance of mangrove species in the various intertidal zones are higher in the landward zone compared to the other two zones. Carbon stocks from mangrove tree biomass in different intertidal zones were highest in the seaward region, and carbon stock densities for seaward, middle ward, and landward zones. This indicates that these zones may exhibit differences in ecosystem productivity, carbon storage, and sequestration capacity. This underscores the importance of understanding and preserving mangrove habitats across their intertidal gradient for effective coastal management and carbon storage strategies.

ACKNOWLEDGMENT

The authors thank the Department of Environment and Natural Resources-Community Environment and Natural Resources Office of Gingoog City for their invaluable logistical and technical support during the study.

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Received 09 June, 2024; Accepted 22 July, 2024

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Indian Journal of Ecology (2024) 51(4): 772-783
DOI: https://doi.org/10.55362/IJE/2024/4308

Manuscript Number: 4308
NAAS Rating: 5.38

Studies on Effects Environment on Finger Millet Genotypes for Seed and Fodder Yield Based on AMMI and BLUP Model

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***Abstract*:** The study was carried out to assess the patterns of GEI governing seed and fodder yield, identify stable and high seed and fodder yielding finger millet genotypes evaluated in ten locations in *Kharif*-2022 in India. The variance due to genotypes, environment and GEI was highly significant for seed and fodder yield. Upon comparison of different AMMI and BLUP models, BLUPg and BLUPge were the best prediction models that adequately explained the variation due to GEI for seed and fodder yield, respectively. The GGE biplot indicated that WN 577 and TNEc 1342 were the ideal genotypes for seed and fodder yield, respectively; the genotype with maximum mean and high stability was IIMR-FM-R21-8012 for seed and fodder yield. IIMR-FM-R21-8012 performed better for seed and fodder yield across maximum test locations. WN 577 and IIMR-FM-R21-8001 showed excellent stability across all the test locations based on AMMI stability indices, while IIMR-FM-R21-8012 and PR 1734 based on BLUP model stability indices for seed yield. Whereas, for fodder yield the genotypes IIMR-FM-R21-8012 and TNEc 1341 were highly stable based on AMMI- and BLUP model stability indices. Therefore, this study identified IIMR-FM-R21-8012 and PR 1734; IIMR-FM-R21-8012 and TNEc 1341 as worthy genetic resources for seed and fodder yield, respectively.

Keywords: GEI, Finger millet, Multi-environment trial, Yield stability, GGE biplot

Finger millet, *Eleusine coracana* (L.) Gaertn subsp. coracana, an annual drought-hardy and subsistence crop of small holding farmers in India and eastern Africa belongs to the subfamily Chloridoideae of the family Poaceae. Archeological records suggest that finger millet was first cultivated in Ethiopia and Uganda (Hilu and De Wet 1976). Due to its drought-hardy nature and nutritional significance, it is cultivated across arid and semiarid tropics and subtropics. However, the seed yield of finger millet is stagnant with an average of 1755 tonnes (Indiastat 2021, https://www .indiastat.com/data/agriculture). The focus on genetic improvement in finger millet was meagre resulting in use of traditional and unimproved finger millet varieties for commercial cultivation. As a result of this, both seed and fodder yielding capacity of finger millet cultivars is stagnant. Predominantly, finger millet varieties in cultivation in India are majorly through pedigree selection (55%), pure line selection (39%) from germplasm accessions (Nagaraja et al 2022). Additionally, finger millet breeding is constrained due to its pollination behavior. Hence, developing widely adaptable, stable and high seed and fodder yielding finger millet cultivars tolerant to biotic and abiotic factors to promote its production and productivity is the need of the hour. However, cultivars bred at various breeding stations have varying responses to environmental conditions. Therefore, the evaluation of the genotypes in the pipeline to be released for commercial cultivation under numerous target production environments aids in identification of stable and superior cultivars that shall facilitate cultivar deployment. Such multi-environment trials (METs) aid in the identification of stable cultivars with high seed and fodder yield potential. Most often than not, the response to selection is confounded by the genotype by environment interaction (GEI) during multi-environment trials. To effectively identify superior cultivars in the final selection cycles, while predicting their potential performance in various environments, it is imperative to quantify GEI.

MATERIAL AND METHODS

Experimental material: A total of 28 finger millet genotypes (Table 1) including twenty-three advanced breeding lines and five checks were evaluated for seed and fodder yield during *Kharif*-2022 rainy season across ten Indian locations (Table 2) in randomized complete block design in three replicates as

Table 1. Pedigree of the finger millet genotypes used in the study

Genotype	Pedigree	Centre
BUFM 19-E-1	Selection from local germplasm of Akole Tahsil, Ahmednagar	Buldana, Maharashtra
GE 6541	Selection from elite GE 6541 line from Bengaluru	Kolhapur, Maharashtra
GPU 105	GPU 28 × KMR 630 (3-1-2)	Bengaluru, Karnataka
GPU 106	GPU28 × GE 4593 (1-6)	Bengaluru, Karnataka
IIMR-FM-R21-8001	Gamma mutant from MR6 variety	Hyderabad, Telangana
IIMR-FM-R21-8006	Pedigree selection from GPU28 × GPU48	Hyderabad, Telangana
IIMR-FM-R21-8011	Pedigree selection from GPU28 × IE 990	Hyderabad, Telangana
IIMR-FM-R21-8012	Pedigree selection from PR 202 × GPU 48	Hyderabad, Telangana
KIFMG 211	Selection from germplasm accession IE 4497	Kolhapur, Maharashtra
KMR 654	Indaf 5 × IE- 2712	Mandya, Karnataka
KMR 655	Indaf 5 × GE -1409	Mandya, Karnataka
PPR 1216	Vakula × Srichaitanya	Perumallapalli, Andhra Pradesh
PPR 1272	Kalyani × PES 110	Perumallapalli, Andhta Pradesh
PR 1734	GPU 28 (ms) × PR 202	Peddapuram, Andhra Pradesh
TNEc 1341	TNEc 1228 × GE 276	Athiyandal, Tamil Nadu
TNEc 1342	KWFM × KOPN 565	Athiyandal, Tamil Nadu
VL 402	GPU 28 × VL 347	Almora, Uttarakhand
VL 409	KMR 118 × VL 347	Almora, Uttarakhand
VR 1163	VR 708 × GPU 48	Vizianagaram, Andhra Pradesh
VR 1171	PR 202 × GPU 48	Vizianagaram, Andhra Pradesh
WN 577	GPU 48 × GE 4931	Waghai, Gujarat
WN 660	Selection from germplasm accession IE 4656	Waghai, Gujarat
WN 666	Selection from germplasm accession IE 4657	Waghai, Gujarat
CFMV 1 (Check)	VL 330 × GE 532	Vizianagaram, Andhra Pradesh
CFMV 2 (Check)	Pure line selection from Dangs district	Waghai, Gujarat
GPU 67 (Check)	Selection from GE 5331	Bengaluru, Karnataka
PR 202 (Check)	Pure line selection from Mettachodiragi of Arakku valley	Peddapuram, Andhra Pradesh
VL 376 (Check)	GE 4172 × VL ragi 149	Almora, Uttarakhand

Table 2. Geographical identity and climate variables of the locations during the crop growth period

Location	T. Max.	T. Min.	Rainfall (mm)	Latitude	Longitude	Altitude (ft.)
Bengaluru, Karnataka	28.35	19.71	43.53	12.97° N	77.59° E	3020
Berhampur, West Bengal	35.26	24.37	86.70	19.31° N	84.79° E	78
Dahod, Gujarat	30.41	22.74	72.76	22.83° N	74.26°E	984
Dapoli, Maharashtra	31.04	24.56	45.00	17°46'3.71"N	73°11'27.64"E	800
Hageri, Karnataka	36.89	25.87	28.00	15° 09' 00.89” N	76° 52' 07.05” E	226
Jagdalpur, Chattisgarh	28.13	20.85	62.09	19.08 º N	82.02 º E	1811
Nandyal, Andhra Pradesh	34.90	24.98	16.80	15°29′19″ N	78°29′11″ E	666
Perumallapalle, Andhra Pradesh	35.33	25.96	28.07	13.60° N	79.35° E	1000
Vizianagaram, Andhra Pradesh	30.78	28.75	60.10	18.10° N	83.39° E	242
Waghai, Gujarat	27.59	23.29	55.00	20.77° N	73.49° E	830

T. Max.: Maximum temperature; T. Min.: Minimum temperature part of initial varietal trial (IVT). Hereafter, both advanced breeding lines and checks are referred to as "genotypes"; location and environment are used interchangeably for the sake of simplicity. Each genotype was sown in a plot size of 3×2.25 meters (m). Therefore, the area of each plot was 6.75 square meters. Each genotype was sown in 10 rows of 3m length spaced 30cm apart. The recommended crop management practices were adopted to raise a healthy crop. Plot seed/fodder yield (kg/plot) was considered for further analysis.

Statistical analysis: The phenotypic data of seed and fodder yield collected from the twenty-eight finger millet genotypes evaluated across ten test locations was confirmed for homogeneity of variances by Bartlett test (Bartlett 1937). To determine the significance level of genotypes (G), locations (L) and GLI (genotype × location interaction), the data was subjected to combined ANOVA using mixed linear model (R Core Team 2020). The AMMI model was used to determine the GLI effects of twenty-eight finger millet genotypes to assess their adaptability and stability across the ten test locations. The genotypes were treated as fixed sources of variation, while the locations as random. The AMMI amalgamates ANOVA for genotype and location main effects with PCA for GLI with the axes of the principal components of interactions (IPCA) (Gauch 1988; Yan et al 2007). The AMMI model used is as follows:

$$Y_{ij} = \mu + g_i + e_i + \sum_{k=1}^{n} \lambda_k a_{ik} \gamma_{jk} + e_{ij}$$

Y_{ij} = Seed/Fodder yield of the i^{th} genotype in the j^{th} location

μ = Experimental genotype mean of seed/fodder yield

g_i and e_j = Genotype and location deviations from the grand mean of seed/fodder yield

λ_k = Eigen value of the PCA analysis axis k

α_{ik} and γ_{jk} = Genotype and location principal component scores for axis k

N = Number of principal components retained in the model

e_{ij} = Error term

In the BLUP method, the effects of genotype and GLI are considered to be random. Contrary to the AMMI model, a linear mixed model is used and the formula is as follows: Y = X*β*+ Zu + *ℰ,* where *β* is the data vector of the fixed unknown effect (the average value of the block in each location), u is the GLI + genotype effect, X and Z represent the matrix involving*β*, u and Y and *ℰ* is the random errors' vector. In order to better predict the AMMI and the BLUP model family, root mean square prediction difference (RMSPD) estimates were used to compare (Piepho 1994).

Genotype + Genotype × environment (GGE) bi-plot is a subjective/qualitative means to characterize patterns of GLI and assess the relative stability of test genotypes. The GGE bi-plot is constructed using the first two principal components (PC1 and PC2) derived using adjusted seed or fodder yield from ANOVA (Yan 2001, Yan 2002). The GGE bi-plot is suggestive of visual interpretation of the GLI patterns, representativeness and discriminating ability of the locations and relative stability of test genotypes. In the current study, the biplots were based on singular-value partitioning = 2, transformed (transform = 0), environment-centered (centering = 2) and standard deviation-standardized (scaling = 0).

Twelve AMMI model-based stability indices *viz.,* AMMI Stability Index (ASI), AMMI stability value (ASV), AMMI Based Stability Parameter (ASTAB), Sum Across Environments of Absolute Value of GEI Modelled by AMMI (AVAMGE), Annicchiarico's D Parameter values (Da), Zhang's D Parameter (Dz), Averages of the squared eigenvector values (EV), Stability Measure Based on Fitted AMMI Model (FA), Modified AMMI Stability Index (MASI), Modified AMMI Stability Value (MASV), Sums of the absolute value of the IPCA scores (SIPC) and Absolute value of the relative contribution of IPCAs to the interaction (Za) were computed for each of the genotype for seed and fodder yield using the package 'ammistability' in R software (Ajay et al 2019). Additionally, the BLUP-based stability parameters such as harmonic mean of genotypic values (HMGV) to infer both seed/fodder yield and stability, relative performance of genotypic values (RPGV) to investigate the mean seed/fodder yield and genotypic adaptability and harmonic mean of relative performance of genotypic values (HMRPGV) to evaluate stability, adaptability and seed/fodder yield simultaneously (de Resende 2004) were also estimated. The analysis was computed using the metan package in R software version 4.2.1 (Olivoto and Lucio 2020).The Spearman's rank correlations among all the twelve AMMI stability indices was computed.

RESULTS AND DISCUSSION

Mean seed and fodder yield: The mean seed yield of the twenty-eight test genotypes across ten test locations varied from 4.19 kg/plot (IIMR-FM-R21-8012 in Nandyal) to 0.46 kg/plot (VR 1163 in Dapoli; Fig. 1a), whereas the fodder yield varied from 11.18 kg/ plot (PR 202 in Perumallapalle) to 0.59 kg/plot (VL 402 in Dapoli; Fig. 1b). The grand mean seed yield of genotypes *viz.,* IIMR-FM-R21-8012 (2.11 kg/plot) and PR 1734 (2.09 kg/plot) was the highest (Fig. 1a). Fodder yield the genotypes IIMR-FM-R21-8012 (6.17 kg/plot) and TNEc 1341(6.00 kg/plot) were the best performers (Fig. 1b). The average seed and fodder yield of all the genotypes was higher in Nandyal *i.e.,* 3.12 kg/plot and 8.54 kg/plot, respectively. There were significant variation for genotypes, locations and GLI for both seed and fodder yield (Data not shown). Similar results were reported by Kendel and Sener (2015) in wheat and Sarkar et al (2014) in Barley.

Additive main effect and multiplicative interaction: The AMMI analysis of variance indicated that the genotypes, locations and GLI effects were highly significant (p <0.001) for seed and fodder yield (Table 3). The partitioning of variance components of AMMI analysis of variance highlighted that locations accounted for 81.43 and 88.03 % of the total observed variation for seed and fodder yield, respectively. This indicated that the test locations were particularly diverse and greatly impacted genotypes' potential to produce seed and fodder yield. Most often than not, the contribution of test locations is relatively higher than other sources of variation in multi-environment trials (Badu-Apraku et al 2012). Earlier, Yan et al (2000) put forth that about 80% of the variation could be attributed to environment, whereas, 20% to both genotypes and GEI in wheat yield trials. While, genotypes accounted for 5.38 and 3.51 %, and GLI accounted for 13.18 and 8.44%, respectively for seed and fodder yield. A significant GLI necessitated the need to identify adaptable genotypes with consistently high seed and fodder yield (Yan and Tinker 2006) and indicated the possible existence of different mega-environments. Furthermore, four and two principal components were significant for seed and fodder yield, respectively. Similar to our results, a large proportion of total variation contributed by the environment has been reported earlier in finger millet (Adugna et al 2011, Molla et al 2013, Dagnachew et al 2014, Birhanu et al 2016, Lakew et al 2017, Seyoum et al 2019) and little millet for seed and fodder yield (Nagaraja et al. 2023). The joint effect of the four and two significant principal components of GLI accounted for 85 % and 62.10 % of the whole effect it had on the variation for seed and fodder yield, respectively (Table 3). The first principal component accounted for 34.60% of the variation caused by the interaction, while 23.70, 17.50 and 9.90% of the variation was caused by PC2, PC3 and PC4, respectively for seed yield

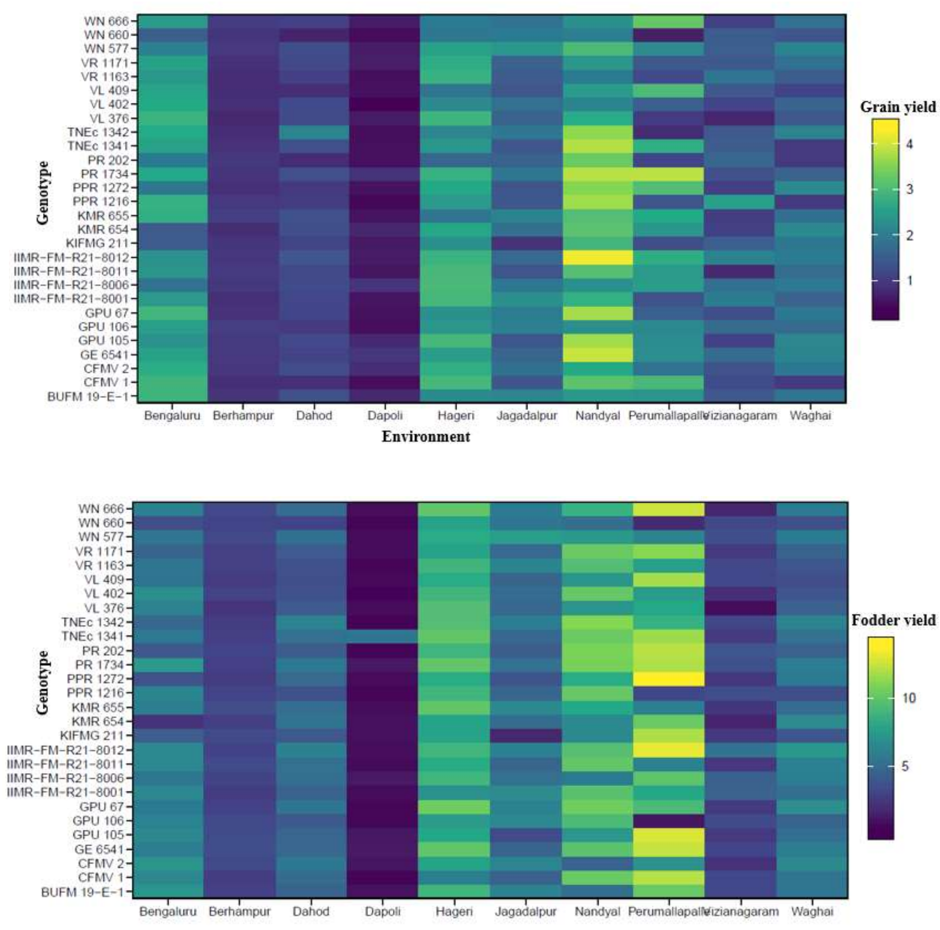

Fig. 1. Mean yield of 28 finger millet genotypes across in each of the ten locations for (a) seed yield and (b) fodder yield

(Table 3). Likewise, for fodder yield, PC1 accounted for 42.20% of the variation caused by the GEI, while 19.90 of the variation was caused by PC2 for fodder yield (Table 3).

Prediction accuracy of AMMI and BLUP Model: Root mean square prediction difference was used to predict the accuracy of AMMI and BLUP model family members for seed and fodder yield and the results are based on the average of 200 predictions of RMSPD for each test model. The model with the smallest RMSPD value is defined as the most accurate prediction and vice versa. For seed yield (Fig. 2a), BLUPg(due to genotype effects) was the most accurate prediction model among all evaluated models, while BLUPge (due to genotype and environment effects) for fodder yield (Fig. 2b). The genotypes IIMR-FM-R21-8012 and PR 1734 produced higher seed yield relatively based on BLUPg predicted values (Table 4), while IIMR-FM-R21-8012 and TNEc 1341 produced higher fodder yield relatively across the ten locations based on BLUPge predicted values (Data not shown).

GGE bi-plot for Interpretation of GLI

Ranking genotypes relative to the ideal genotype: WN 577 (Fig. 3a) and TNEc 1342 (Figure 3b) were more

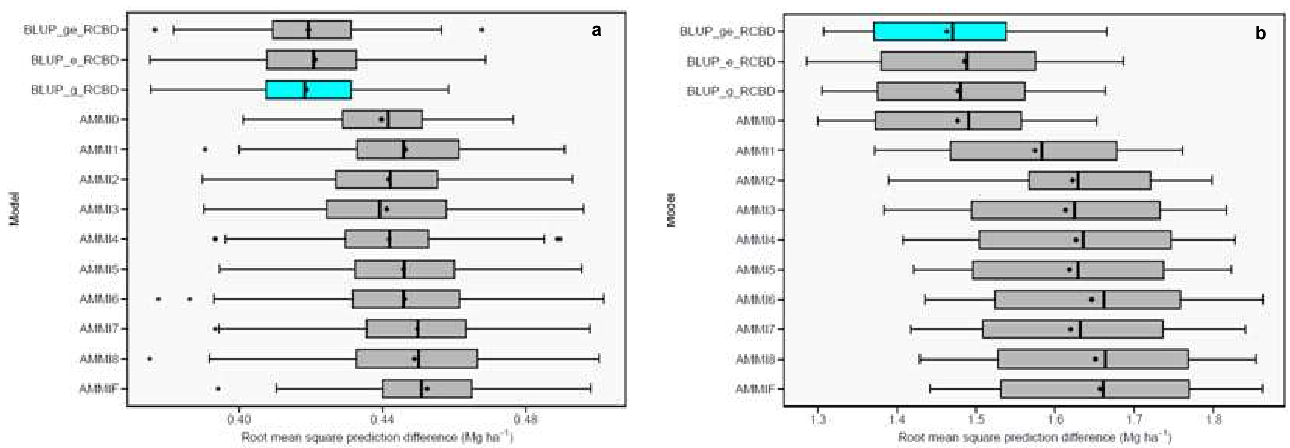

Fig. 2. Boxplot of RMSPD values for different AMMI and BLUP model family members for (a) seed yield and (b) fodder yield

Table 3. AMMI analysis of variance for seed and fodder yield of twenty-eight finger millet genotypes evaluated across ten locations

Source of variation	Degrees of freedom	Sum of squares		Mean sum of squares		'F' value		Probability		Proportion (%)	
		SY	FY	SY	FY	SY	FY	SY	FY	SY	FY
Location	9	398.89	4893.30	44.32	543.70	78.78	57.25	0.00	0.00	-	-
Replication (Location)	20	11.25	189.90	0.56	9.50	4.66	6.21	0.00	0.00	-	-
Genotype	27	26.40	195.40	0.96	7.24	8.11	4.73	0.00	0.00	-	-
GLI	243	64.52	469.50	0.26	1.93	2.20	1.26	0.00	0.00	-	-
PC1	35	22.38	197.20	0.63	5.63	5.29	3.66	0.00	0.00	34.60	42.20
PC2	33	15.37	93.19	0.46	2.82	3.86	1.84	0.00	0.00	23.70	19.90
PC3	31	11.31	55.01	0.36	1.77	3.02	1.15	0.00	0.26	17.50	11.80
PC4	29	6.39	43.92	0.22	1.51	1.82	0.98	0.00	0.49	9.90	9.40
PC5	27	4.26	41.68	0.15	1.54	1.31	1.00	0.13	0.46	6.60	8.90
PC6	25	2.94	16.67	0.11	0.66	0.97	0.43	0.50	0.99	4.50	3.60
PC7	23	1.25	12.43	0.05	0.54	0.45	0.35	0.98	0.99	1.90	2.70
PC8	21	0.56	3.87	0.02	0.18	0.22	0.12	1.00	1.00	0.90	0.80
PC9	19	0.29	3.46	0.01	0.18	0.13	0.12	1.00	1.00	0.40	0.70
Residuals	540	65.09	825.60	0.12	1.53	-	-	-		-	-
Total	1082	630.90	7041.13	-	-	-	-	-		-	-

SY: Seed yield; FY: Fodder yield

desirable for seed and fodder yield, respectively. Contrastingly, WN 660 was of course the poorest for seed and fodder yield as it was consistently the poorest. “High stability” of a genotype is worthwhile only when correlated with mean performance. WN 660 is highly “stable”, this does not mean WN 660was good; it only means that the relative performance of WN 660 was consistent. WN 660 was even poorer than the highly variable, least stable genotype KIFMG 211 for seed yield and GPU 106 for fodder yield, because KIFMG 211and GPU 106 performed reasonably well in at least some locations. This illustration, is a proof that how misleading it can be to search and select for “stability” genes alone. “Stable” genotypes are desirable only when coupled with high mean performance.

Mean performance and stability of the genotypes: The single-arrowed line in the biplot is the average-environment coordination (AEC) abscissa (or AEA); it points to higher mean seed/fodder yield across locations. PR 1734 produced highest mean seed yield, followed by IIMR-FM-R21-8012 and PPR1272; IIMR-FM-R21-8011 had mean seed yield similar to the grand mean; and WN 660 had the lowest mean seed yield (Fig. 4a). The genotype IIMR-FM-R21-8012 produced the highest mean fodder yield, followed by TNEc 1341 and GPU 67; KMR 655 produced mean fodder yield similar to the grand mean; WN 660 had the lowest mean fodder yield (Fig. 4b). The AEC ordinate is indicated by the double-arrowed line, which signifies higher variability and poor stability in either direction. Thus, TNEc 1342 was highly unstable whereas WN 577 stable for seed yield. The genotype PR 1734 was highly stable and GPU 106 unstable for fodder yield.

Table 4. Predictive value of BLUP genotype effect of seed yield

Genotype	Seed yield	Genotype	Seed yield
BUFM 19-E-1	1.80	PPR 1216	1.78
CFMV 1	1.74	PPR 1272	1.85
CFMV 2	1.86	PR 1734	2.00
GE 6541	1.82	PR 202	1.76
GPU 105	1.76	TNEc 1341	1.78
GPU 106	1.75	TNEc 1342	1.84
GPU 67	1.81	VL 376	1.68
IIMR-FM-R21-8001	1.79	VL 402	1.61
IIMR-FM-R21-8006	1.86	VL 409	1.60
IIMR-FM-R21-8011	1.74	VR 1163	1.61
IIMR-FM-R21-8012	2.01	VR 1171	1.71
KIFMG 211	1.53	WN 577	1.88
KMR 654	1.64	WN 660	1.43
KMR 655	1.77	-	-

Which-won-where: The equality line between PR 1734 and IIMR-FM-R21-8012 indicated that PR 1734 was better in Perumallapalle, Bengaluru and Hageri, whereas IIMR-FM-R21-8012 in the other locations for seed yield (Fig. 5). The equality line between IIMR-FM-R21-8012 and KIFMG 211 indicated that IIMR-FM-R21-8012 was better than KIFMG 211 across all the locations. Note that TNEc 1342 located on the line that connects IIMR-FM-R21-8012 and KIFMG 211, indicates that the rank of genotypes was IIMR-FM-R21-8012>TNEc 1342>KIFMG 211 true across all locations for seed yield. Likewise, the equality line between IIMR-FM-R21-8012 and PR 202 indicated that IIMR-FM-R21-8012 was better across most of the locations, whereas PR 202 in Perumallapalle for fodder yield (Fig. 5). TNEc 1342 and TNEc 1341 located on the line that connects IIMR-FM-R21-8012 and PR 202, indicated that the rank IIMR-FM-R21-8012>TNEc 1342>TNEc 1341>PR 202 was true in all locations for fodder yield. The equality lines divided the biplot into sectors and the winning genotype for each sector was located on the respective vertex. The ten locations fell into two sectors both for seed and fodder yield. The genotype PR 1734 was the winner in Perumallapalle, Bengaluru and Hageri, and IIMR-FM-R21-8012 across remaining locations for seed yield. The genotype PR 202 was the winner in Perumallapalle; IIMR-FM-R21-8012 for the other locations for fodder yield. This pattern suggests that the target locations may consist of two different mega-environments and that different genotypes should be selected and deployed for each.

Discriminating ability of test locations: The measure of the discriminating ability of a test location is based on the concentric circles on the biplot that assist in contemplating the length of the location vectors which is equivalent to the standard deviation within the respective location. With relatively longer location vectors, Perumallapalle and Nandyal were most discriminating and informative test locations both for seed and fodder yield (Fig. 6a and Fig. 6a). The test locations Berhampur and Dapoli with shorter vectors for seed yield and Vizianagaram for fodder yield (Fig. 6b) were non-discriminative and non-informative. They provide meagre information on the performance of the genotypes and hence shall not be useful as test locations for further seed/fodder yield trials.

Representativeness of test locations: The average location (represented by the arrow) has the average coordinates of all test locations and AEA (Average-Environment Axis) is the line that passes through the average location and the biplot origin. The test locations Berhampur and Dapoli with a smaller angle with AEA were most representative whereas, Perumallapalle and Vizianagaram

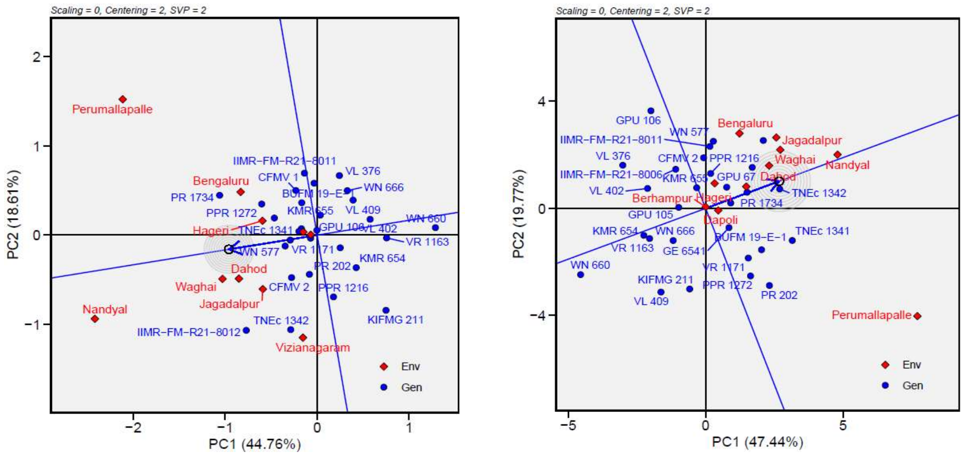

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Fig. 3. Average environment coordination view of GGE-biplot based on environment-focused scaling for the ideal genotypes of twenty-eight finger millet genotypes for (a) seed yield and (b) fodder yield

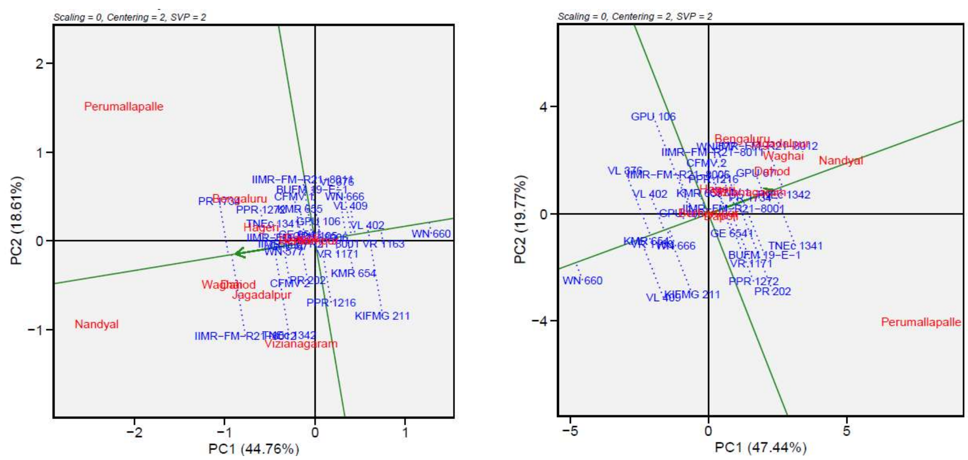

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Fig. 4. Average environment coordination view of GGE-biplot based on environment-focused scaling for the mean performance vs. stability of twenty-eight finger millet genotypes for (a) seed yield and (b) fodder yield

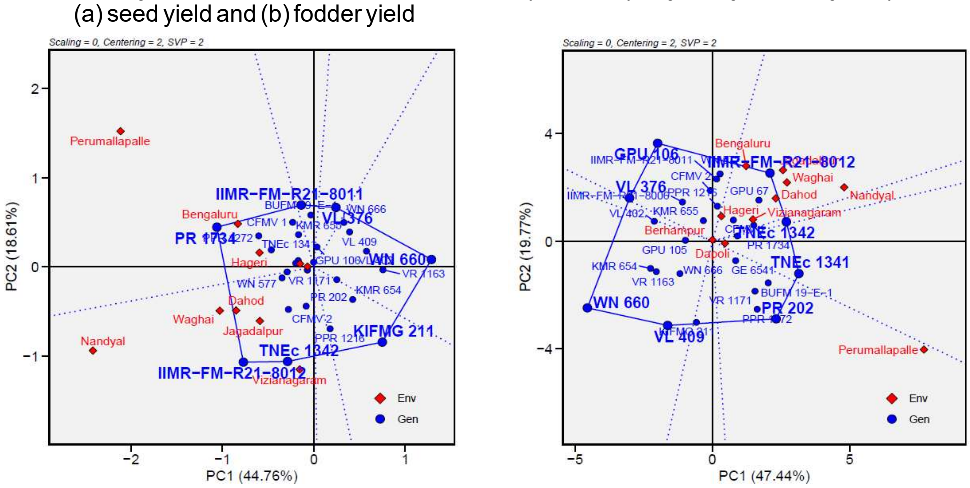

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Fig. 5. Polygon view of GGE-biplot based on the symmetrical scaling for “which won-where” pattern of twenty-eight finger millet genotypes and ten locations for (a) seed yield and (b) fodder yield

Table 5. Estimates of AMMI-based stability parameters of twenty-eight finger millet genotypes evaluated across ten locations

Genotype	ASI		ASV		ASTAB		AVAMGE		DA		DZ		EV		FA	
	SY	FY	SY	FY	SY	FY	SY	FY	SY	FY	SY	FY	SY	FY	SY	FY
BUFM 19-E-1	0.11	0.28	0.49	1.52	0.27	0.63	1.94	3.85	0.78	2.14	0.35	0.30	0.03	0.04	0.60	4.60
CFMV 1	0.14	0.16	0.61	0.85	0.30	0.60	2.13	4.01	0.84	1.84	0.36	0.33	0.03	0.05	0.70	3.40
CFMV 2	0.06	0.19	0.25	1.01	0.26	0.40	1.80	3.96	0.70	1.62	0.37	0.25	0.03	0.03	0.49	2.64
GE 6541	0.02	0.12	0.09	0.63	0.00	0.09	0.29	1.54	0.13	0.83	0.05	0.10	0.00	0.00	0.01	0.70
GPU 105	0.01	0.12	0.04	0.65	0.10	0.12	1.12	2.27	0.42	0.94	0.25	0.13	0.01	0.00	0.18	0.89
GPU 106	0.04	0.45	0.17	2.41	0.12	1.36	1.32	5.93	0.49	3.23	0.25	0.42	0.01	0.09	0.24	10.48
GPU 67	0.07	0.08	0.32	0.47	0.23	0.12	1.55	2.03	0.63	0.86	0.37	0.14	0.03	0.01	0.40	0.74
IIMR-FM-R21-8001	0.01	0.09	0.07	0.48	0.01	0.07	0.44	1.71	0.18	0.71	0.09	0.10	0.00	0.00	0.03	0.50
IIMR-FM-R21-8006	0.04	0.22	0.18	1.19	0.41	0.30	2.05	3.68	0.79	1.55	0.51	0.19	0.06	0.01	0.63	2.42
IIMR-FM-R21-8011	0.12	0.15	0.54	0.80	0.27	0.18	1.49	0.04	0.77	1.15	0.35	0.16	0.03	0.01	0.60	1.32
IIMR-FM-R21-8012	0.14	0.02	0.61	0.13	0.49	0.00	2.38	0.51	1.02	0.24	0.48	0.04	0.05	0.00	1.06	0.05
KIFMG 211	0.19	0.17	0.38	0.89	0.44	0.16	2.41	2.59	1.04	1.15	0.42	0.14	0.04	0.01	1.09	1.33
KMR 654	0.10	0.18	0.46	0.96	0.35	0.44	2.27	4.00	0.83	1.66	0.43	0.27	0.04	0.03	0.69	2.76
KMR 655	0.08	0.09	0.34	0.51	0.11	0.06	0.97	1.64	0.49	0.68	0.24	0.08	0.01	0.00	0.24	0.46
PPR 1216	0.15	0.09	0.64	0.51	0.41	0.23	1.95	2.62	0.96	1.13	0.44	0.20	0.05	0.02	0.92	1.28
PPR 1272	0.18	0.32	0.79	1.70	0.28	0.68	2.07	4.20	0.88	2.29	0.32	0.30	0.02	0.04	0.78	5.26
PR 1734	0.23	0.13	1.01	0.72	0.45	0.23	2.76	2.94	1.12	1.21	0.40	0.19	0.04	0.01	1.25	1.47
PR 202	0.07	0.43	0.32	2.31	0.35	1.11	2.00	6.11	0.81	2.99	0.44	0.37	0.04	0.06	0.65	8.96
TNEC 1341	0.18	0.37	0.80	1.98	0.31	0.81	2.22	5.86	0.91	2.56	0.34	0.31	0.02	0.05	0.83	6.56
TNEC 1342	0.16	0.27	0.68	1.46	0.62	0.61	2.81	5.05	1.15	2.10	0.54	0.30	0.07	0.04	1.34	4.41
VL 376	0.09	0.37	0.42	1.98	0.47	1.05	2.28	5.00	0.93	2.78	0.51	0.38	0.06	0.07	0.88	7.73
VL 402	0.13	0.26	0.58	1.37	0.24	0.39	1.82	3.54	0.75	1.78	0.33	0.22	0.02	0.02	0.57	3.18
VL 409	0.08	0.14	0.35	0.74	0.19	0.50	1.38	3.89	0.61	1.67	0.32	0.30	0.02	0.04	0.38	2.80
VR 1163	0.20	0.10	0.86	0.56	0.50	0.23	2.67	2.57	1.10	1.14	0.47	0.20	0.05	0.02	1.21	1.31
VR 1171	0.07	0.29	0.33	1.54	0.07	0.50	1.07	3.94	0.42	2.01	0.17	0.25	0.00	0.03	0.17	4.06
WN 577	0.01	0.16	0.07	0.87	0.05	0.23	0.76	2.25	0.30	1.28	0.16	0.18	0.00	0.01	0.09	1.64
WN 660	0.24	0.42	1.03	2.23	0.60	2.22	3.14	9.08	1.23	3.74	0.50	0.60	0.06	0.18	1.53	14.00
WN 666	0.60	0.07	0.25	0.39	0.27	0.11	1.82	1.80	0.73	0.80	0.38	0.14	0.03	0.01	0.53	0.65

Cont...

Table 5. Estimates of AMMI-based stability parameters of twenty-eight finger millet genotypes evaluated across ten locations

Genotype	MASI		MASV		SIPC		ZA	
	SY	FY	SY	FY	SY	FY	SY	FY
BUFM 19-E-1	0.11	0.28	0.79	1.52	0.70	1.10	0.10	0.13
CFMV 1	0.15	0.16	0.84	0.85	0.91	0.93	0.14	0.08
CFMV 2	0.08	0.19	0.75	1.01	0.89	0.89	0.11	0.09
GE 6541	0.02	0.12	0.13	0.63	0.15	0.38	0.02	0.04
GPU 105	0.04	0.12	0.45	0.65	0.50	0.50	0.05	0.05
GPU 106	0.06	0.45	0.55	2.41	0.48	1.53	0.06	0.19
GPU 67	0.08	0.08	0.55	0.47	0.75	0.47	0.09	0.04
IIMR-FM-R21-8001	0.02	0.09	0.20	0.48	0.19	0.38	0.02	0.04
IIMR-FM-R21-8006	0.07	0.22	0.68	1.19	0.94	0.67	0.10	0.09
IIMR-FM-R21-8011	0.13	0.15	0.76	0.80	1.01	0.60	0.15	0.07
IIMR-FM-R21-8012	0.15	0.02	1.05	0.13	1.08	0.13	0.14	0.01
KIFMG 211	0.19	0.17	0.99	0.89	1.02	0.42	0.18	0.06
KMR 654	0.12	0.18	0.82	0.96	1.14	0.91	0.15	0.09
KMR 655	0.08	0.09	0.46	0.51	0.66	0.31	0.09	0.04
PPR 1216	0.16	0.09	0.96	0.51	1.23	0.53	0.18	0.05
PPR 1272	0.18	0.32	0.80	1.70	0.68	1.10	0.13	0.13
PR 1734	0.23	0.13	1.01	0.72	0.76	0.67	0.15	0.07
PR 202	0.10	0.43	0.83	2.31	1.03	1.21	0.12	0.16
TNEC 1341	0.18	0.37	0.84	1.98	0.80	1.00	0.15	0.14
TNEC 1342	0.17	0.27	1.19	1.46	1.25	1.10	0.17	0.13
VL 376	0.12	0.37	0.94	1.98	1.26	1.42	0.15	0.17
VL 402	0.14	0.26	0.71	1.37	0.94	0.74	0.14	0.10
VL 409	0.09	0.14	0.58	0.74	0.85	0.81	0.11	0.07
VR 1163	0.20	0.10	1.02	0.56	1.33	0.60	0.20	0.05
VR 1171	0.08	0.29	0.40	1.54	0.43	0.86	0.07	0.11
WN 577	0.03	0.16	0.34	0.87	0.33	0.68	0.04	0.08
WN 660	0.24	0.42	1.13	2.23	1.35	0.07	0.22	0.22
WN 666	0.09	0.07	0.81	0.39	0.83	0.42	0.11	0.04

ASI= AMMI stability index; ASV= AMMI stability value; ASTAB=AMMI-based stability parameter; AVAMGE= Absolute value of GEI modeled by AMMI; DA= Annicchiarico's D parameter; DZ= Zhang's D parameter; EV= Averages of the squared eigenvector values and FA= Fitted AMMI model; MASI=Modified AMMI Stability Index; MASV= Modified AMMI Stability Value; SIPC= Sums of absolute value of the IPC scores; ZA= Absolute value of the relative contribution of IPCs to the interaction and WAAS= Weighted average of absolute score; SY: Seed yield; FY: Fodder yield

with a greater angle with AEA were least representative for seed yield. For fodder yield, Nandyal was most representative while, Perumallapalle and Bengaluru were least.Nandyal was both discriminating and representative location both for seed and fodder yield indicating its potential in identifying generally adapted genotypes. Perumallapalle was discriminating but non-representative test location for seed and fodder yield signifying its use selecting specifically adapted genotypes.

Association among different stability parameters: Various AMMI-based stability indices such as ASI, ASV, ASTAB, AVAMGE, DA, DZ, EV, FA, MASI, MASV, SIPC and Za were computed both for seed and fodder yield (Table 5). The lower the score of the stability index, higher is the stability of the genotype and vice versa. The scores of EV were close to 0, followed by Za. The genotypes WN 577, IIMR-FM-R21-8001and GE 6541 were highly stable based on all the estimated stability indices for seed yield. Subsequently, the genotypes IIMR-FM-R21-8012 and WN 666 were highly stable for fodder yield. The order of the rank of these genotypes varied for each of the stability index. These differences may be attributable to the variation in estimation methods that consider the first two or all the significant PCs. Nevertheless, a similar trend in identifying stable genotypes was observed for all the stability indices. Similar results were reported in by Cheloei et al (2020) in rice and Anuradha et al (2022) in finger millet using AMMI stability indices.

In an effort to disclose the relationship between each of the AMMI stability indices, Spearman's rank correlation uncovered strong association among almost all the estimated AMMI-based stability indices. The stability indices, ASI and ASV were significantly associated in positive direction for seed yield (Fig. 7a). The stability index AMGE was not significantly associated with any other stability index in positive direction both for seed and fodder yield (Fig. 7a and 7b). Significant association of MASV with all the stability parameters at a relatively higher magnitude in positive direction except AMGE. It was ascertained that ASI and ASV; MASV and ASI; MASV and ASV; MASV and MASI; MASI and ASI; MASI and ASV were 100% associated for fodder yield (Fig. 7b).

BLUP-based stability parameters to identify stable genotypes: Based on all three BLUP-based stability estimates for seed yield, the genotypes IIMR-FM-R21-8012 and PR 1734 were the top two rankers in that order (Table 6). The genotypes IIMR-FM-R21-8012 and TNEc 1341 were highly stable and produced maximum fodder yield. Although the BLUP-based stability indices were applied to various crops to estimate the stability and adaptability, only one study by Anuradha et al (2021) was reported in finger millet.

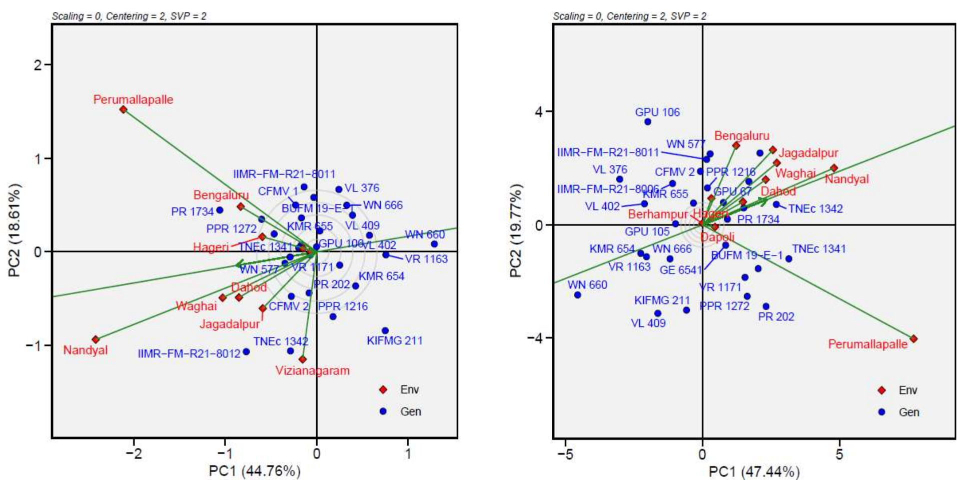

Fig. 6. Discriminative vs. representativeness view of GGE biplot for (a) seed yield and (b) fodder yield of twenty-eight finger millet genotypes evaluated across ten locations

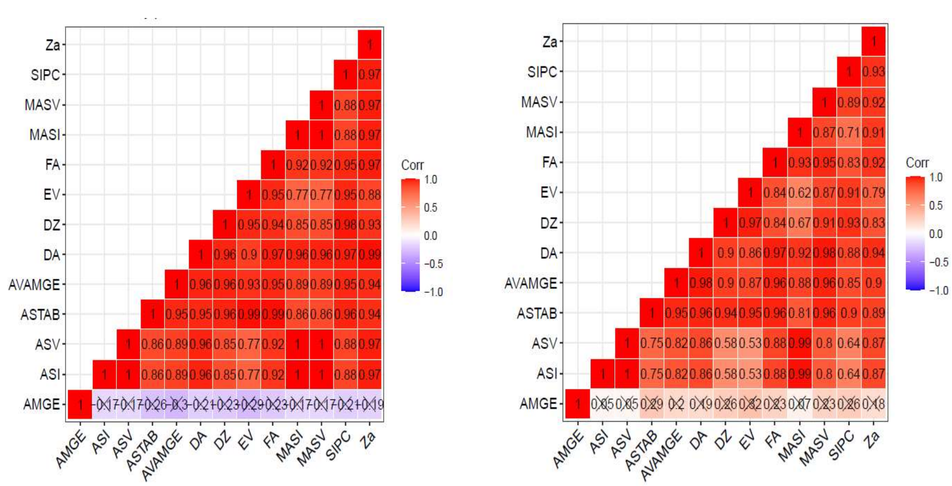

Fig. 7. Correlation between different AMMI stability parameters estimated for (a) seed yield and (b) fodder yield

Table 6. Estimates of BLUP-based stability parameters of fifteen finger millet genotypes evaluated under twenty test environments

Genotype	HMGV		RPGV		HMRPGV	
	SY	FY	SY	FY	SY	FY
BUFM 19-E-1	1.50	3.79	1.05	1.09	1.04	1.08
CFMV 1	1.39	3.33	0.98	1.02	0.97	1.02
CFMV 2	1.56	3.51	1.08	1.04	1.08	1.04
GE 6541	1.51	3.51	1.05	1.04	1.05	1.04
GPU 105	1.48	3.10	1.02	0.96	1.01	0.96
GPU 106	1.40	3.04	0.99	0.97	0.99	0.97
GPU 67	1.45	3.85	1.03	1.11	1.03	1.10
IIMR-FM-R21-8001	1.46	3.51	1.03	1.04	1.03	1.04
IIMR-FM-R21-8006	1.61	3.22	1.10	0.99	1.09	0.98
IIMR-FM-R21-8011	1.38	3.54	0.98	1.05	0.97	1.05
IIMR-FM-R21-8012	1.71	4.36	1.19	1.20	1.18	1.18
KIFMG 211	1.18	2.46	0.84	0.89	0.83	0.88
KMR 654	1.35	2.15	0.93	0.85	0.92	0.82
KMR 655	1.45	3.26	1.02	1.00	1.02	1.00
PPR 1216	1.45	3.32	1.02	1.02	1.01	1.02
PPR 1272	1.49	3.49	1.05	1.04	1.05	1.04
PR 1734	1.69	3.80	1.17	1.09	1.17	1.08
PR 202	1.41	3.50	1.00	1.05	0.99	1.05
TNEC 1341	4.41	4.38	1.01	1.18	1.00	1.15
TNEC 1342	1.50	3.88	1.06	1.11	1.05	1.11
VL 376	1.33	2.00	0.94	0.84	0.92	0.80
VL 402	1.25	2.25	0.89	0.87	0.89	0.84
VL 409	1.24	2.38	0.88	0.88	0.87	0.86
VR 1163	1.25	1.97	0.90	0.85	0.89	0.80
VR 1171	1.39	3.40	0.97	1.03	0.97	1.02
WN 577	1.56	3.70	1.09	1.08	1.09	1.07
WN 660	1.10	0.79	0.78	0.75	0.77	0.53
WN 666	1.24	2.62	0.88	0.91	0.88	0.90

HMGV= Harmonic mean of genotypic values; RPGV= Relative performance of the genotypic values and HMRPGV= Harmonic mean of the relative performance of genotypic values; SY: Seed yield; FY: Fodder yield

CONCLUSION

The current study deciphered the effects of genotype×environment interaction for seed yield and fodder yield in finger millet genotypes. The seed yield and fodder yield was significantly affected by environment and genotype × environment interaction. While, BLUPg and BLUPge prediction models amply explained the variation due to GEI for seed and fodder yield, respectively. This study identified IIMR-FM-R21-8012 and PR 1734; IIMR-FM-R21-8012 and TNEc 1341 as worthy genetic resources for seed and fodder yield, respectively. They can be further tested across multi-locations and further released for commercial cultivation across farmers fields.

AUTHORS CONTRIBUTIONS

Conceptualization of research (TEN, SB, CN, S and GKN); Designing of the experiments (SB, CN, S and GKN); Contribution of experimental materials (TEN, SB, CN, S and GKN); Execution of field/lab experiments and data collection (SB, CN, S and GKN); Analysis of data and interpretation (TEN and GPS); Preparation of the manuscript (TEN and GPS).

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Received 21 January, 2024; Accepted 10 June, 2024

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Indian Journal of Ecology (2024) 51(4): 784-787
DOI: https://doi.org/10.55362/IJE/2024/4309

Manuscript Number: 4309
NAAS Rating: 5.38

Genetic Diversity Analysis of Mungbean [*Vigna radiata* (L.) Wilczek] Genotypes under Rainfed Condition of Thar Desert

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Abstract: Field experiment with 38 varieties was conducted to study the genetic divergence in the mungbean variety at Agricultural University, Jodhpur during *Kharif* 2019. Significance difference was observed among all 11 characters studied. These genotypes were grouped into nine clusters which indicate the existence of an ample amount of genetic diversity in the variety and therefore signify the scope of selection for genetic improvement of mungbean. The maximum intra-cluster distance was exhibited in cluster I, while the maximum inter-cluster distance was exhibited between II and XI. The greater distance between two clusters indicates the presence of wider genetic diversity among the genotypes of those clusters. Therefore, genotypes belonging to diversified clusters may be used in a hybridization programme for developing the high-yielding variety in mungbean.

Keywords: Genetic divergence, Clusters, Mungbean, Seed yield

Mungbean (*Vigna radiata* L. Wilczek, 2n=22, *Fabaceae*) is an important pulse crop which is broad cultivated throughout India. Mungbean is a short day, hot season crop, mainly grown in arid and semi-arid regions. Mungbean has 22 chromosomes in the 2n set and a relatively modest (579 Mb) genome (Kang et al 2014). The names greensoy, green gram, green bean, mash bean, and gold engram are also used to describe it (Markam et al 2018). Mungbean has become an extremely valuable short-lived grain legume crop with many desirable characteristics, such as wide adaptability, low input requirements and the ability to improve soil fertility (Pooran and G. M., Can 2021). According to 3rd advance estimates for 2021-2022, the overall production of pulses in India to be 27.75 million tonnes. In India, a total of 2.85mt mungbean productions including 1.48mt in *kharif* and 1.37mt in *rabi*, accounting for 10% of all pulse production (Directorate of Economics and Statistics, Ministry of Agriculture and Farmers Welfare 2022). India is the principle producer of mungbean in the world with an annual production of 3.17 mt from an area of 5.50 mha with the productivity of 570 kg per ha and contributing 10.30 per cent to the total pulses production (Anonymous 2022-23). It is a drought hardy crop with ability to grow under harsh climate and medium to low rainfall conditions and grows on a variety of soils including black, red lateritic, gravelly and sandy soils. Well drained fertile sandy loam soil with a pH between 6.3 - 7.5 is the best for mungbean cultivation (Sharma 2016). Genetic diversity is a dominant factor and also a precondition in any hybridization programme. Introduction of diverse parents in hybridization programme serves the purpose of combining advisable recombination. Multivariate analysis by means of Mahalanobis D^2 statistic is a dominant tool in quantifying the degree of divergence at genotypic level. Therefore, an attempt has been made in the present inspection with a view to approximate genetic divergence among a set of 38 genotypes of mungbean.

MATERIAL AND METHODS

The present study was carried out during *Kharif*, 2019 at Agriculture University, Mandor, Jodhpur. The experimental material consisted of 38 genotypes (Table 1) and was sown on July 23, 2019 in RBD design with three replications. The data were recorded for 11 characters viz. days to 50% flowering, days to maturity, 100 seed weight (g) and protein content (%) on a whole plot basis whereas, plant height (cm), pods per plant, pod length (cm), branches per plant, seeds per pod, seed yield per plant (g) and harvest index (%) were measured on five competitive plants in each replication. The statistical analysis was performed using INDOSTAT 8.1 and XLSTAT 2021.2.2 software. Diversity analysis (D^2) was done by following the method of Mahalanobis (1936) and grouped into separate clusters following the Toucher's method as suggested by Rao (1952). Average intra and inter-cluster distances were determined using GENRES version 3.11, 1994 Pascal Intl. Software as suggested by Singh and Chaudhary (1977).

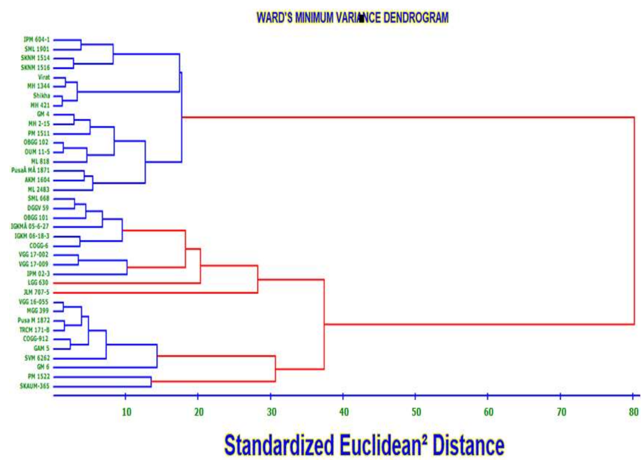
RESULTS AND DISCUSSION

There were significant differences among genotypes for all 11 characters recommended that the material has sufficient genetic diversity to support the breeding programme for improving the seed yield of mungbean. In this study, 38 genotypes were assemble into nine clusters based on D^2 values using Tocher's method. The cluster-I contains maximum (29) genotypes, followed by cluster-II with two, while cluster-III, IV, V, VI, VII, VIII and IX were monogenotypic (Table 2 and Fig. 1). Similar findings were observed by Markam et al (2018), Talukdar et al (2020), Wesly et al (2020), Gupta et al (2021), Sridhar et al (2022), Kingsly et al. (2023) and Srivastava et al (2024).

Amongst the characters, plant height contributed highest towards genetic divergence (45.38%) followed by pods per plant, 100-seed weight and days to 50% flowering (9.53%) while the remaining characters contributed little to genetic divergence [Markam et al 2018, Mathankumar et al 2020, Talukdar et al 2020, Gupta et al 2021, Tiwari et al 2022 and Srivastava et al 2024] (Table 3). The greatest intra-cluster distance was approximate in cluster-I (12.43) and cluster-II (6.44) (Table 4). The highest inter-cluster distance was observed between cluster-II and IX (46.44) followed by cluster-II and VII, cluster-II and V, cluster-II and III, cluster-II and VII and cluster-II and VI suggesting broad diversity between genotypes of these clusters (Goyal et al 2021, Gupta et al 2021, Sridhar et al 2022). The diversity was also supported by the considerable amount of variation among the cluster means for distinct characters (Table 5). The data suggested that the cluster mean for days to 50% flowering

Table 1. List of mungbean genotypes used for present investigation

Source	Name of genotypes
IIPR, Kanpur, U.P. 02-	IPM 02-3, IPM 604-1,Virat, Shikha M
SDAU,S.K. Nagar, Gujarat	SKNM 1514, SKNM 1516, GM 6, GM 4
PAU, Ludhiana, Punjab	ML 818, ML 2483, SML 1901, SML 668
Hisar, Haryana	MH 2-15, MH 421, MH 1344, SVM 6262
NPRC,Vamban, T.N.	VGG 17-002, VGG 17-009, VGG 16-055
IARI, New Delhi	Pusa M 1871, Pusa M 1872 871
OUAT, Bhubaneswar, Odisha	OBGG 101,1OBGG 102
IGKVV, Raipur, Chhattisgarh	IGKM 05-6-27, IGKM 06-18-3
GBPUA & T, Pant Nagar, Uttarakhand	PM 1511, PM 1522
Coimbatore, T.N.	CO-6, COGG-912
Anand, Gujarat	GAM 5
ARS, Lam, A.P.	LGG 630
ARS, Dharwad, Karnataka	DGGV- 59
ARS, Madhira, Telangana	MGG 399
Agartala, Tripura, Bangladesh	TRCM 171-B-B-12-6
Berhampur, Odisha	OUM 11-5
MPKV, Jalgaon, M. H.	JLM 707-5
PDKV, Akola, M.H.	AKM- 1604
Srinagar, J & K	SKAU-M-365



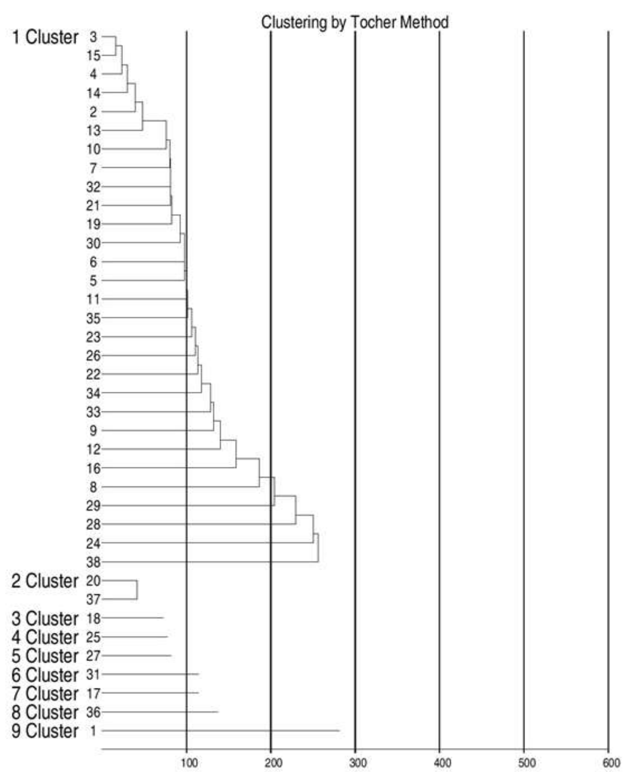


Fig. 1. Clustering pattern among 38 genotypes of mungbean (Tocher's method)

Table 2. Clustering pattern among 38 genotypes of mungbean (Tocher's method)

Cluster	Number of genotypes	Genotypes
I	29	Virat, MH1344, Shikha, MH421, IPM 604-1, MH2-15, ML 2483, GM-4, DGGV-59, PusaM-1872, VGG16-055, GAM-5, SKNM-1516, SKNM-1514, SML1901, DUM11-5, OBGG102, PM1511, OBGG101, TRCM171-B-B-12-6, MGG399, ML818, SML668, SVM6262, GM6, COGG-912, COGG-6, IGKM 05-6-27, SKAU-M-365
II	2	Pusa M-1871, AKM-1604
III	1	VGG17-009
IV	1	IGKM 06-18-3
V	1	PM 1522
VI	1	LGG 630
VII	1	VGG 17-002
VIII	1	JLM707-5
IX	1	IPM 02-3

was maximum in cluster VI (57.00) and the minimum in cluster II (41.83). Days to maturity were show highest and lowest means in cluster VIII (82.67) and cluster I (74.33). Cluster IX exhibited highest mean for plant height (69.73 cm),

Table 3. Contribution of different characters towards genetic divergence in 38 mungbean genotypes

Source	Contribution (%)	Times ranked 1st
Days to 50% flowering	9.53%	67
Days to maturity	0.57%	4
Plant height (cm)	45.38%	319
No. of pods per plant	16.79%	118
Pod length (cm)	0.14%	1
No. of branches per plant	2.70%	19
Number of seeds per pod	0.00%	0
100 seed weight (g)	16.50%	116
Seed yield per plant (g)	1.56%	11
Harvest Index (%)	6.54%	46
Protein content (%)	0.28%	2

Table 4. Intra (Diagonal) and inter-cluster average of D^2 values of 38 mungbean genotypes

Clusters	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V	Cluster VI	Cluster VII	Cluster VIII	Cluster IX
Cluster I	12.43	21.47	16.88	17.58	23.14	20.32	22.36	17.84	28.78
Cluster II		6.44	33.03	30.71	37.78	30.76	38.43	30.92	46.44
Cluster III			0.00	15.07	17.24	18.31	10.70	15.08	16.77
Cluster IV				0.00	9.04	14.67	13.66	16.33	25.42
Cluster V					0.00	18.41	14.24	16.89	23.26
Cluster VI						0.00	18.01	21.25	28.07
Cluster VII							0.00	21.64	17.41
Cluster VIII								0.00	23.29
Cluster IX									0.00

Table 5. Cluster means for seed yield and yield attributing characters in 38 mungbean genotype

Clusters	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V	Cluster VI	Cluster VII	Cluster VIII	Cluster IX
Days to 50% flowering	43.53	41.83^{L}	48	46	48.33	57^{H}	49.33	43.33	44
Days to maturity	74.33^{L}	76	81	74.67	75.67	80.33	78	82.67^{H}	77.33
Plant height (cm)	41.09	20.87^{L}	55.87	51.13	57.27	51.40	62.73	46.80	69.73^{H}
No. of pods per plant	13.13	12.30	12.60	22.73	25.53^{H}	18.27	16.27	19.93	11.87^{L}
Pod length (cm)	7.23	7.21	6.93	6.89	7.33^{H}	7.06	7.01	5.28^{L}	6.95
No. of branches per plant	1.52	1.40	1.20^{L}	1.60	2.27^{H}	2.07	1.33	2.07	1.80
Number of seeds per pod	9.89	9.57	9.40	10.53	11.07^{H}	8.80	10.07	8.60^{L}	10.07
100 seed weight (g)	4.51	4.41	4.53	3.79	4.15	3.94	3.40^{L}	5.85^{H}	4.85
Seed yield per plant (g)	7.71	5.27^{L}	7.77	10.37	11.65^{H}	6.23	6.75	9.93	6.27
Harvest Index (%)	29.31	30.65	32.43	30.33	34.60^{H}	12.60^{L}	33.50	28.27	20.23
Protein content (%)	24.28	25.12	22.27	25.43	24.57	26.33^{H}	21.97^{L}	22.63	24.80

while lowest was in cluster II (20.87 cm) (Jadhav et al 2021, Sridhar et al 2022, Kingsly et al 2023).

CONCLUSION

The percentage contribution towards genetic divergence was found high for plant height followed by pods per plant and 100 seed weight. Maximum inter cluster divergence was observed between cluster II and XI followed by cluster II and VII preferable that good recombinants can be obtain by mating between the genotypes. Out of 38 genotypes, PM 1522, GM-6, IGKM 06-18-3 and GM-4 were encouraging in seed yield and other characters. Hence, these genotypes would be used as parental source for upcoming breeding programmes.

ACKNOWLEDGEMENT

The authors are thankful to the Sitaram Kumhar, Sesame Breeder, Agricultural Research Station (Agriculture University, Jodhpur) and department of Genetics and Plant Breeding, Agriculture University, Mandore, Jodhpur for providing the valuable genotypes.

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Received 13 February, 2024; Accepted 21 June, 2024

Indian Journal of Ecology (2024) 51(4): 788-791
DOI: https://doi.org/10.55362/IJE/2024/4310

Manuscript Number: 4310
NAAS Rating: 5.38

Effect of Integrated Nitrogen Management on Productivity and Available Nutrient Status in Soil after Harvest of Dwarf Ricebean (*Vigna Umbellata*) under Rainfed Condition

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Abstract: Rice bean [*Vigna umbellata* (Thunb.), previously *Phaseolus calcaratus* is a non-conventional and underutilized bean. All the parameters like nodulation, yield, quality of dwarf rice bean was highest with application of 30 Kg N/ha (Urea)+ VC @5 t/ha + Neem@75Kg/ha which was statistically at par with 20 kg N/ha (Urea) + VC @ 5 t/ha + Neem@75kg/ha. Available nutrient status in soil after harvest was also highest in 30 Kg N/ha (Urea)+ VC @5 t/ha + Neem@75Kg/ha. Minimum was in VC @2.5 t/ha + Neem@50kg/ha.

Keywords: Integrated nitrogen management, Neem, Rice bean, Urea, Vermicompost.

Rice bean [*Vigna umbellata* (Thunb.) is a warm-season annual vine legume with yellow flowers and small edible beans. It belongs to the family Leguminosae, sub family Papilionaceous. Grown mainly for its beans, it is equally important as vegetable (green pod), fodder and folk medicine. A lesser-known pulse among the Asiatic *Vigna*, has long been considered as a food security crop of small and marginal farmers of Southeast Asia. Considered as a nutritionally rich food and fodder, is also a source of genes for biotic and abiotic stress tolerance including drought, soil acidity and storage pest. Despite of being a high-yielding nutritionally rich crop majority of its germplasm accessions and varieties suffers from many undesirable attributes, including asynchronous and late maturity, indeterminate growth habit, high pod dehiscence and seed shattering habit, and enhanced level of a few anti-nutritional components as compared to other major food legumes resulting underutilization of this crop.

In the year 2019-20 India produced 23.03 million tons of total pulses (Anonymous 2021). By 2050, the domestic requirements would be 26.50 million tons, necessitating stepping up production (Singh et al 2015). Efficient nutrient management is required to harness the maximum yield of the crop. Among the major nutrients, nitrogen is considered as one of the important nutrients required for optimum growth and development of the crop. The nitrogen which is supplied through inorganic fertilizers continuously will affect soil health and crop yield. Again, use of vermicompost or neem cake alone will result in poor yield of the crop as the nutrient content is less in manure. Therefore, integrated nutrient management seems an attractive option to improve soil health and crop yields (Sarwar et al 2021). Vermicompost contains nutrients in forms that are readily taken up by the plants, such as nitrates, exchangeable phosphorus and soluble potassium, calcium and magnesium. It also contains higher amount of humic acid and biologically active substances such as plant growth regulators. Integration of vermicompost with inorganic fertilization tend to increase the yield of black gram (Manivannan et al 2009). Neem Cake organic manure protects plant roots from nematodes, soil grubs and white ants probably due to its residual limoniid content. It also acts as a natural fertilizer with pesticidal properties. Neem cake also reduces alkalinity in soil, as it produces organic acids on decomposition. Being totally natural, it is compatible with soil microbes, improves the rhizosphere microflora and also enhances the fertility of the soil. Neem cake improves the organic matter of the soil, which helps to improve soil texture, water holding capacity, and soil aeration for better root development (Lalnunpui et al 2018).

Organic and inorganic fertilizers are applied in combination to fulfil the crop nutrient requirements in integrated nutrient management. Combined use of organic and inorganic resulted in better growth associated with increased availability of nutrients resulted in better development of yield attributes (De et al 2011). Integrated nutrient management exerts positive impact on biological, physical and chemical properties of soil. Limited work has been done on these aspects in dwarf rice bean. Hence, the present investigation was done in order to study the effect of integrated nitrogen management on nodulation, yield, quality and available nutrient status in soil after harvest of dwarf rice bean.

MATERIAL AND METHODS

A field experiment was conducted at the Agronomy field, College of Agriculture, Central Agricultural University, Imphal during the *kharif* season of 2021. The experimental site is located at $24^0$45' N latitude and $93^0$54' E longitude and at an altitude of 774 meters above mean sea level. This site falls under the Eastern Himalayan Region (II) and the agroclimatic zone Subtropical Zone (NEH-4) of the state of Manipur.

The chemical analysis of soil showed that the soil is clay in texture and medium in available N (260.51 Kg/ha), Available P_2O_5 (26.10 Kg/ha) and available K_2O (232.31 Kg/ha). The experiment was conducted laid out in a Randomized Block Design consisting of eight treatments replicated thrice. The treatments were T_1: 10 kg N/ha (Urea) + VC @ 2.5 t/ha + Neem @ 50kg/ha, T_2: 10 kg N/ha (Urea) + VC @ 5 t/ha + Neem @ 75kg/ha, T_3: 20 kg N/ha (Urea) + VC @2.5 t/ha + Neem @ 50 kg/ha, T_4: 20 kg N/ha (Urea) + VC @ 5 t/ha + Neem @ 75kg/ha, T_5: 30 kg N/ha (Urea) + VC @ 2.5 t/ha + Neem @ 50kg/ha, T_6: 30 Kg N/ha (Urea)+ VC @ 5 t/ha + Neem @ 75Kg/ha, T_7: VC @ 2.5 t/ha + Neem @ 50kg/ha and T_8: VC @ 5 t/ha + Neem @ 75kg/ha. Rice bean (Local Variety) was sown in line, with the recommended spacing of 60 cm line to line and 20 cm plant to plant on 13 th July, 2021 with seed rate of 15 Kg/ha. The gross experimental area was 223.2 m^2. All of the plots received the recommended dose of fertilizer 60:20 kg PK/ha, applied uniformly in the form of single super phosphate and muriate of potash respectively. In addition to that nitrogen through urea, vermicompost and neem were also applied as per treatments. Just before application, the necessary amount of organic manures and fertilizers were individually weighed. After this all the fertilizers and organic manures of each plot were applied in the form of a continuous band in furrows and were mixed with soil. Data recorded were on nodulation like number of nodules, fresh and dry weight of nodules, yield attributes like number of pods per plant, number of seed per pod, number of seeds per plant and test weight, yield parameters like grain yield (q/ha), stover yield (q/ha) and harvest index (%), quality parameters like crude protein content in seed (%), crude protein yield (Kg/ha) and post-harvest nutrient status. Nodulation recorded 3 times at 60, 90 DAS and at harvest. Whereas, yield, yield attributes, quality and post-harvest nutrient status were recorded at harvest. Data obtained on various variables were analyzed by analysis of variance technique. The level of significance of the different sources of variation was tested by use of F test at 5% critical difference (CD) value.

RESULTS AND DISCUSSION

Nodulation: The number of root nodules per plant, fresh weight of root nodules, and dry weight of root nodules increased up to 90 DAS and thereafter declining till harvest (Table 1 and 2). This might be due to autoregulation of nodulation (AON), which causes disintegration of root nodules post-flowering stage (Downie, 2014). T_6 treatment, followed by T_4, recorded the highest number of root nodules per plant, fresh weight of root nodules, and dry weight of root nodules at all stages of sampling and T_7 recorded the least. This may be attributed to the higher level of inorganic fertilization in T_6, which may have stimulated nodule formation. The carbon and nitrogen in organic manure could be easily used as energy and nutrient sources for soil microorganisms, and this might increase the number of nodules too (Basu et al 2008). These results are supported by the findings of Meena et al (2014), Devi et al (2016), Raj et al (2019) and Pratap et al (2020).

Table 1. Number of nodules and Fresh weight of nodules of dwarf rice bean as influenced by integrated nitrogen management

Treatments	Number of nodules			Fresh weight of nodules (g)		
	60 DAS	90 DAS	At harvest	60 DAS	90 DAS	At harvest
T_1	174.67	304.97	52.67	1.09	2.66	0.60
T_2	180.33*	310.90*	55.33	1.33	2.91*	0.90
T_3	176.23	306.67	53.33	1.18	2.70	0.70
T_4	182.67*	312.33*	56.60*	1.42*	3.00*	1.05*
T_5	178.80*	308.67	54.77	1.23	2.84*	0.80
T_6	184.33	314.67	57.40	1.55	3.12	1.13
T_7	167.33	297.33	48.73	0.60	2.20	0.27
T_8	173.33	303.67	51.33	0.91	2.53	0.50
CD (p=0.05)	6.46	5.46	1.81	0.18	0.36	0.22

*On par with highest treatment

Yield and yield attributes: Yield attributes like pods per plant, number of seeds per pod, and number of seeds per plant were significantly influenced by different treatments. T_6 recorded the highest, followed by T_4 and T_7 recorded the least. Profuse nodulation might lead to increased nitrogen fixation, which might in turn have a beneficial effect on the photosynthetic activity of plants. This might be attributed to the larger availability of stored photo assimilates that are translocated towards the development of reproductive organs. The 100 seed weight was maximum in T_6 followed by T_4, T_2, and T_5. This may be due to the greater accumulation and translocation of photosynthates from source to sink, which might have resulted in slightly bolder seeds. These results are in consonance with the findings of Kamal et al (2021) and Biswash et al (2014). Similar pattern was also observed in the grain yield, straw yield, and harvest index. This might be due to the cumulative effect of yield attributes on account of increased growth, which was due to higher biomass accumulation during the vegetative phase leading to increased bearing capacity, which ultimately increased yield parameters. Similar findings were also reported by Khan et al (2013) and Banotra et al (2021) . Similarly, harvest index also recorded the highest in T_6, and did not differ significantly from other treatments. T_7 significantly recorded the lowest harvest index. These results were in conformity with the findings of and Dhakal et al (2015) and Kamal et al (2021)

Biochemical analysis: The crude protein content of dwarf rice bean seed was highest by T_6, which was statistically at par with T_4 (Table 3). This could be due to increased nitrogen fixation by the bacteria, which in turn improved the absorption and utilization of nitrogen and enhanced the activity of nitrate reductase, which plays a very significant role in the synthesis of proteins in seeds. The findings of Dhakal et al (2015), Chauhan et al (2016), and Banotra et al (2021) support these conclusions. Due to the accumulation of greater crude protein content in seeds along with a higher seed yield, crude protein yield followed similar trend. Devi et al 2021 also found a similar result.

Post-harvest nutrient status: The T_6 recorded the highest

Table 2. Dry weight of nodules per plant and yield attributes of dwarf rice bean as influenced by integrated nitrogen management

Treatments	Dry weight of nodules per plant (g)			Yield attributes			
	60 DAS	90 DAS	At harvest	Pods/plant	Seeds/pod	Seeds/plant	100 seed weight (g)
T_1	0.36 (0.93)	1.68	0.09 (0.77)	58.90	6.77	398.56	19.60
T_2	0.68 (1.08)*	1.90*	0.39 (0.94)	64.10	7.30	468.48	20.24*
T_3	0.40 (0.95)	1.73	0.18 (0.83)	60.89	6.97	424.20	19.87
T_4	0.73 (1.11)*	2.00*	0.44 (0.97)*	66.90*	7.57*	506.21*	20.43*
T_5	0.59 (1.04)*	1.80	0.25 (0.87)	62.80	7.17	449.79	20.02*
T_6	0.80 (1.14)	2.10	0.52 (1.01)	68.27	7.78	531.17	20.64
T_7	0.08 (0.76)	1.28	0.05 (0.74)	51.00	6.00	306.03	18.90
T_8	0.25 (0.86)	1.51	0.08 (0.76)	57.53	6.57	377.57	19.50
CD (p=0.05)	0.10	0.26	0.06	4.12	0.41	43.32	0.70

*On par with highest treatment

Table 3. Yield, quality parameters and post-harvest nutrient status of dwarf rice bean as influenced by integrated nitrogen management

Treatments	Yield (q/ha)			Quality parameters		Post-harvest nutrient status (Kg/ha)		
	Grain yield	Stover yield	Harvest Index	Crude protein content (%)	Crude protein yield (kg/ha)	N	P_2O_5	K_2O
T_1	16.27	33.93	32.41	19.53	317.77	279.52	28.77*	266.20
T_2	18.5	36.60*	33.57	21.00	388.51	309.42	33.90*	277.98*
T_3	17.37	34.63	33.40	20.07	348.48	292.69	29.73*	267.50
T_4	19.43*	37.77*	33.98	21.50*	417.74*	317.60	34.53*	278.80*
T_5	18.00	35.33	33.83	20.50	368.94	326.14*	30.90*	268.13
T_6	20.10	38.27	34.45	22.03	443.22	342.87	35.83	279.52
T_7	12.27	29.87	29.23	17.57	215.48	240.75	27.37	267.37
T_8	14.5	32.57	30.80	19.07	276.26	253.24	32.64*	276.71*
CD (p=0.05)	1.05	2.80	2.47	0.66	26.01	22.56	0.96	3.86

*On par with highest treatment

Available Nitrogen which was found to be statistically at par with T_5 (Table 3). The lowest Available Nitrogen (kg/ha) was recorded in T_7. Similarly, the highest Available Phosphorus was recorded in T_6 and it was followed by T_4, T_2, T_8, T_5, T_3, T_1 and the lowest Available Phosphorus was recorded in T_7. Likewise, highest Available Potassium was recorded in T_6 and it was at par with T_4, T_2 and T_8 and the lowest Available potassium was recorded in T_7. Vermicompost contains appreciable amount of nutrients with in deal pH range, which may have contributed to their elevated status in the soil following harvest. Additionally, formation of organic acids by vermicompost had a beneficial influence on the characteristics of the soil and the mineralization of phosphorus, potassium, and nitrogen through leaf fall and rhizodeposition, legume crops contribute a significant quantity of organic residues to the soil. The intermediate acids created during the decomposition of organic residues also solubilize fixed forms of phosphorus and nitrogen, increasing the amounts of these nutrients. The findings of Meena et al (2015), Kanwar et al (2017) and Jat et al (2008) confirm these conclusions.

CONCLUSION

The application of 30 Kg N/ha (Urea)+ VC @5 t/ha + Neem @ 75 Kg/ha performed better in all parameters like nodulation, yield and yield attributes, quality and post-harvest nutrient status after harvest when compared to other treatments, but 20 kg N/ha (Urea) + VC @ 5 t/ha + Neem @ 75 kg/ha was statistically on par. Application of 20 kg N/ha (Urea) + VC @ 5 t/ha + Neem @ 75 kg/ha is recommended for farmers because of its potential to achieve equivalent benefits compared to highest treatment in addition to this, can reduce quantity of inputs applied which in turn decreases cost of production.

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Received 22 February, 2024; Accepted 10 June, 2024

Indian Journal of Ecology (2024) 51(4): 792-795
DOI: https://doi.org/10.55362/IJE/2024/4311

Manuscript Number: 4311
NAAS Rating: 5.38

Influence of Crop Diversification in Potato-Based Cropping Sequence on Growth, Productivity and Economics of Potato in Red and Lateritic Soil of West Bengal

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Abstract: Field experiment was conducted at Agricultural farm of the Institute during 2020-21 and 2021-22 to study growth, yield attributes, yield and economics of potato as influenced by potato-based cropping sequences. The experiment, consisted of seven treatments (viz. Potato–sesame; Potato–green gram; Potato–baby corn; Potato–okra; Potato–groundnut; Potato–blackgram and Potato–vegetable cowpea. Potato in potato– groundnut sequence exhibited highest growth, yield attributes (number of tubers hill^{-1} and fresh weight of tubers hill^{-1}) with tuber and haulm yield of 23.95 and 1.30 t ha^{-1}, respectively. Highest gross return, net return and return per rupee investment in potato was also achieved from potato–groundnut sequence (₹ 264 × 10^3 ha^{-1}, ₹ 174 × 10^3 ha^{-1} and 2.91, respectively). These were at par with potato in potato––vegetable cowpea, potato–blackgram and potato–green gram sequences and significantly higher than potato in potato-sesame, potato–baby corn and potato–okra cropping sequences. Inclusion of legume crops in potato–based cropping sequences enhanced tuber and haulm yield of potato resulting in higher return from the sequence.

Keywords: Cropping sequence, Economics, Growth, Potato and yield

The rice-wheat cropping system (RWCS) has been practiced by farmers in Asia and this cropping system is one of the world's largest agricultural production systems, covering an area of 26 million hectares spread over Indo-Gangetic Plains (IGP) in South Asia and China (Singh et al 2019) and is the most important cropping system of India adopted on about 10.5 M ha (Sarkar 2015) and has played a significant role in food security of the country. However, in recent years sustainability of RWCS is adversely affected as yields of both rice and wheat are either stagnant or decreasing due to deterioration of soil health; resurgence of diseases, insects, and weeds; environmental pollution/ degradation; decrement in factor productivity or input-use efficiency; increase in cultivation costs and reduction in profit margins (Gautam and Sharma 2004, Gangwar and Prasad 2005, Reddy and Suresh 2009, Chauhan et al 2013). Traditionally, prior to the Green Revolution, agriculture was more diversified and sustainable (Paroda 2019). Scientific advancements and options for improved varieties and new crops led to a shift towards a few crops having potential to yield more and provide a higher income. Such an approach eventually narrowed down dependence to just a few crops like wheat, rice, maize, sugarcane, *etc*. In Green Revolution era (1967-68 to 1977-78), the major focus was on cereals (mainly rice and wheat). Over the years since then, fortunately, food basket has started to diversify again, although more progress still needs to happen.

Crop diversification largely depends on technological innovations aimed at sustainable intensification and increased productivity while reducing the cost of inputs so as to raise the income of farmers. The dynamic aspect of diversification includes the accommodation of new crops or cropping systems that are best suited to prevailing eco-regional conditions while ensuring higher production and income. By growing a variety of crops, farmers lower their risk and can gain access to national and international markets. Agricultural intensification has helped us achieve food security in the past, but now we need to reorient existing cropping systems to be more sustainable and to continue addressing our household food, nutrition, and environmental security. Legume-inclusive production systems can play important roles by delivering multiple services at production-system level, due to the capacity to fix atmospheric nitrogen making them potentially highly suitable for inclusion in low-input cropping systems, and at cropping system levels, as diversification of crops in agroecosystems based on few major species, breaking the cycles of pests and diseases. In India, over the years, the new cropping systems have become predominant in view of their higher productivity as well as income for farmers. Examples are rice-wheat cropping system in the north, groundnut in Gujarat, sugarcane in the north, chickpea in southern states, arhar in the north-western states, soybean in Madhya Pradesh and adjoining states, and winter maize in Bihar. Unfortunately, most of these systems require diversification for greater sustainability and conservation of natural resources. There is need to bring reforms in the existing cropping systems that are more scientifically based and more suited to varying agro-climatic conditions. Diversification of cropping systems is necessary to get higher yield and return, to maintain soil health, preserve environment and meet daily requirement of human and animals (Saha et al 2020). Thus, not only the number of crops but the type of crops included in the cropping sequence are also important and dependence on cereal crops need to be shifted to other food crops like potato, vegetables, root crops, pulse and oil seeds (Samui et al 2004). Hence, an attempt was made to identify suitable cropping sequence for red and lateritic soil of West Bengal with a view to utilize resources judiciously for optimal production levels at reduced costs and with minimum impact on the environment.

MATERIAL AND METHODS

The field experiment was conducted during *rabi* and summer seasons of 2020-21 and 2021-22 at Agricultural farm (23˚ 39' N latitude, 87˚ 42' E longitude at an elevation of 58.9 m above mean sea level), Institute of Agriculture, Visva-Bharati, Sriniketan, West Bengal. The soil of the experimental site was sandy loam in texture, acidic in nature (pH 5.12), low in organic carbon (0.42%), available nitrogen (140.31 kg N ha^{-1}) and phosphorus (20.14 kg P_2O_5 ha^{-1}) and medium in available potassium (192.67 kg K_2O ha^{-1}) content. The experiment, comprising of seven cropping systems was laid out in randomized block design with three replication (Table 1). The recommended dose of fertilizers (200:150:150 kg of N: P_2O_5:K_2O kg ha^{-1}) was applied in potato where half quantity of total nitrogen, entire P_2O_5 and K_2O was applied as basal. Top dressing of the remaining nitrogen was done at the time of earthing up at 30 DAP (days after planting). Potato (variety Kufri jyoti) was planted on flat beds with a spacing of 50 cm × 25 cm on November 30, during both the years of 2020-21 and 2021-22, and harvested on March 02, during both years, Summer crops viz, sesame (var. Roma), green gram (var. Samrat), baby corn (hybrid hm-4), okra (Hybrid F-1), groundnut (TAG-24), blackgram (Kalindi) and vegetable cowpea (Pusa sukomal) were sown on March 09 and harvested during last week of June and first week of July during 2021 and 2022, respectively. The summer crops were raised as per recommended package of practices for each crop. The biometric observations for different growth parameters and yield attributes of potato were recorded at regular interval. The dry matter accumulation of plant samples was recorded by drying the plant samples in hot air oven at 65˚ C for 48 hours, till constant weights were obtained. The crop growth rate was calculated as increase in dry matter per unit of land area per unit of time and expressed as (g m^{-2} day^{-1}).

$$CGR = (W_2 - W_1) / (t_2 - t_1)$$

Where W_2 and W_1 are the final and initial dry weights at times t_2 and t_1, respectively.

Weight of fresh tubers was taken from randomly selected plants in each plot and the tuber bulking rate (TBR) between 30 to 45, 45 to 60 and 60 to 75 DAP was estimated and expressed as (g m^{-2} day^{-1}).

$$TBR = (W_2 - W_1) / (t_2 - t_1)$$

Where W_2 and W_1 are the final and initial fresh weights of tubers per unit area at times t_2 and t_1, respectively.

The tuber growth rate (TGR) was calculated by taking dry weights of potato tubers at 30 to 45, 45 to 60 and 60 to 75 DAP and expressed as (g m^{-2} day^{-1}) .

$$TGR = (TW_2 - TW_1) / (t_2 - t_1)$$

Where TW_2 and TW_1 are the final and initial dry weights of tubers per unit area at times t_2 and t_1, respectively.

Table 1. Growth attributes of potato as influenced by crop diversification in potato-based cropping sequences (Pool data for 2 years)

Treatment	Plant height (cm) at harvest	LAI at 60 DAP	Dry matter accumulation (g m^{-2}) at harvest	CGR (g m^{-2} day^{-1}) at 60-75 DAP	TBR (g m^{-2} day^{-1}) at 60-75 DAP	TGR (g m^{-2} day^{-1}) at 60-75 DAP
T_1 - Potato–sesame	83.0	4.57	592.3	10.66	83.53	12.09
T_2 - Potato–green gram	87.4	4.86	652.0	12.08	85.26	13.61
T_3 - Potato–baby corn	82.8	4.56	543.8	9.33	81.71	12.06
T_4 - Potato–okra	82.7	4.48	533.4	9.62	79.07	11.38
T_5 - Potato–groundnut	89.7	5.07	686.8	12.68	88.42	14.93
T_6 - Potato–blackgram	87.4	4.94	665.3	12.24	86.33	13.79
T_7 - Potato–vegetable cowpea	88.0	4.94	654.6	11.78	87.42	15.39
CD (p=0.05)	NS	NS	NS	NS	NS	0.96

RESULTS AND DISCUSSION

Growth attributes of potato: The growth attributes of potato *viz*. plant height, leaf area index, dry matter accumulation, CGR, TBR and TGR at different growth stages were significantly influenced by crop diversification in various potato–based cropping sequences on pooled data basis (Table 1). The highest plant height (89.7 cm at harvest), LAI (5.07 at 60 DAP), dry matter accumulation (686.8 g m^{-2}) and CGR (12.68 g m^{-2} day^{-1} at 60-75 DAP) of potato was observed in potato–groundnut sequence which was at par with potato in potato–vegetable cowpea, potato–blackgram and potato–green gram sequences, but significantly higher when compared to other sequences, *viz*. potato–sesame, potato–baby corn and potato–okra. Higher growth attributes in potato-legume sequences over potato-non legume ones might be attributed to the fact that N fixation occurred in legumes which might have led to higher carryover effect on soil fertility parameters resulted in higher availability and uptake of nutrients by potato crop.

Highest TGR (15.39 g m^{-2} day^{-1}) of potato was observed at 60-75 DAP in potato–vegetable cowpea sequence which was statistically at par with potato–groundnut, potato–blackgram and potato–green gram sequences but significantly higher than potato-non legume cropping sequences during all the growth stages which might be due to higher accumulation of photosynthates into the tubers thus increasing the fresh weight and dry weight of tubers. However, TBR was not influenced significantly by various potato-based cropping sequences The higher growth attributes of potato in potato-legume sequences might be attributed to the 'nitrogen effect' of the associated legume crop through N provision from BNF (Peoples et al 2009). Angus et al (2015) also reported similar results in wheat when it was grown in wheat-legume sequences. Similar results in terms of higher growth attributes in rice was reported by Saha et al (2020).

Yield components and yield of potato: The significant response was found from crop diversification in potato–based cropping sequences on yield components (Table 2) of potato (i.e., number of tubers $hill^{-1}$ and fresh weight of tubers $hill^{-1}$). at harvest. Among different potato–based cropping sequences, highest number of tubers per hill and fresh weight of tubers per hill was in potato–groundnut sequence (6.88 and 312.1 g, respectively) because of the nitrogen effect of the legume crop which resulted in higher number of tubers in potato crop. The significant response was recorded in tuber yield of potato due to inclusion of various crops in potato–based cropping sequences whereas the haulm yield showed no significant response. Tuber yield of potato was significantly higher in potato-groundnut sequence (23.95 t ha^{-1}) due to higher growth parameters and yield components which finally led to higher tuber yield. This was followed by potato–vegetable cowpea (23.67 t ha^{-1}), potato–blackgram (23.64 t ha^{-1}) and potato–green gram (23.51 t ha^{-1}). However, these treatments were at par with each other (Table 2). In terms of tuber yield of potato, potato–sesame, potato–baby corn and potato–okra sequences, were significantly lower when compared to potato–legume-based sequences. Inclusion of legume crops in the sequences might have enhanced the yield components of potato resulting in higher yield when compared with non–legume crops in the sequence. The crop yield after legumes is often enhanced due to combined and interrelated effects of nitrogen provision and non-nitrogen effects (suppressed pest and disease infestation, improved soil properties (Robson et al 2002, Peoples et al 2009 , Ditzler et al 2021) and phosphorus mobilization (Shen et al 2011). Similar results of higher yield associated with the inclusion of

Table 2. Yield components, yield and economics of potato as influenced by crop diversification in potato-based cropping sequences (Pool data for 2 years)

Treatment	Number of tubers $hill^{-1}$	Fresh weight (g) of tubers/hill at harvest	Tuber yield (t ha^{-1})	Haulm yield (t ha^{-1})	Gross return (× 10^3 ₹ ha^{-1})	Net return (× 10^3 ₹ ha^{-1})	Return per rupee investment (₹)
T_1	6.17	281.5	22.43	1.20	247	157	2.72
T_2	6.55	291.0	23.51	1.25	259	169	2.85
T_3	6.17	280.4	22.40	1.19	247	156	2.72
T_4	6.16	277.6	22.40	1.19	247	156	2.72
T_5	6.88	297.5	23.95	1.30	264	174	2.91
T_6	6.65	292.8	23.64	1.27	260	170	2.87
T_7	6.65	295.4	23.67	1.29	261	171	2.88
CD (p=0.05)	NS	6.50	0.75	NS	7.74	7.74	0.09

NS - Non-Significant, See Table 1 for treatment details legume crops have been reported by Angus et al (2015) and Mukherjee (2016).

Economics: The gross return, net return and return per rupee invested in potato were significantly influenced by various potato-based cropping sequences. The highest gross return (₹ 264 × 10^3 ha^{-1}), net return (₹ 174 × 10^3 ha^{-1}) and return per rupee investment (₹ 2.91) in potato was under potato-groundnut sequence which was statistically at par with potato–vegetable cowpea, potato–blackgram and potato–green gram sequences. However, these were significantly higher than potato in potato–sesame, potato–baby corn and potato–okra sequences. This could be primarily due to higher yield of potato which was associated with nitrogen effect of legumes under these sequences. Saha et al. (2020) also reported similar results in rice when inclusion of legume crops in rice–based cropping systems exerted positive influence in increasing the yield of rice resulting in higher gross return, net return and return per rupee investment. Diversification with high-value crops encouraged the export of farm produce, bringing more profits as mentioned by Singh et al (2019).

CONCLUSION

Potato in potato–groundnut cropping sequence produced higher tuber yield, gross return, net return and return per rupee investment which was statistically at par with potato in potato–vegetable cowpea, potato–blackgram and potato–green gram sequences. Potato–legume-based cropping sequences exhibited significantly higher tuber yield and economic returns over potato–sesame, potato–baby corn and potato–okra sequences.

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Received 16 February, 2024; Accepted 20 June, 2024

Indian Journal of Ecology (2024) 51(4): 796-799
DOI: https://doi.org/10.55362/IJE/2024/4312

Manuscript Number: 4312
NAAS Rating: 5.38

Exploring Synergistic Effects of Cowdung and Vermicompost on Radish (*Raphanus sativus* L.) Morphology and Yield

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Abstract: The integration of organic amendments in crop cultivation is gaining attention for its potential to improve soil health and boost radish yield in Bangladesh. The experiment was conducted at Noakhali Science & Technology University to evaluate the impact of organic manures on the growth and yield of radish. Using a randomized complete block design, the experiment included four treatments: T_0 (no organic manure), T_1 (cowdung at 30 tha^{-1}), T_2 (vermicompost at 30 tha^{-1}), and T_3 (combination of cowdung and vermicompost at 15 tha^{-1} each). Both cowdung and vermicompost significantly enhance radish cultivation compared to the control condition. Growth parameters, including plant height, leaf length, leaf breadth, and leaf number, showed the highest values in treatment T_3. Yield-contributing parameters, such as root length, root diameter, root weight, and gross yield were also highest in treatment T_3 with a gross yield of 17.73 t/ha. Conversely, the lowest values for both growth and yield parameters, including a gross yield of 6.11 t ha^{-1}, were observed in the control treatment (T_0). The findings indicate that the application of both cowdung and vermicompost significantly enhances radish growth and yield, with the combined treatment (T_3) showing superior performance compared to other treatments.

Keywords: Cowdung, Vermicompost, Radish, Growth, Yield

Radish (*Raphanus sativus* L.) is a herbaceous annual root crop from the Brassicaceae family, originated in Central or Western China, as well as the Indo-Pak subcontinent (Kaur et al 2023). It is planted mostly as an annual vegetable and a biannual crop, depending on its use and is a cool-weather vegetable crop in particular. Asian variants, on the other hand, tolerate higher temperatures than European kinds. Except for a few months in the summer, radishes can be cultivated in Bangladesh virtually all year (Sharma et al 2019). Radish have a variety of skin colours (yellow, red, black, purple, and sometimes pinkish white), but their flesh is usually white. The taste, size, and length of the edible radish root vary throughout the world. This plant's noteworthy characteristic is its short cycle time of roughly 30 days, which allows for significant benefits in working capital (Sa'id et al 2022). It contains calcium, potassium, phosphorus, and vitamin C. It is high in ascorbic acid and a range of minerals (Pathak et al 2017). Numerous antioxidants, including vanillic acid, pyrogallol, catechin, and other phenolic compounds, are found in radishes. While radish is typically grown on large farms in Bangladesh, urban farmers typically grow the crop on their roofs and homesteads (Ali et al 2023). In Bangladesh, radish is currently grown on 26228 hectares of land, yielding 286543 metric tonnes of radishes a year (BBS 2020).

Farmers usually apply nitrogenous, phosphatic, and other chemical fertilizers that increase plant yield significantly and supply plant nutrients (Pahalvi et al 2021). But, most of these chemical fertilizers are costly and degrade the quality of produce, which lowers net profit and returns to farmers. Additionally, consumers' expectations regarding the quality of produce and its availability throughout the year are rising (Kushwah et al 2020). One substitute for conventional methods of giving plants nutrients is the application of organic fertilizers. The status of soil fertility can be ascertained by evaluating the properties of the soil after the addition of organic matter (Islam et al 2023, Hashan et al 2023). In addition to its many other beneficial effects on the soil, organic compost has a slow-release effect on nutrients. Because organic fertilizers release nutrients into the plant gradually, using them is therefore cost-effective for farmers. To maintain soil fertility and productivity while increasing crop productivity, organic manures like cow dung, and vermicompost have become more popular in recent years (Pokharel et al 2023).

The past several years has seen a sharp increase in the usage of sustainable farming methods due to growing consumer concerns about issues like soil conservation, food safety, and quality. The fundamental principle of sustainable agriculture defined as a set of methods that protect the environment and resources without sacrificing human needs is the use of organic manures (Kumar et al 2018). In consideration of the aforementioned data, a field investigation was conducted to determine the effect of different organic manures and evaluate the potential of organic manures to improve radish growth and yield that can be economically beneficial for farmers.

MATERIAL AND METHODS

The study was carried out at the agricultural research field of Noakhali Science and Technology University, which is situated in Noakhali-3814, Bangladesh (Latitude: 22.7916° N; Longitude: 91.1028° E) from February 2022 to May 2022(Table 1 , 2). The experiment was in randomized complete block design with four treatments and three replications, designated as T_0 (No organic manure), T_1 (Cow dung 30 tha^{-1}), T_2 (Vermicompost 30 tha^{-1}) and T_3 (Cow dung 15 tha^{-1} and Vermicompost 15 tha^{-1}), respectively. Radish seeds were sown on 14th February 2022, using the line sowing method with a plant spacing of 25 cm x 15 cm with appropriate agronomic practices. Harvesting of radishes began on 1st April 2022.

Observations were recorded for various growth and yield parameters, including plant height (cm), number of leaves per plant, leaf length (cm), leaf breadth (cm), root length (cm), root diameter (cm), fresh weight of root per plant (g), and gross yield (t ha^{-1}). The collected data for the study's parameters were analysed statistically using Statistix10. Analysis of variance for different parameters was conducted using the "F" test, and mean differences were determined following the approach suggested by Gomez and Gomez 1984.

RESULTS AND DISCUSSION

Growth parameters: The growth parameters of radishes such as plant height, leaf length, number of leaves per plant, and leaf breadth at various stages of growth (15, 30, and 45 days after sowing) varied significantly in treatments (Table 3). Application of combined cow dung and vermicompost exhibited significantly higher plant height at each growth stage, reaching 27.43 at 45 DAS than all other treatments. The highest leaf length (22.1 cm at 45DAS) was in T_3 whereas the shortest leaf length at the same stage (10 cm) was in T_0. The number of leaves per plant, displayed the highest count at all stages in T_3, reaching 13.4 at 45DAS, emphasizing the positive influence of cow dung and vermicompost. The leaf breadth was significantly influenced by organic manures, with T_3 resulting in the broadest leaves (8.9 cm) at 45DAS. Conversely, T_0 had the narrowest leaves at 45DAS (4.8 cm), emphasizing the impact of organic manure on leaf breadth (Table 3).

These findings collectively underscore the positive impact of the application of cow dung and vermicompost on various growth parameters, highlighting their role in enhancing the overall development and quality of radish plants. The comparison with the control underscores the significance of organic manures in mitigating growth limitations and fostering robust plant development. These findings agree with earlier researchers (Kiran et al 2016, Khatri et al 2019, Diya et al 2023).

Table 2. Characteristics of soil

Constitution	Value
A. Physical properties of the initial soil (0-15 cm depth)	
Sand (%)	20
Silt (%)	67
Clay (%)	13
Soil textural class	Silt Loam
Particle density (g/cc)	2.60
Bulk density (g/cc)	1.35
Porosity (%)	46.67
B. Chemical characteristics of soil	
pH	7.501
Organic matter (%)	0.109
Total nitrogen (%)	0.101
Available phosphorus (ppm)	12.000
Exchangeable potassium (me %)	0.014

Source: Soil Resource and Development Institute (SRDI), Noakhali

Table 1. Average monthly temperature, humidity, and rainfall on the experimental plot during radish growth (Feb-May 2022)

Month	Temperature°C			Relative humidity (%)	Total rainfall (mm)	Sunshine(hrs)
	Maximum	Minimum	Average			
February	28.0	18°C	23°C	58	12.3	9.3
March	32°C	22°C	27°C	55	8.1	9.1
April	34°C	25°C	29°C	65	73.4	8.5
May	34°C	26°C	30°C	73	178.5	8.0

Source: Weather Station, Maijdee, Noakhali

Table 3. Effect of cow dung and vermicompost on growth parameters of radish (DAS)

Treatment	Plant height			Leaf length			Leaf number			Leaf Breath		
	15 DAS	30 DAS	45 DAS	15 DAS	30 DAS	45 DAS	15 DAS	30 DAS	45 DAS	15 DAS	30 DAS	45 DAS
T_0	6.03c	10.23c	12.9d	5.3c	8.5b	10b	3.7b	5.3b	6.7b	2.1b	3.1b	4.8b
T_1	15.8b	19.7b	21.86c	14.7b	17.8a	19.4a	8.4a	10.4a	12.4a	4.3a	6.8a	7.9a
T_2	16.7b	21.3b	23.1b	15ab	18a	20.4a	8.1a	10.4a	13.2a	4.7a	6.9a	8.2a
T_3	18.16a	24.46a	27.43a	15.3a	19.8a	22.1a	9.5a	11.4a	13.4a	5.6a	7.4a	8.9a
Level of significant	**	**	**	**	**	**	**	**	**	**	**	**
CV%	3.53	4.78	1.93	5.81	4.78	5.39	10.45	7.06	5.48	12.37	9.2	7.8

** Indicates a significant level at 0.1%. $T_{0=}$ no organic manure, $T_{1=}$ cowdung at 30 tha^{-1}, T_2= vermicompost at 30 tha^{-1}, and $T_{3=}$ combination of cowdung and vermicompost at 15 tha^{-1}each; DAS= Days after sowing

Table 4. Effect of cow dung and vermicompost on yield and yield contributing parameters of radish

Treatment	Root length	Root diameter	Root weight	Gross yield (t/ha)
T0	9.26b	2.24b	67.91a	6.11c
T1	14.2ab	3.2ab	143.37a	12.9ab
T2	18.08a	3.88a	190.39a	17.13a
T3	20.57a	4.01a	196.98a	17.73a
Level of significant	**	**	*	**
CV%	16.7	13.07	29.62	13.1

* and ** indicate a significant level at 1 and 0.1%, respectively. $T_{0=}$no organic manure, $T_{1=}$cowdung at 30 tha^{-1}, T_2= vermicompost at 30 tha^{-1}, and $T_{3=}$combination of cowdung and vermicompost at 15 tha^{-1}each.

Yield contributing parameters: The impact of various organic manures on radish root characteristics was assessed, revealing significant effects on both root length and root diameter (Table 4). In terms of root length, application of cow dung and vermicompost at 15 t ha^1 exhibited the longest roots, measuring 20.57 cm. The control with no organic manure he shortest root length (9.26 cm). This result highlights the positive influence of different levels of organic fertilizer, specifically cow dung and vermicompost, in enhancing the root length of radish plants. Similarly, for root diameter, the application of different organic fertilizers significantly influenced the diameter of radish roots. Treatment T_3 demonstrated the highest root diameter (4.01 cm), followed by T_2 and T_1, while the lowest root diameter (2.24 cm) was observed in T_0 . These findings emphasize that the incorporation of organic manures, particularly cow dung and vermicompost, led to a substantial increase in the diameter of radish roots. Similar findings were reported by earlier researchers (Kiran et al 2016, Khatri et al 2019, Diya et al 2023).

Yield parameters: The application of different organic manures profoundly influenced yield-related parameters of radish, manifesting in notable effects on both the fresh weight of roots per plant and the gross yield per hectare (Table 4). In terms of fresh weight of roots per plant, treatment T_3, incorporating cow dung and vermicompost at 15 t ha^1, yielded the highest fresh weight at harvest (196.98 g), followed closely by T_2 (190.39 g). Conversely, treatment T_0 recorded the lowest fresh weight of roots per plant (64.91 g). These results underscore the positive impact of different organic manures, particularly Cow dung and Vermicompost, in enhancing the fresh weight of radish roots. Similarly, for gross yield per hectare, the influence of various treatments on radish yield was significant. Treatment T_3 again emerged as the top-performing, producing the highest gross yield of radish at 17.73 t^{ha1}, while treatment T_0, the control with no organic manure, exhibited the lowest gross yield at 6.11 t ha-1 . This outcome demonstrates that the application of different organic manures, specifically Cow dung and vermicompost, positively impacted the gross yield of radish, highlighting the efficacy of these organic inputs in enhancing overall productivity. These findings are also aligned with other researchers (Kiran et al 2016, Khatri et al 2019, Diya et al 2023).

CONCLUSIONS

The application of organic manures, such as cowdung and vermicompost, substantially improves radish cultivation in comparison to control conditions. The combination of cowdung and vermicompost has a more positive impact on all growth and yield parameters than their separate applications. Further extensive research across different locations is recommended to substantiate these findings and fully exploit the potential of these organic amendments in radish cultivation.

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Received 02 May, 2024; Accepted 15 July, 2024

Indian Journal of Ecology (2024) 51(4): 800-805
DOI: https://doi.org/10.55362/IJE/2024/4313

Manuscript Number: 4313
NAAS Rating: 5.38

Impact of Agronomic Practices on Soil Parameters in Broccoli under Agro-climatic Zone-II of Himachal Pradesh

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Abstract: Field experiment with thirteen treatments comprised of three dates of transplanting, two mulching and two irrigation levels was laid out in 2021-22. The use of black poly mulch in main, mid, and late season transplanting with irrigation and rainfed conditions had a significant impact on organic carbon content, DTPA extractable micronutrient cations, and available boron content of the soil in broccoli. The maximum organic carbon was recorded in mid-season transplanted broccoli with mulch in rainfed conditions. DTPA extractable Cu, Zn, Mn and available boron was maximum under late season transplanted broccoli with mulch in irrigated conditions. The DTPA extractable Fe was in main season transplanted broccoli with mulch in rainfed conditions. However, treatments without mulch in main, mid and late season transplanting with irrigation and rainfed conditions significantly affected the pH, EC, available N content in soil. Maximum pH was in control and also in late season transplanted broccoli without mulch in rainfed conditions. The maximum EC was also recorded in late season transplanted broccoli without mulch in rainfed conditions. The significant highest available N was recorded in main season transplanted broccoli without mulch in rainfed conditions. However, the effect of different transplanting, mulching and irrigation application on the available phosphorus and potassium content of soil remained non-significant. It is concluded that mulching improved soil parameters and provides suitable condition for broccoli in agro-climatic zone-II of Himachal Pradesh.

Keywords: Mulching, Transplanting, Broccoli, Irrigation, Soil parameters

The farmers are heavily reliant on rainfall and are unable to produce yields of higher quality when the soil is not provided with sufficient irrigation. The main obstacles to boosting agricultural productivity are the uneven distribution of rains with frequent dry spells in the winter, the occurrence of sub-optimal soil temperatures, and the poor retentivity of hill soils for water and nutrients. Low soil temperature, which has a more significant impact on seed germination, seedling emergence, and early plant growth than on later stages of growth, is one of the other important variables that have slowed the growth and productivity of winter-season crops in the mid-hills. To overcome these restrictions, proper soil and water management has required in-situ moisture conservation through the use of mulches. The practice of mulching has the potential to significantly boost crop growth, yield and net return by reducing soil warmth, increasing the availability of both applied and native nutrients, and satisfying the partial irrigation water demand. Mulch can be made from a variety of materials, including grass, wood, sand, plastic film, wheat straw, rice straw and rice husk (Uwah and Iwo 2011). Khurshid et al (2006) observed that mulching can greatly enhance the physico-chemical qualities of soil, optimise the use of water and nutrients, control weed development, promote infiltration and decrease water loss due to excessive evapotranspiration. Sinkeviciene et al (2009) noted that organic mulches have positive effects on soil characteristics, which enhance soil quality and production. Crop residue mulching improve water retention and soil organic carbon at the surface layer (Saroa and Lal 2003). Youssef et al (2021) revealed that organic mulch directly alters the soil's biological properties and fertility in addition to increasing yield, soil water content and minimum soil temperature. The availability and uptake of nutrients by plants were both increased by increased soil water storage as a result of mulching (Tan et al 2009). By increasing the agronomic value of soil physical qualities, straw mulch has also been proven to dramatically improve soil-water-crop connections.

Global interest in irrigation development and agricultural water management is rising as a result of worries about a lack of water owing to a changing and unpredictable environment. The lengthy droughts and irregular rainfall patterns that hinder the growth of crops have been brought on by global warming. Smallholder farmers have over time adapted a variety of traditional agricultural methods through the use of local knowledge and adaptations that are best suited to their local conditions, which are primarily characterised by the scarcity of water supplies. Under these water-strapped circumstances, there are a number of variables that can affect crop productivity. Mulching is one of the most suitable water conservation techniques (Khurshid et al 2006). Thus, for crop production in dry and semi-arid environments, a combination of suitable irrigation, mulching, and transplanting provides an effective soil and water conservation approach (Jia et al 2018).

Broccoli first originated in the Mediterranean and East-Asian regions. As per final estimate of 2022-23, the area under broccoli and cauliflower in Himachal Pradesh is 5.55 thousand hectare with production of 123.07 thousand metric tonnes. In India, area under this cole crop is 491.49 thousand hectare with production of 9548.01 thousand metric tonnes (Anonymous 2024). Temperatures between 17°C and 23°C are ideal for broccoli growth on a regular basis. Broccoli is the most productive type for boosting farmer income in high-altitude and tribal locations (Sivakumar et al 2022). This study was conducted by adjusting transplanting dates, mulching, and irrigation application in the mid-hill zone agro-climatic zone-II of Himachal Pradesh in order to produce broccoli commercially, which is an emerging challenge in the changing environmental conditions that make it difficult for farmers to cultivate broccoli appropriately.

Table 1. Treatment details

Sr. No.	Treatments
T_1	Control
T_2	Main season transplanting + Mulch + Irrigation
T_3	Main season transplanting + Mulch + Rainfed
T_4	Mid-season transplanting + Mulch + Irrigation
T_5	Mid-season transplanting + Mulch + Rainfed
T_6	Late season transplanting + Mulch + Irrigation
T_7	Late season transplanting + Mulch + Rainfed
T_8	Main season transplanting + No Mulch + Irrigation
T_9	Main season transplanting + No Mulch + Rainfed
T_{10}	Mid-season transplanting + No Mulch + Irrigation
T_{11}	Mid-season transplanting + No Mulch + Rainfed
T_{12}	Late season transplanting + No Mulch + Irrigation
T_{13}	Late season transplanting + No Mulch + Rainfed

MATERIAL AND METHODS

The present field experiment on broccoli crop was conducted at Experimental Farm of Department of Environmental Science, College of Forestry, Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India during the winter season of 2021-22. The climate of the area is sub-tropical to sub-temperate and sub-humid characterized by cold winters and experiences distinguished major seasons in the year. The area is situated at 30.86°N latitude and 77.17°E longitude an altitude of 1275m above the mean sea level. The annual normal of maximum and minimum temperature, relative humidity, and rainfall of the area is 25.3°C, 11.4°C, 61 per cent, and 111.9 cm, respectively.

Experimental methodology: The soils of the experimental field were deep brown in color with a loam texture. The Broccoli (*Brassica oleracea* var italica) crop was sown in the main season, mid-season, and late season in the nursery on 12th September 2021, 02nd October 2021, and 23rd October 2021, respectively. Farm Yard Manure was applied 10 days before transplanting at the rate of 10 kg per bed. FYM was applied as per the package of practices for vegetable crops, Directorate of Extension Education, Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh. The treatment details are given in Table 1. About 500 grams soil sample is taken for laboratory analysis purposes from the experimental area and various soil parameters were analyzed by following standard procedures (Table 2 and 3).

Table 2. Analytical methods followed in soil analysis

Soil characteristics	Method of estimation	Reference
pH	pH (1: 2.5 soil: water)	Jackson (1973)
Electrical conductivity	EC bridge (1: 2.5 soil: water)	Jackson (1973)
Organic carbon	Wet combustion method	Walkley and Black (1934)
Bulk density	Core sampler method	Blake and Hairtge (1986)
Particle density	Pycnometer method	Blake and Hairtge (1986)
Porosity	One minus ratio of bulk density to particle density and multiplied by 100	Blake and Hairtge (1986)
Water holding capacity	International pipette method	Piper (1966)
Available nitrogen	Alkali permanganate method	Subbiah and Asija (1956)
Available phosphorus	Olsen's method	Olsen et al (1954)
Available potassium	Ammonium acetate method	Hanway and Heidel (1952)
DTPA extractable Fe, Mn, Zn, Cu	Atomic absorption spectrophotometer method using DTPA as extractant	Lindsay and Norvell (1978)
Available boron	Hot water soluble	Berger and Troug (1939)

RESULTS AND DISCUSSION

Soil physical parameters: Soil physical parameters were significantly affected by black poly mulch, irrigation and transplanting in broccoli with significantly higher bulk density (1.31 Mg/m^3) in T_{10}, T_{11} and T_{13} (Table 4). The highest particle density (2.63 Mg/m^3) was in T_9 and the lowest particle density (2.43 Mg/m^3) in T_6. The porosity was significantly higher (53.06 %) in T_2. The lowest porosity of 47.91 % was in T_9. Among the water-holding capacity of the soil, the maximum WHC (76%) was in T_6 while the minimum water-holding capacity (58%) in soil in T_{12} and T_{13}, respectively. Black poly mulch significantly affected the physical properties of soil, as it increased the porosity and water-holding capacity of soil and decreased bulk and particle density. The decrease in bulk and particle density might be due to soil loosening brought on by the decomposition of mulches and producing topsoil. However, there is an increment in porosity and water-holding capacity. This might be due to the increased porosity and decreased compaction (due to decreased soil bulk density) in mulched plots that may enhanced aeration and microbial activities in the soil and increased root penetration. Mulching can prevent erosion, inhibit weed growth, and contribute organic matter to the soil (Bot and Benites 2005). Numerous types of organic mulches are frequently used in landscaping to suppress weeds and improve plant health (Tiquia 2002).

Soil Chemical Parameters

pH, electrical conductivity and organic carbon: The significantly higher pH (7.60) was in control and T_{13} followed by T_5 (7.50). The lowest pH (6.80) was in T_3. The electrical conductivity was significantly higher value of 0.82 μs/cm was under T_{13} followed by 0.80 μs/cm in T_{12}. The minimum EC (0.55 μs/cm) was in T_8. Among the organic carbon content of the soil, the maximum organic carbon (2.83%) was in T_7 followed by 2.57% in T_{11}. The lowest organic carbon content of 1.69% in soil was under T_9 and T_1 (Table 5). Among soil chemical parameters, the addition of organic matter during mulch breakdown, which releases organic acids and dissolves them from their soluble state, maybe the cause of the lowered soil pH in mulched treatments. Karp et al (2006) also reported the lowest values of soil pH in mulch treatments. The electrical conductivity of soil was also reduced in treatments with mulch and the reason for the decrease in soil EC may be due to mulches, which decrease soil water evaporation and, in turn, cause less salt to build up in the soil. It may also be because salts that are water-soluble are absorbed by the mulch layer, which lowers the EC of water when it reaches the soil layer. Mulching reduces salt build-up and evapotranspiration (Zhang et al 2008). The lower soil EC could be the result of less salt building up in the topsoil layer. The higher value of organic carbon in treatments with mulch is due to mulching with crop residues increasing nutrient availability and regulating soil temperature The maximum organic carbon recorded in treatment T_7 also encourages beneficial soil microbial activities, worms, soil organic matter, and carbon storage. It also inhibits weed growth and improves product quality, which in turn increases crop health and yield (Lal 2004). It might also be because organic mulches, as they decompose, add carbonaceous material to the soil. Because it might directly affect soil bulk density, the increased soil organic carbon is particularly crucial for crop development.

Table 3. Soil properties before sowing

Soil parameters	Initial values
Soil pH	7.51
Electrical conductivity (μs/cm)	0.70
Organic carbon (%)	1.76
Bulk density (Mg/m^3)	1.32
Particle density (Mg/m^3)	2.62
Porosity (%)	49.65
Water holding capacity (%)	51
Available nitrogen (kg/ha)	348.95
Available phosphorus (kg/ha)	42.14
Available potassium (kg/ha)	232.18
DTPA extractable Cu (mg/kg)	1.57
DTPA extractable Zn (mg/kg)	4.95
DTPA extractable Mn (mg/kg)	15.40
DTPA extractable Fe (mg/kg)	38.02
Available boron (mg/kg)	0.78

Available primary macronutrients: The significantly higher soil available nitrogen (361.50 kg/ha) was in T_9 followed by T_{10} and lowest in T_3 (Table 5). Among available phosphorus and available potassium content in the soil, the effect of different treatments was non-significant. The available phosphorus varied from 40.86 to 42.97 kg/ha and available potassium varied from 230.29 to 234.31 kg/ha. The findings presented here are closely consistent with Scharenbroch and Lloyd (2004). The higher soil available nitrogen was recorded in non-mulched treatments and the lowest soil available nitrogen was noted under treatment with mulch. The temporary reduction of soil N availability could result from mulch application. Similar results were also recorded by Rhoades (2012). The effect of black poly mulch, irrigation and transplanting dates on available phosphorus and potassium was remained non-significant. Taufiq et al (2017) also reported that the effects of mulching on some of the soil parameters including available potassium were insignificant.

DTPA extractable micronutrients: The DTPA extractable micronutrient content in soil varied significantly by the different treatments with maximum DTPA Cu, Zn and Mn (2.18, 9.25 and 20.56 mg/kg, respectively) under T_6. The lowest values of DTPA Cu and Zn (1.75 and 5.18 mg/kg) in T_1. However, the minimum value of DTPA Mn (16.28 mg/kg) was in T_{12}. DTPA extractable Fe, the was maximum (44.12 mg/kg) in T_3 and the minimum (38.46 mg/kg) T_1 (Table 5). The increase in micronutrient content in treatments with mulch is due to the increase in the availability of nutrients in the soil may be related to effective weed management, increased organic carbon contents, and better soil moisture and temperature. The DTPA extractable Cu, Zn and Mn percent increase was maximum under T_6 (38.85, 86.87 and 33.51%). The highest percent increase of 16.04 % DTPA in extractable Fe under T_3. Prasad and Chakravorty (2017) also observed

Table 4. Impact of black poly mulch, irrigation, and transplanting dates on soil physical parameters on broccoli

Treatments	Bulk density (Mg/m^3)	Particle density (Mg/m^3)	Porosity (%)	Water holding capacity (%)
T_1	1.29	2.62	49.43	59
T_2	1.28	2.49	53.06	71
T_3	1.26	2.52	50.00	69
T_4	1.28	2.57	49.61	67
T_5	1.28	2.61	48.47	63
T_6	1.26	2.43	51.64	76
T_7	1.26	2.48	50.40	73
T_8	1.28	2.61	48.47	69
T_9	1.27	2.63	47.91	65
T_{10}	1.31	2.47	53.06	62
T_{11}	1.31	2.57	50.78	59
T_{12}	1.30	2.60	50.38	58
T_{13}	1.31	2.62	50.19	58
Mean	1.28	2.56	50.17	65.31
CD (p=0.05)	0.02	0.05	1.14	2.04

Table 5. Impact of black poly mulch, irrigation, and transplanting dates on soil chemical parameters in broccoli

Treatments	pH	EC (μs/cm)	Organic carbon (%)	Available			DTPA Extractable				Available B (mg/kg)
				N (kg/ha)	P (kg/kg)	K (kg/ha)	Cu (mg/kg)	Zn (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	
T_1	7.60	0.71	1.69	342.16	41.93	230.29	1.75	5.18	17.22	38.46	0.20
T_2	7.00	0.60	2.08	334.24	40.95	232.32	2.04	8.17	20.25	41.05	0.59
T_3	6.80	0.63	2.31	329.41	41.98	231.34	2.05	8.43	18.29	44.12	0.60
T_4	7.30	0.62	1.71	349.87	42.92	232.31	1.80	6.06	16.98	41.49	0.56
T_5	7.50	0.71	1.84	336.75	42.97	233.36	1.87	5.93	16.35	41.89	0.51
T_6	6.90	0.62	2.62	356.19	41.91	234.31	2.18	9.25	20.56	41.61	0.61
T_7	7.00	0.69	2.83	352.48	40.89	231.33	2.15	8.86	19.14	42.08	0.61
T_8	7.20	0.55	1.69	358.89	42.81	232.37	1.84	6.57	17.56	39.85	0.50
T_9	7.30	0.79	1.82	361.50	40.86	231.32	1.80	5.47	16.75	40.60	0.52
T_{10}	7.10	0.69	2.34	360.58	42.84	233.35	1.94	7.28	18.77	42.37	0.55
T_{11}	7.20	0.69	2.57	358.26	41.90	231.38	2.07	8.67	18.37	39.87	0.55
T_{12}	7.40	0.80	1.98	355.78	42.93	233.36	1.91	6.32	16.28	39.34	0.52
T_{13}	7.60	0.82	1.82	340.31	42.93	231.40	1.84	5.70	16.97	39.31	0.51
Mean	7.22	0.69	2.10	348.96	42.14	232.19	1.94	7.07	17.96	40.93	0.53
CD (p=0.05)	0.36	0.03	0.10	17.43	NS	NS	0.10	0.36	0.90	2.03	0.03

that the beneficial interaction between mulches and micronutrients improved soil moisture conservation, which is followed by improved uptake and assimilation of applied nutrients. Sinkeviciene et al (2009) concluded that mulches have a good impact on boosting the number of soil nutrients that are available to plants.

Available boron: The maximum available boron content in soil was under T_6 and T_7 (0.61 mg/kg) followed by T_3 (0.60 mg/kg). whereas, the minimum available boron content (0.20 mg/kg) was in T_1 (Table 5). Mulching led to an increase in available boron content. The available boron content of mulched treatments is comparatively higher than unmulched treatments and control. Similar results were also recorded by Manorama et al (2021) in mulching on oil palm (*Elaeis guineensis* Jacq.).

CONCLUSIONS

Mulches were superior to without mulched treatments in terms of the organic carbon content of the soil. The loosening of soil caused by mulching, which produces topsoil, maybe the cause of the decrease in bulk density and particle density. Bulk density may have increased under the unmulched treatment as a result of surface soil compaction, which had a negative impact on crop development. In dry, semi-arid, subhumid, and temperate regions, intensifying mulching practices leads to an improvement in the physical environment of the soil and enhance plant growth indices. The study concluded that mulches are the most effective way to provide the ideal soil environment for broccoli growth in Himachal Pradesh's mid-hills. Therefore, farmers will employ this method to save moisture, prevent weeds, greatly improve soil health, and increase crop yield. Additionally, this will significantly contribute to attaining sustainable global food security.

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Received 12 February, 2024; Accepted 10 June, 2024

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Indian Journal of Ecology (2024) 51(4): 806-812
DOI: https://doi.org/10.55362/IJE/2024/4314

Manuscript Number: 4314
NAAS Rating: 5.38

Microbial Consortia: Sustainable Alternative to Maize Residue Burning and Way to Enhance Nitrogen in Calcareous Soil

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Abstract: Crop residue burning is a major environmental problem that causes air pollution and greenhouse gas emissions. This study aimed to evaluate the effect of microbial consortia and nutrient boosters (urea and jaggery) on maize residue decomposition and nitrogen mineralization in calcareous soil. Thirteen treatments with different combinations of microbial consortia, urea, jaggery and residue application methods (surface or incorporation) were compared with a control (soil only) in a laboratory incubation experiment. The microbial consortia and nutrient boosters significantly increased the available nitrogen content in soil compared to the control and treatments with only residue. The highest increase (21.9%) was in the treatment with incorporated residue, 1% consortia, 1% urea, and 2% jaggery. This treatment also achieved the highest rate of nitrogen mineralization. Incorporation of residue and amendments generally resulted in higher nitrogen availability than surface application. Meanwhile, microbial consortia degraded the high carbon and nitrogen (C:N) ratio maize residue and released mineral nitrogen to the soil. Furthermore, urea and jaggery provided nitrogen and carbon sources for the microbes, boosting nitrogen availability. Therefore, these findings suggest that microbial consortia, urea, and jaggery are effective amendments for enhancing nitrogen availability from maize residue in soil, and can provide a sustainable alternative to residue burning by accelerating decomposition and nutrient mineralization.

Keywords: Microbial consortia, Nutrient boosters, Maize residue, Nitrogen mineralization, Calcareous soil

Maize is India's third most important cereal crop after rice and wheat. India ranks 4th in the world in terms of maize cultivation area and 7th in production, accounting for approximately 4% of global maize area and 2% of the total production (Kaur et al 2023). From 1950-51 to 2018-19, India's maize production has seen a significant increase from 1.73 million MT to 27.8 million MT, marking an almost 16-fold growth. The average yield has improved from 547 kg/ha to 2965 kg/ha, a more than 5-fold increase, while the cultivation area has expanded nearly threefold (AICRIP 2020). In India, maize is primarily cultivated in two seasons: rainy (*kharif*) and winter (*rabi*). Kharif maize accounts for approximately 83% of the maize area, with rabi maize covering the remaining 17%. A significant portion of the kharif maize area, exceeding 70%, is grown under rainfed conditions.

However, a challenge arises in the continuous cropping system. After harvesting *kharif* maize, farmers need to prepare the field for rabi maize. This necessitates the removal of leftovers after harvest for field preparation and prompt sowing of the next crop (Kumar et al 2023). The two main options for residue management are either burning or incorporating the residues into the soil (Bamboriya et al 2020). Burning poses environmental issues, producing global warming gases and causing severe pollution. India, the second largest agro-based economy with year-round crop cultivation, generates a large amount of agricultural waste, including crop residues (Bhuvaneshwari et al 2019). In the absence of adequate sustainable management practices, approximately 40-60 percent of crop waste is burned every year in India, causing excessive particulate matter emissions and air pollution (Huang et al 2022). Crop residue burning has become a major environmental problem causing health issues as well as contributing to global warming (Deshpande et al 2023). On the other hand, incorporating residues into the field takes more time for decomposition due to the wider carbon and nitrogen ratio of crop residue. This can initially immobilize mineral nutrients, especially nitrogen, leading to nutrient deficiencies in growing crops (Meena et al 2020). To address these challenges, a solution involves applying extra nitrogen fertilizer, but this can exacerbate volatilization and nutrient losses due to high temperatures. In-situ crop residue incorporation, composting and mechanization are a few effective sustainable techniques that can help to curtail the issue while retaining the nutrients present in the crop residue in the soil (Kaur and Singh 2022). There is a need for a supporting platform to solve issues such as crop residue burning.

In response to these concerns, a strategy has been developed. Lignin and cellulose-degrading microbial consortia were prepared to enhance maize residue decomposition and nutrient mineralization in calcareous soil. The objective of the experiment to study aims to investigate the impact of prepared microbial consortia on both maize residue decomposition and nitrogen mineralization in calcareous soil. Additionally, it seeks to evaluate how the method of microbial consortia application, whether surface or soil incorporation, influences nitrogen mineralization and its rate in the same soil type. This innovative approach aims to expedite residue decomposition, minimize nutrient deficiencies, and reduce the window period for sowing the next crop.

MATERIAL AND METHODS

Soil and crop residue samples for the incubation experiment were collected at 11°00'55"N 76°56'15"E from the Eastern block farm of Tamil Nadu Agricultural University (TNAU), Coimbatore, Tamil Nadu, India. The soil is classified as *Vertic ustropept*, belonging to the Inceptisol order and Periyanaickenpalayam soil series. It is a mixed black calcareous, fine, montmorillonitic, isohyperthermic soil. The soil sample was collected from the 0–15 cm depth layer using a metal core sampler and air-dried under shade, processed then sieved through a 2-mm mesh and divided into two subsamples. One subsample was used for the laboratory incubation experiment and other subsample was used for the determination of physical and chemical properties following standard methods (Table 1). Cellulose and lignin was determined and listed in Table 2 (Sadasivam 1966)

Table 1. Initial characteristics of the soil used for the incubation study

Soil properties	Mean
pH (1:2.5 soil: water)	8.34
EC (dS m^{-1}; 1:2.5 soil: water)	0.45
Total carbon (%)	0.71
Oxidizable organic carbon (%)	0.43
Available N (kg ha^{-1})	267
Available P (kg ha^{-1})	17.54
Available K (kg ha^{-1})	356
Total N (%)	0.13
Bulk density (Mg m^{-3})	1.45

Incubation experiment: An incubation experiment was conducted at Department of Soil Science and Agricultural Chemistry, TNAU, Coimbatore during 2022 to determine nitrogen mineralization and to evolve a technology to enhance the minerlaization potential and to increase the nutrient releasing capacity. Including absolute control, there were 13 treatments, namely residue alone, residue + microbial consortia, residue + microbial consortia + nutrient boosters (different rates urea and jaggary) and they were applied under two methods *viz.,* either on the surface or incorporated into the soil (Table 3). The treatments were replicated thrice. The microbial consortium was prepared by isolating bacteria and fungi from native soil using serial dilution techniques. Efficient cultures were combined to form the consortium for this study. Nutrient boosters, namely urea and jaggery, served as an initial nutrient source—comparable to "ready-to-serve" food—for the microbial consortia. This strategy supported their survival and multiplication and helped prevent immobilization during the early stages of crop residue decomposition.

Approximately 1000 g of air-dried, 2 mm sieved soil was treated with separate crop residues of cotton, maize, and cowpea, mixed in ratios of 4.6 g, 5.2 g, and 0.78 g, respectively. These ratios are equivalent to the dry matter yields of 10.4 tonnes, 9.1 tonnes, and 1.6 tonnes per hectare for cotton, maize, and cowpea, respectively. The soil was then mixed with the specified quantities of microbial consortia and nutrient boosters. For surface application, each residue was placed on the soil surface, while for incorporation, the residues were thoroughly mixed into the soil. Water was added to reach field capacity, and the samples were incubated at 30±2°C for 120 days in a laboratory incubator. The treated samples were maintained at field capacity (28.8%, w/w) throughout the incubation period, with water loss due to evaporation compensated by adding distilled water at each sampling interval. Soil samples were collected at 0, 7, 15, 30, 60, 90, and 120 days of incubation and analyzed for inorganic nitrogen (NH4+ -N and NO3- -N).

To assess nitrogen mineralization, inorganic nitrogen (NH4+ -N and NO3- -N) was extracted with a 2 M KCl solution at a 1:10 soil-to-solution ratio at the end of each incubation period. NH4+ -N was determined by steam distillation with magnesium oxide (MgO) in a micro-Kjeldahl distillation unit (Keeney and Nelson 1982). The same procedure was

Table 2. Initial chemical characteristics of the crop residues used for the study

Residue type	Total C (%)	Total N (%)	C/N ratio	Cellulose (%)	Lignin (%)	Hemicellulose (%)
Maize	41.32	0.86	48.0	31.21	13.18	24.12

applied for NO3- -N after reduction with Devarda's alloy. The amount of N mineralized (NH4+ -N and NO3- -N) at a given time 't' was calculated by subtracting the mineral-N content (NH4+ -N and NO3- -N) of the soil at the start of incubation from the mineral N at time 't'.

Statistical analysis: The study used SPSS 21.0 software (IBM) to analyze the significant interaction among the method of application, microbial consortia, and duration. The interaction was also visually represented by a violin plot for total mineral nitrogen mineralization, which was analyzed using GraphPad Prism software. Mean comparisons were conducted using the LSD post-hoc test, which compared all possible pairs of means (McKnight et al 2020).

RESULTS AND DISCUSSION

The experiment demonstrated significant influences of application method, incubation duration, and their interaction on NH_4^+-N content in maize residue. Treatments with microbial consortia, urea, and jaggery (T_6-T_{13}) exhibited higher NH_4^+-N content than the control (T_1) and treatments with only soil and residue (T_2, T_3). Treatments incorporating microbial consortia and nutrient boosters exhibited higher ammonical nitrogen content than the control and treatments with only maize residue or residue + consortia (Fig. 1). The treatments with 1% consortia, 1% urea, and 2.0% jaggery (T_9) and 1% consortia + 1% urea + 1.5% jaggery (T_{13}) recorded the highest NH_4^+-N values (45.71 and 43.12 mg/kg, respectively) on the 45th day, indicating their effectiveness in enhancing nitrogen mineralization. NH_4^+-N content initially increased up to the 45th day, followed by decreases in T_{10}, T_{11}, T_{12}, and T_{13}, possibly due to a balance between mineralization and immobilization processes (Ali et al 2021). Surface application (T_2) and consortia (T_4) showed negative values up to 40 and 35 days, respectively, while residue incorporated soil (T_3, T_5) showed negatives up to 35 and 30 days, indicating net immobilization. T_2 and T_4 turned positive from the 30th day, indicating free NH_4^+-N (Fig. 1 and Table 5).

In treatments with residue alone or residue + consortia, the inorganic nitrogen (N) concentrations decreased and were much lower than in the control up to 30 days after incubation. This suggests that adding high C:N ratio residue stimulated microbial growth and N immobilization, especially in the initial days of the experiment. T_6 to T_{13} consistently showed positive values, indicating ammonification and NH_4^+-N release. Both surface application and incorporation of maize residue with microbial consortia and nutrient boosters showed similar N mineralization trends up to the 45th day, followed by a slight decrease up to the 75th day. Khali et al (2005) and Rosenkranz et al (2012) observed that N mineralization was dominated by ammonification during the first 30 days after incorporating crop residues. Thereafter, NH_4^+-N released from the ammonification was nitrified to NO_3^--N, which could explain the declining trend of NH_4^+-N after 45 days of incubation in surface applied and residue incorporated soil. Method of application also significantly affected the NH_4^+-N mineralization (Abiven and Recous

Table 3. Treatment details

Treatments	Surface application
T_1	Control
T_2	Soil + Crop residue
T_3	Soil + residue + Microbial consortia (1%)
T_4	T_3 + Nutrient Booster (0.5% Urea + 1.5% Jaggery)
T_5	T_3 + Nutrient Booster (0.5% Urea + 2.0% Jaggery)
T_6	T_3 + Nutrient Booster (1.0% Urea + 2.0% Jaggery)
T_7	T_3 + Nutrient Booster (1.0% Urea + 1.5% Jaggery)
Incorporated into soil	
T_8	Soil + Crop residue
T_9	Soil + residue + Microbial consortia (1%)
T_{10}	T_3 + Nutrient Booster (0.5% Urea + 1.5% Jaggery)
T_{11}	T_3 + Nutrient Booster (0.5% Urea + 2.0% Jaggery)
T_{12}	T_3 + Nutrient Booster (1.0% Urea + 1.5% Jaggery)
T_{13}	T_3 + Nutrient Booster (1.0% Urea + 2.0% Jaggery)

Table 4. Percentage increase of available nitrogen in soil after 90 days of maize residue application with microbial consortia, urea, and jaggery

Treatments	% increase over control
T1- Control	-
T2- Soil + residue (Surface	5.6
T3- Soil + Residue (incorporated)	6.7
T4- Soil + residue + 1% consortia (S)	9.7
T5- Soil + residue + 1% consortia (I)	10.8
T6- Soil + residue + 1% consortia + 0.5% Urea + 1.5% Jaggery	14.1
T7- Soil + residue + 1% consortia + 1% Urea + 1.5% Jaggery	14.5
T8- Soil + residue + 1% consortia + 0.5% Urea + 2.0% Jaggery	13.4
T9- Soil + residue + 1% consortia + 1.0% Urea + 2.0% Jaggery	16.0
T10- Soil + residue + 1% consortia + 0.5% Urea + 1.5% Jaggery	13.8
T11- Soil + residue + 1% consortia + 1% Urea + 1.5% Jaggery	19.3
T12- Soil + residue + 1% consortia + 0.5% Urea + 2.0% Jaggery	17.1
T13- Soil + residue + 1% consortia + 1.0% Urea + 2.0% Jaggery	21.9

2007). The incorporating residues with soil enhanced the N mineralization .Gupta et al (2010) also reported that the N release from surface residues was reduced compared to sub-surface placement.

The decrease in NH_4^+-N content at day 15 for T_2 and T_3 indicated increased microbial activity, potentially leading to enhanced immobilization rates. This indicate that the initial plant residue quality influenced the N mineralization in crop residues, and that the high C:N ratio of maize residue caused immobilization (Chaves et al 2021). However, T_9 and T_{13}, with increased urea and jaggery content, showed a stable NH_4^+-N content throughout the experiment, possibly due to reduced nitrification via heterotrophic denitrification stimulated by jaggery. Urea can provide a readily available source of nitrogen, and jaggery can stimulate the microbial activity and carbon supply (Krausfeldt and Marz et al 2020). These results are also supported by the findings of previous studies. Nishio and Oka (2003) reported that incorporating rice and wheat straw enhanced the immobilization of both nitrate and ammonium because the high C:N ratio did not meet the microbial N requirements. The slight increase in NH_4^+-N is mainly due to the decline in the C:N ratio of the decomposing crop residue; once the crop residue C:N ratio is less than 21:1, the microbial N will be mineralized (Walley and Yates 2002).

Nitrate nitrogen: The NO_3^--N content in maize residue increased significantly in all treatments regardless of the method of residue application (Table 6, Fig. 2). The highest nitrification was in T_{13} (soil + residue + 1% consortia + 1.0% urea + 2.0% jaggery) with 71.23 mg/kg of NO_3^--N at 45th DAI, followed by T9 (soil + residue + 1% consortia + 1.0% urea + 1.5% jaggery) with 67.95 mg/kg at 60th DAI. Nutrient boosters provided a ready-made food source for microorganisms, enhancing their activity and leading to higher mineralization and nitrification. Immobilization occurred on the 15th day after incubation in T_4 (soil + residue + consortia). T_2 (soil + residue) also recorded immobilization (6.45 mg/kg of NO_3^--N) compared to T_1 (soil) (7.32 mg/kg) but later progressed to NO_3^--N mineralization until the end of the incubation period. Anguria et al (2017) indicated that plant residues with low biochemical quality tend to initiate decomposition slowly due to immobilization of nutrients, especially N, at the early phase of their decomposition. Nitrate content increased up to 45 days in all treatments, followed by a decreasing trend that stabilized afterwards. This pattern reflects the release of N from decomposable residue fractions, subsequent utilization by soil microbes,

Table 5. Effect of maize residue and microbial consortia on ammonium nitrogen (NH_4^+-N mg/kg) dynamics over incubation time

Treatments	Surface applied residues						Treatments	Residues incorporated with soil					
	Incubation intervals (days)							Incubation intervals (days)					
	15	30	45	60	75	90		15	30	45	60	75	90
T_2	-6.38*	-1.64	2.47	0.81	3.00	2.40	T_3	-6.00	-0.70	6.56	2.53	4.38	2.99
T_4	-8.52	-5.23	4.29	9.22	8.77	8.10	T_5	-9.63	-2.82	5.90	11.82	11.33	8.97
T_6	8.39	10.07	18.60	14.77	14.72	12.53	T_{10}	8.21	13.08	23.24	17.38	17.07	14.67
T_7	10.11	15.82	21.03	17.84	17.49	17.07	T_{11}	11.70	16.81	24.00	19.32	18.82	18.68
T_8	8.57	13.70	19.82	14.93	14.86	16.93	T_{12}	10.43	14.61	20.13	16.28	16.08	15.73
T_9	11.63	17.39	21.12	17.18	16.89	24.91	T_{13}	13.09	19.69	26.59	22.88	22.02	21.40

*negative values indicate immobilization of nitrogen

Table 6. Effect of maize residue and microbial consortia on nitrate nitrogen (NO_3^--N) dynamics over incubation time

Treatments	Surface applied residues						Treatments	Residues incorporated with soil					
	Incubation intervals (days)							Incubation intervals (days)					
	15	30	45	60	75	90		15	30	45	60	75	90
T_2	-0.87	2.9	6.03	7.99	5.87	3.83	T_3	-1.43	3.49	6.45	8.82	6.36	5.05
T_4	-1.18	3.97	7.23	9.49	10.05	9.02	T_5	-1.06	5.71	8.69	11.92	13.27	10.52
T_6	14.13	27.95	37.7	38.05	30.84	28.92	T_{10}	15.52	29.96	39.42	38.05	31.14	30.23
T_7	22.44	42.17	50.62	57.96	50.12	47.5	T_{11}	23.29	47.22	59.95	58.18	52	52.32
T_8	14.55	29.18	40.65	39.78	30.43	28.82	T_{12}	15.81	30.41	43.23	45.13	36	34.6
T_9	23.1	44.25	53.88	60.89	50.81	52.2	T_{13}	24.22	50.31	63.66	69.37	63.93	62.91

*negative values indicate immobilization of nitrogen and decomposition of more recalcitrant residue components.

Treatments T_9 and T_{13}, surface applied and incorporated with soil, respectively, displayed the highest NO_3^--N content throughout the incubation period emphasizing their effectiveness in promoting N mineralization from maize residue(Table 6, Fig. 2). The high carbon and nitrogen ratio of maize residue in T_2 might have limited N availability for microbial metabolism, resulting in immobilization. However, as days progressed, mineral nitrogen release increased significantly in both methods of residue application. Treatments with soil + residues + nutrient boosters (urea and jaggery) significantly increased nitrification throughout the incubation period in both surface and incorporation methods. This study evidenced that higher urea and jaggery levels (1% vs. 0.5%, 2% vs. 1.5%) mineralized higher NH_4^+-N and NO_3^--N content in maize residues. This suggests that these

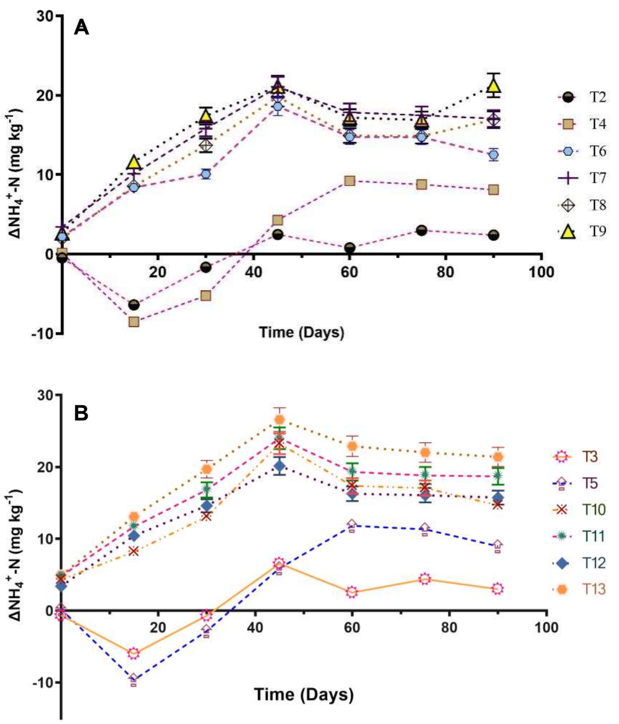

Fig. 1. Temporal dynamics of NH_4^+-N content (mg/kg) in maize crop residues: **A)** Surface applied **B)** Incorporated with soil

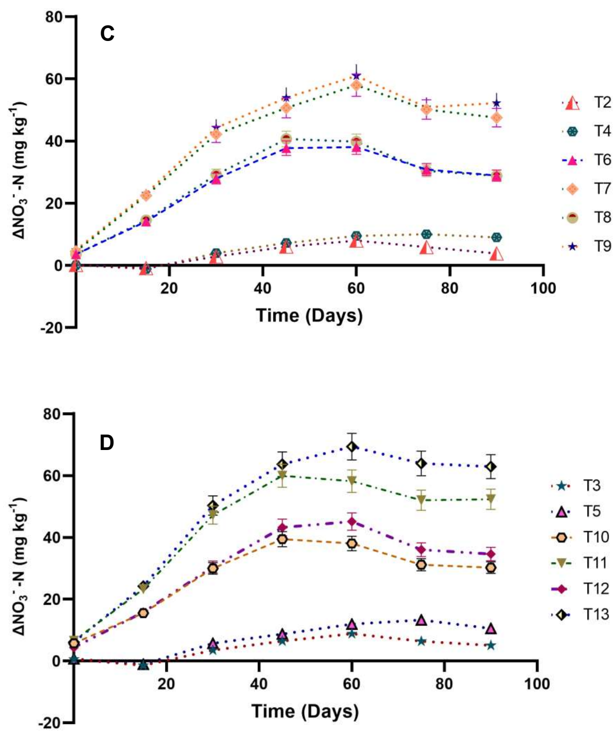

Fig. 2. Temporal dynamics of NO_3^--N content (mg/kg) in maize crop residues: **C)** Surface applied **D)** Incorporated with soil

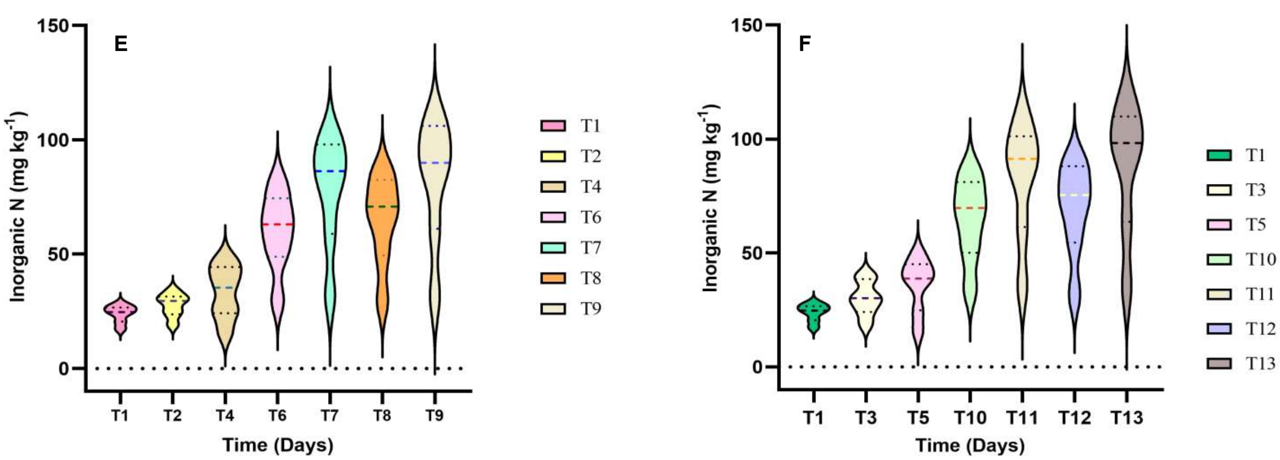

Fig. 3. Total mineral nitrogen mineralization (mg/kg) from maize crop residues: **E)** Surface applied **F)** Incorporated with soil

nutrients were limiting factors in the decomposition process. The addition of microbial consortia, urea, and jaggery can affect these factors and stimulate nitrification. However, the presence of organic carbon sources, like jaggery, may also inhibit nitrification by competing with nitrifying bacteria for oxygen and lowering soil pH.

NH_4^+-N and NO_3^--N concentrations were significantly higher in incorporated treatments than in surface applied treatments. This is due to the high contact between soil and residues in incorporated treatments, while adding consortia with nutrient boosters, the organisms proliferated more and enhanced the mineralization of both NH_4^+-N and NO_3^--N. The NH_4^+-N concentration was higher than the NO_3^--N concentration in the first 45 days, accounting for 70% of total inorganic N. This is in agreement with Kara (2000), where proteins and amino acids from crop residues are first converted to NH_4^+-N before being nitrified to NO_3^--N in the presence of oxygen. The high concentration of NH_4^+-N in the first 45 days, together with decarboxylation of organic acid anions, may explain the strong increase in soil pH of the residue treatments (Table 5, Fig. 1). From day 45, the lower percentage of total inorganic N as NH_4^+-N, as well as the increase in NO_3^--N concentrations (Fig. 2), suggests that nitrification became more important. The strong increase of nitrate nitrogen concentrations in consortia, nutrient boosters and residue incorporated treatments after 45th day resulted in significant decrease of soil pH, due to the proton release during nitrification

Violin plot result: The violin plot shows the changes in total mineral nitrogen (TMN) content in soil over 90 days for 13 treatments (Fig. 3). Treatments with microbial consortia and nutrient boosters (T_6-T_{13}) had higher TMN than the control (T_1) and treatments with only residue (T_2 and T_3), indicating enhanced nitrogen mineralization from maize residue. TMN increased for all treatments until day 45, then decreased or stabilized, reflecting microbial decomposition and nitrogen utilization. Treatments T_9 and T_{13}, with 1% consortia, 2% jaggery, and 1% consortia, 1% urea, 1.5% jaggery, respectively, displayed the highest TMN, affirming their substantial nitrogen mineralization potential. In contrast, treatments with only residue (T_2 and T_3) showed net TMN immobilization at first, followed by gradual mineralization from day 30, indicating microbial consumption followed by residue decomposition and nitrogen release. The results highlight the significant enhancement of nitrogen mineralization from maize residue in soil with microbial consortia and nutrient boosters. The combination of 1% consortia with 2% jaggery or 1% consortia, 1% urea, and 1.5% jaggery was the most effective in this study. Soil N availability may be important for residue decomposition. The soils with maize residue alone had lower cumulative N mineralization than unamended soil. The addition of microbial consortia and nutrient boosters resulted in higher mineral N than unamended soil; the cumulative mineral N for residues incorporated with soil was higher than for residues applied on soil surface.

Percentage increase over control: The highest percentage of available nitrogen increase over control was in T_{13} and T_{11} with 21.9% and 19.3%, respectively (Table 4). The lowest percentage of available nitrogen increase over control was in T_2 and T_3 with 5.6% and 6.7%, respectively. The incorporation of residue and amendments resulted in higher percentage of available nitrogen increase over control than the surface application of the same treatments. The result suggests that the combined application of microbial consortia, urea, and jaggery can enhance the nitrogen availability in soil, and that the incorporation of these amendments can improve the nitrogen use efficiency. Available nitrogen in T_6 to T_{13} was significantly higher than in the control and residue alone treatments, suggesting that the microbial biomass took up the ready source food from nutrient boosters and mineralized the nutrients from maize residue to the soil. Marz et al (2020) achieved maximum mineralization by adding an additive nutrient source.

CONCLUSION

Microbial consortia and nutrient boosters (urea and jaggery) increased the available nitrogen content in soil compared to the control and treatments with only residue. The highest increase was in incorporated residue with 1% consortia, 1% urea, and 2% jaggery. Incorporation generally resulted in higher increases than surface application. This indicates that incorporation improved soil-residue contact and microbial activity, enhancing N mineralization. Microbial consortia degraded the high C:N ratio maize residue and released mineral nitrogen to the soil. Urea and jaggery provided N and C sources for the microbes, boosting N availability. These results suggest that microbial consortia, urea, and jaggery were effective amendments for increasing N availability from maize residue in soil. Therefore, the acceleration of decomposition through the application of lignolytic consortia and the simultaneous mineralization of the nutrient from residue will synchronize the nutrient requirement of the upcoming crop. Consequently, this might be an alternative way to enhance soil ecology through avoiding huge chemical fertilizers and incorporation of crop residues instead of residue burning.

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Received 22 March, 2024; Accepted 30 June, 2024

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Indian Journal of Ecology (2024) 51(4): 813-819
DOI: https://doi.org/10.55362/IJE/2024/4315

Manuscript Number: 4315
NAAS Rating: 5.38

Irrigation Levels and Anti-Transpirants Impact on Growth Attributes and Phenology of Different Varieties of Indian Mustard (*Brassica juncea* L.)

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Abstract: Field experiment was carried out during 2017-18 and 2018-19 at Regional Research Station, Bawal, Haryana, India to examine the consequences of different levels of irrigation and anti-transpirants application on mustard crop. The experiment had three irrigation levels (I1: control, I2: one irrigation at 40 DAS, I3: two irrigation at 40 and 75 DAS), and two varieties (V1: RH-725, V2: RH-749) in main plots, whereas, four anti-transpirants (A1: control, A2 : PMA @ 250 ppm at 45 and 90 DAS, A3 : 6 % kaolin at 45 and 90 DAS and A4: PMA @ 250 ppm + 6% kaolin at 45 and 90 DAS) in sub plots. The different irrigation levels and anti-transpirants significantly influenced the performance of RH-749 and RH-725 mustard varieties. Growth attributes such as plant height, number of primary and secondary branches per plant, dry matter accumulation, crop growth rate, relative growth rate, leaf area index, leaf area duration and number of days for maturity of mustard significantly in two irrigation at 40 and 75 DAS (At pre-bloom + pod filling stage) as compared to control (no post-sowing irrigation) irrigation level. In the case of anti-transpirants, highest growth attributes and number of days taken to physiological maturity of mustard was recorded in A4 as compared to A1 but it was at par with A3 anti-transpirants. Among the varieties, RH-749 performed better compared to RH-725 variety under different treatments. The interaction between I3 irrigation level and A4 anti-transpirants was significantly superior as compared to others. Moreover, mustard yield was significantly and positive correlated with different growth attributes.

Keywords: Anti-transpirants, Indian mustard, Interaction, Irrigation, Varieties, Correlation, Yield, Levels

Mustard (*Brassica juncea* L.) is a very important *rabi* season oilseed crop of India. It is cultivated on 6.69 million hectares of area with 10.11 million tonnes production and 1511 kg/ha productivity in India during 2020-21, whereas in Haryana state, crop grown on 0.61 million hectares area and produce 1.28 million tonnes with average productivity of 2098 kg/ha (Anonymous 2021). India is a key player in the global oilseeds scenario with 12-15 per cent of oilseeds area, 6-7 per cent of vegetable oils production, 9-11 per cent of the total edible oils consumption and 14 per cent of vegetable oil imports (Bhukhar et al 2022) . The average productivity of Indian mustard in India during last one and half decade, oscillating between 1.0 to 1.2 tonnes/ha, which is much below the world average of 1.98 tonnes/ha. Moreover, there is wider yield gaps when productivity of India is compared with countries like Germany (4.3 tonnes/ha), France (3.8 tonnes/ha) and UK (3.4 tonnes/ha).

The production of mustard is not being fully exploited because of the lack of proper information of water requirement. It is well known that water management is one of the major factors responsible for achieving better harvest in crop production. Efficient irrigation through timely supply of water in desirable amount and with proper irrigation method not only improves the crop yields but also improve water use efficiency. Research studies indicated the beneficial effect of irrigation on performance of mustard. Kumar and Dhillon (2023) reported three irrigations at branching, flowering and siliqua-formation stages resulted in significantly higher seed yield, oil content, oil yield and protein content. Piri et al (2019) concluded that application of two irrigations at 45 and 90 DAS significantly increased higher growth yield attributes and yield of mustard. Applications of two irrigations significantly increased seed yield by 52.8% over one irrigations. Ray et al (2016) observed that two irrigations at 30 and 60 DAS resulted in highest gross and net returns. Adequate supply of moisture in soil helps in proper utilization of plant nutrients, resulting in proper growth and high yield. Therefore, there is need for appropriate solution to fulfil the irrigation requirement of mustard crop. For increasing the productivity of mustard crop the improved varieties which are capable of giving high yields need to be cultivated.

Recently, antitranspirants are used in agricultural field which reduce transpiration rate from plant leaves by reducing the size and number of stomata and gradually hardening them to stress. Antitranspirants which minimize transpiration could possibly outcome of higher food production by realizing yield potential of different varieties. The application of anti-transpirants foliar spray may be an option to improve the biometric parameters. Rajput (2012) concluded that combined spray of PMA @ 250 ppm + kaolin (6%) at 45 and 90 days after sowing recorded significantly higher yield, net returns and water use efficiency. Kumar et al (2018) reported that application of PMA @ 250 PPM + kaoline (6%) at 45 and 90 DAS recorded significantly higher seed yield and net return. The present investigation was aimed to evaluate the Indian mustard varieties under different irrigation level and anti-transpirants.

MATERIAL AND METHODS

Site specifications: The experiment was conducted at Regional Research Station, Bawal of Chaudhary Charan Singh Haryana Agricultural University, Hisar during 2017-18 and 2018-19. The site is located in south-west (SW) zone of Haryana which comes under arid and semi-arid region having latitude and longitude of 28.10N, 76.50 E, respectively above mean sea level of 266 meters. The climate is arid and semi-arid type, with severe cold days in winter and hot sunny days in summer season. The experimental soil was sandy loam in texture. The mean maximum temperature touches as high as 48^{0}C during summer season. However, minimum temperature of 2-3^{0}C is recorded during winter months. The south-west monsoon (SWM) brings rain from July-September providing 80-85 % of total annual rainfall of the region. The weather remains dry except light rainfall during the months From October-April. However, the high temperature is prevailing in June.

Experimental details: The experiment was laid out in split plot design having twenty-four treatment combinations with three replications by keeping levels of irrigation and varieties as main plot and anti-transpirants in sub plots

The pH of the experimental soil was alkaline in nature (8.24) having electrical conductivity of 0.19 ds/m. The organic carbon, available nitrogen, available phosphorus and available potassium content were 0.23 %, 148 kg/ha, 14.22 kg/ha and 208 kg/ha, respectively (Jackson, 1973, Rechard 1954, Walkely and Black 1947, Subbaiah and Asija 1956, and Olsen et al 1954). The pre-sowing irrigation was applied before seed bed preparation to ensure adequate moisture at the time of planting. To have a good soil tilth and well pulverized seed bed, the field was ploughed twice with the help of disc harrow, once with cultivator followed by planking. Layout was done by using rope and hand hoe. Mustard variety RH-749 and RH-725 was sown with row spacing of 30 cm by 'pora' method with hand plough. Irrespective of treatments, thinning of extra plant was done 20 days after sowing by hand pulling to obtain the recommended intra-row spacing of 15 cm. To eliminate weeds in all the plots of experimental area, 1st hoeings was done at 25 days after sowing. Application of irrigation as per the treatment and crop was harvested at ground level with the help of sickle. The above ground harvested biomass from each plot was tied in bundles, tagged and sun dried. Dry bundles of individual plots were weighed to have total biological yield. The crop was threshed by manual laborers and was weighed to get seed yield, stover yield and biological yield kg/plot. Thereafter, these yields were converted into kg/ha.

Observation recorded: The five plants were selected from each plot for recording various growth attributes such as plant height, number of primary and secondary branches per plant, dry matter accumulation, crop growth rate, relative growth rate, leaf area index and leaf area duration recorded at specified growth stages of crop. The harvesting of rows of net plot was done manually.

Crop growth rate (g/m$^{2/}$day): Crop growth rate (CGR) indicates increase in dry weight (W) of plant in a unit time (T) per unit land area (P). CGR was calculated using the following formula (Reddy and Reddi 2009).

$$CGR=\frac{(W2-W1)}{P\ (T2-T1)}$$

Where, P is the land area per plant and W1 and W2 are dry weights of plant at T1 and T2 time, respectively.

Relative growth rate (g/g/day): Relative growth rate (RGR) indicates the amount of growing material per unit dry weight of plant per unit time was calculated (Reddy and Reddi 2009).

$$RGR=\frac{(LogeW2-LogeW2)}{(T2-T1)}$$

Where, W1 and W2 are dry weights of plant at T1 and T2 time, respectively.

Leaf area index (LAI): LAI was worked out with following formula (Watson 1952)

$$\text{Leaf area index}=\frac{\text{Leaf area (cm}^2)}{\text{Leaf area (cm}^2)}$$

Leaf area duration (LAD): Leaf area duration (LAD) express the magnitude and persistence of leaf area or leafiness during the period crop life (Hunt 1978).

$$LAD=\frac{LAI_1/LAI_2}{2}(t_2-t_1)$$

Where, LAI1 and LAI2 are leaf area index at the time t1 and t2, respectively.

t2- t1 is the interval of observation in days.

Statistical analysis: Experimental data were statistically analyzed by using SPSS software.

RESULTS AND DISCUSSION

Effect of irrigation: The successive increase in number of irrigations (I1 to I3) at different phenological stages did not influence the plant stand at 20 DAS and at maturity as well as days to 50 % flowering of mustard but the mean plant height increased with advancement in age, but the increase in the height was faster up to 120 days as compared to later period of growth (Table 1). Application of two irrigations at 40 and 75 DAS significantly recorded the maximum plant height of at 60, 90, 120 DAS as well as harvest, and was at par with treatment one irrigation at different days after sowing except at harvest. The shortest plants were under control throughout the growth periods. Significantly higher number of primary and secondary branches per plant were under application of two irrigations at 40 and 75 days after sowing as compared to those receiving one irrigation at 40 DAS and over control. The significantly maximum dry matter accumulation was with application of two irrigations at 40 and 75 days after sowing and was at par with treatment I2 (one irrigation at 40 DAS) at harvest only, but significantly superior over control (Table 2). Percentage increase in dry matter accumulation at harvest with application of two irrigations at 40 and 75 DAS was 2.97 % over I2 and 6.62 % over I1. The increase in crop growth rate was observed with the advancement of crop age and maximum between 60-90 DAS in all three levels of irrigation. The application of two irrigations at 40 and 75 DAS significantly recorded the maximum crop growth rate at 30-60 and 60-90 DAS and was at par with treatment I2 (one irrigation at 40 DAS) at 60-90 DAS only during 2017-18, but significantly superior over control. Percentage increase in crop growth rate with application of two irrigations at 40 and 75 DAS was 7.18 and 10.30 % over I2 as well as 20.42 and 15.74 % over I1 at 30-60 and 60-90 DAS, respectively. The maximum relative growth rate was at 30-60, 60-90 and 90-120 DAS and was at par treatment one irrigation at 40 DAS, except at 60-90 DAS in 2018-19 (Table 3). The application of two irrigations at 40 and 75 days after sowing significantly recorded the maximum leaf area index at 60 and 90 DAS and was at par with one irrigation at 40 DAS during both years except at 90 DAS during 2018-19 (Table 4). Irrespective of different treatments application of two irrigations at 40 and 75 DAS recorded significantly higher leaf area at 60 and 90 DAS and was at par with one irrigation at 40 DAS. Wherever, more number of days taken to physiological maturity under application of two irrigations at 40 and 75 days after sowing as compared to over irrigation level I2 and I1. It is well known fact that where enough soil moisture for progressive plant growth is maintained by either providing irrigation or rainfall, it intends to better development of photosynthetic area and results in an accelerate photosynthetic rate. Thus, as a consequence plant growth accelerated and led to a better accumulation of dry matter.

Adequate and timely supply of irrigation water in I3 treatment ensured cell turgidity and consequently higher

Table 1. Plant population (000/ha) and plant height (cm) of Indian mustard as influenced by irrigation levels, varieties and anti-transpirants (Pooled of 2017-18 and 2018-19)

Treatment	Plant population (000/ha)		Plant height (cm)			
	20 DAS	At harvest	60 DAS	90 DAS	120 DAS	At harvest
Irrigation levels (I)						
I_1- Control (No post-sowing irrigation)	213.9	209.8	114.4	172.3	197.3	204.7
I_2- One irrigation at 40 DAS (At pre-bloom stage)	218.5	216.2	120.0	183.5	208.2	217.6
I_3- Two irrigation at 40 and 75 DAS (At pre-bloom + pod filling stage)	218.0	214.9	121.5	186.2	215.0	224.2
CD (p=0.05)	NS	NS	2.2	4.1	6.2	2.6
Varieties (V)						
V_1-RH-725	218.5	214.9	117.1	178.4	203.6	213.7
V_2-RH-749	215.1	212.4	120.2	182.9	210.2	217.3
CD (p=0.05)	NS	NS	1.8	3.3	5.1	2.2
Anti-transpirants (A)						
A_1- Control	218.1	217.7	115.2	178.4	202.8	211.1
A_2- PMA @ 250 ppm at 45 and 90 DAS	215.1	211.9	117.5	179.1	204.9	214.0
A_3- Kaolin 6 % at 45 and 90 DAS	213.0	209.5	119.1	181.1	207.9	216.0
A_4- PMA @ 250 ppm + Kaolin (6%) at 45 and 90 DAS	221.1	215.4	122.8	183.9	212.0	220.9
CD (p=0.05)	NS	NS	3.1	2.5	3.6	4.4

meristematic activity leading to more foliage development, greater photosynthetic rate, higher nutrient uptake and better growth of plant. The increased turgidity in optimum irrigated condition results in higher stomatal conductance and photosynthesis which favoured improved morphological parameters like plant height, leaf area and better allocation of dry biomass in different plant parts. The moisture deficit in no-post sowing irrigation and one irrigation at 40 DAS treatments resulted in dehydration of protoplasm which decreased the turgor potential and turgor driven physiological processes viz., cell division and cell elongation which affected the plant growth (height, number of leaves, branches) and ultimately the total dry matter accumulation. The results are in agreement with earlier studies (Tyagi and Upadhyay 2017, Shivran et al 2018, Mishra et al 2019, Piri et al 2019, Kumar and Dhillon 2023).

Effect of variety: Appreciable effect of different varieties on growth and phonological attributing characters was observed but did not exhibit any influence on plant population at initial and harvest. Between varieties, significantly higher plant height of 120.2, 182.9, 210.2, 217.3 cm at 60, 90, 120 DAS as well as harvest observed with variety RH-749, respectively and was at par with RH-725 at harvest only during 2017-18. Significantly the higher number of primary branches and secondary branches per plant were in RH-749 as compared to RH-725, respectively in both the years (Table 1). The significantly higher number of primary branches and secondary branches per plant as well as dry matter accumulation of at 60, 90, 120 DAS as well as harvest recorded under variety RH-749 as compared to RH-725 (Table 2). The significantly higher crop growth rate at 30-60 and 60-90 DAS and relative growth rate at 30-60, 60-90 and 90-120 DAS observed with y RH-749 as compared to RH-725, respectively (Table 3). There was significantly higher leaf area index as well as leaf area duration at 60-90 and 90-129 DAS observed in RH-749 as compared to RH-725, respectively (Table 4). Percentage increase in leaf area index with RH-749 was 12.12 % and 7.31 % over RH-725 at 60-90 and 90-120 DAS during both year. Significantly more number of days were taken to 50 % flowering and physiological maturity by RH-749 and least number of days were taken to 50 % flowering and physiological maturity by RH-725. This might be due to the genetic makeup of different varieties. Inherent characteristic of particular variety plays a vital role on growth and development of crop, which might be responsible for plant growth in terms of plant height, number of branches per plant, dry matter accumulation, crop growth rate, relative growth rate, leaf area index, leaf area duration etc. These findings are in accordance with the results reported earlier research (Singh et al 2017, Meena et al 2017, Kumar et al 2018, Yadav et al 2018, Jaiswal et al 2019, Rajyalakshmi et al 2019 , Maurya et al 2022).

Effect of anti-transpirants: Marked effect of various anti-transpirants was observed on growth attributing characters

Table 2. Number of primary and secondary branches per plant at harvest and dry matter accumulation (g/plant) of Indian mustard as influenced by irrigation levels, varieties and anti-transpirants (Pooled of 2017-18 and 2018-19)

Treatment	Number of primary branches per plant	Number of secondary branches per plant	Dry matter accumulation (g/plant)			
			60 DAS	90 DAS	120 DAS	At harvest
Irrigation levels (I)						
I_1	4.6	11.4	17.0	43.8	120.0	134.0
I_2	5.7	14.0	20.6	52.9	132.5	143.5
I_3	6.3	15.4	22.3	57.7	139.9	147.9
CD (p=0.05)	0.3	0.7	1.0	1.3	3.4	4.3
Varieties (V)						
V_1	5.4	13.1	19.4	49.8	127.5	138.9
V_2	5.7	14.1	20.5	53.1	134.0	144.7
CD (p=0.05)	0.2	0.5	0.8	1.1	2.8	3.5
Anti-transpirants (A)						
A_1	5.1	12.7	19.1	48.4	124.5	138.4
A_2	5.3	13.3	19.6	50.8	129.0	141.3
A_3	5.7	13.9	20.2	52.5	132.9	142.5
A_4	6.1	14.5	21.0	54.1	136.7	145.1
CD (p=0.05)	0.3	0.8	0.6	1.5	3.5	2.9

See Table 1 for treatment details

but did not exhibit any influence on plant population at initial and harvest as well as days to attain 50 % flowering. Significantly taller plants were recorded with application of PMA @ 250 ppm + kaolin (6%) at 45 and 90 DAS and was at with application of kaolin (6 %) at 45 and 90 DAS over PMA @ 250 ppm at 45 and 90 DAS and control, respectively. There were significantly more number of primary and secondary branches per plant with application of PMA @ 250 ppm + kaolin (6%) at 45 and 90 DAS and was at par with application of kaolin (6 %) at 45 and 90 DAS but significantly superior over PMA @ 250 ppm at 45 and 90 DAS and control (Table 2). Significantly higher dry matter accumulation with application of PMA @ 250 ppm + kaolin (6%) at 45 and 90 DAS (A4) at 60, 90, 120 DAS as well as harvest and was at with application of kaolin (6 %) at 45 and 90 DAS, but significantly superior over PMA @ 250 ppm at 45 and 90 DAS and control.

The significantly higher crop growth rate with application of PMA @ 250 ppm + kaolin (6%) at 45 and 90 DAS at 30-60 and 60-90 and 90-120 DAS and was at par with application of kaolin (6 %) at 45 and 90 DAS, but significantly superior over PMA @ 250 ppm at 45 and 90 DAS and control (Table 3). Significantly higher relative growth rate at 30-60, 60-90 and 90-120 DAS was with both application of PMA @ 250 ppm + kaolin (6%) at 45 and 90 DAS and with application of kaolin (6 %) at 45 and 90 DAS and was at par with application of kaolin (6 %) at 45 and 90 DAS at 60-90 DAS and PMA @ 250 ppm at 45 and 90 DAS during. There was significantly higher leaf area index and leaf area duration at 60-90 and 90-120 DAS recorded with application of PMA @ 250 ppm + kaolin (6%) at 45 and 90 DAS and was at par with both application of kaolin (6 %) at 45 and 90 DAS and PMA @ 250 ppm at 45 and 90 DAS (Table 4). Foliar sprays of PMA @ 250 ppm and kaolin (6%) markedly increase all growth parameters and relative water content and reduce transpiration thus decreasing the loss of water vapour from the leaves and gradually hardening them to stress by closing the stomata for 2-3 days when sprayed on the leaves. Film forming anti-transpirants produce an external physical barrier to retard the escape of water vapour. Another approach to reduce the transpiration rate is by coating the leaf surface with white reflecting materials and kaolin at 6% helps to lower the leaf temperature and reduce the transpiration when applied on foliage which might be responsible for plant growth in terms of plant height, number of branches per plant and dry matter accumulation. Results are in concurrence with those of earlier reports (Badukale et al 2015, Kumar et al 2017, Kumar et al 2018, Mphande et al 2020).

Relationship of different growth attributes with seed yield of mustard crop: The correlation analysis between seed yield and growth attributing characters revealed that seed yield was significantly and positively correlated with growth parameter viz. plant height at harvest, number of primary and secondary branches per plant, dry matter accumulation at harvest and crop growth rate (Table 6).

Table 3. Effect of irrigation levels, varieties and anti-transpirants on crop growth and relative growth of Indian mustard (Pooled of 2017-18 and 2018-19)

Treatment	Crop growth rate ($g/m^2/day$)			Relative growth rate (g/g/day)		
	30-60	60-90	90-120	30-60	60-90	90-120
Irrigation levels (I)						
I_1	11.3	19.8	56.3	0.041	0.054	0.069
I_2	14.2	23.5	59.3	0.044	0.057	0.071
I_3	15.3	26.2	60.9	0.045	0.059	0.071
CD (p=0.05)	0.6	1.2	2.4	0.001	0.000	0.001
Varieties (V)						
V_1	13.2	22.4	57.3	0.043	0.056	0.070
V_2	14.0	24.0	60.4	0.043	0.057	0.071
CD (p=0.05)	0.5	1.0	1.9	0.001	0.000	0.001
Anti-transpirants (A)						
A_1	12.9	21.7	55.9	0.042	0.056	0.069
A_2	13.4	22.6	58.0	0.043	0.056	0.070
A_3	13.8	23.9	59.6	0.043	0.057	0.071
A_4	14.4	24.6	61.9	0.044	0.057	0.071
CD (p=0.05)	0.4	1.3	3.0	0.000	0.001	0.001

See Table 1 for treatment details

Table 4. Effect of irrigation levels, varieties and anti-transpirants on crop growth and relative growth of Indian mustard (Pooled of 2017-18 and 2018-19)

Treatment	Leaf area index (DAS)		Leaf area duration (DAS)		Days taken to 50% flowering	Days taken to physiological maturity
	60-90	90-120	60-90	90-120		
Irrigation levels (I)						
I_1	2.7	3.7	55.6	95.7	43.7	139.0
I_2	3.3	4.4	65.9	115.0	44.9	141.0
I_3	3.4	4.7	68.0	121.4	45.0	142.4
CD (p=0.05)	0.4	0.4	6.8	10.6	NS	1.4
Varieties (V)						
V_1	2.9	4.1	60.1	105.3	43.0	138.7
V_2	3.3	4.4	66.2	116.2	46.0	143.0
CD (p=0.05)	0.4	0.3	5.5	8.7	0.9	1.2
Anti-transpirants (A)						
A_1	2.8	3.9	58.0	100.9	44.4	139.5
A_2	3.2	4.0	63.8	108.6	43.9	140.8
A_3	3.3	4.3	64.8	113.7	44.7	141.1
A_4	3.3	4.7	66.0	119.8	45.1	141.9
CD (p=0.05)	0.4	0.5	5.7	8.7	NS	1.5

See Table 1 for treatment details

Table 5. Correlation coefficient between seed yield and growth attributes (Pooled of 2017-18 and 2018-19)

Characters	Correlation coefficient 'r'
Plant height	0.7455**
Number of primary branches per plant	0.8226**
Number of secondary branches per plant	0.6943**
Dry matter accumulation	0.7658**
Crop growth rate (g/m²/day)	0.8160**

*,**=Significant at 5 and 1 per cent level

CONCLUSIONS

The higher growth and growth traits could be obtained when mustard crop is grown with two irrigations, at 40 and 75 DAS. The variety RH-749 proved to be better as compared to RH-725 in terms of all yield traits. The application of PMA @ 250 ppm + kaolin (6%) at 45 and 90 DAS recorded significantly higher growth and growth parameters. Thus, higher growth and growth parameters can be achieved with mustard variety RH-749 along with application of two irrigations at 40 and 75 DAS and PMA @ 250 ppm + kaolin (6%) at 45 and 90 DAS on loamy sand soils.

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Received 25 February, 2024; Accepted 30 June, 2024

Indian Journal of Ecology (2024) 51(4): 820-827
DOI: https://doi.org/10.55362/IJE/2024/4316

Manuscript Number: 4316
NAAS Rating: 5.38

Characterization and Classification of Desert Depressions Soils in Najaf Province

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***Abstract*:** Three pedons were selected based on the area of the depression in the south desert of Najaf province which located between ˚31 ¯54˝2 and ˚ 29¯49 ˝56 latitude north and ˚44 ¯29 ˝40 and ˚42 ¯46 ˝35 longitude east and represented by Al-Hayadia, Farea Alsalam and Om Al-Habara depressions to characterize and classify the soils of these depressions. A semi-detailed soil survey was conducted using free-lance soil survey method depending on the variance of the observed traits particularly topography, texture, soil colour and natural vegetation. Pedons were detected and morphologically described and a disturbed soil samples were obtained from each horizon for the purpose of conducting physical and chemical analyses, as well as undisturbed soil samples to study the micro-morphological characteristics. There was increase in the total clay content with depth in the pedons of depressions to the level that meets the conditions for the formation of Argillic clay horizon, which was confirmed by the results of micro-slices as the total clay content in the alluvial horizons increased than in the loss horizons. The outcome also indicated that there was increase in calcium carbonate content in all samplesand calcic horizon was formed in most of study pedons. There was decrease in salt content in all studied horizons (0.09-1.24ds.m^{-1}). The gypsum in the soils ranged between 1.55 to 13.38%. Current study results showed the Typic Calciargids in first and second pedons, and Typic Haploargids in the third pedon.

***Keywords*:** Desert depressions, Gypsum, Pedons, Iraq

The western plateau region within Najaf province is one of the dry areas and occupies a large area of this province (Al-Jasany and Abd Al-Zahra 2020). Southern desert lands of Iraq represented about 76114 km^2 or about 1877120 ha which represented approximately 17% of the total area of the whole country and the arable lands about 40000 ha. The height of this area rises 100 -1000 meters above sea level, it also includes the Iraqi desert from a climatic point of view where a dry climate prevails and it constitutes the equivalent of 70% of the country climate. The area of depressions occupies 75970.35 km^2 from the total area of the southern desert (Al-kazaly 2020). Desert depressions are known as floods which are flat surface land lower than the level of neighboring areas and filled with sediments coming from the valleys or the surrounding hills through running water or torrential rains when heavy rain fall occur as these valleys penetrate the area or end there (Al-Ageely 2014). Al-Isawy et al (2019) indicated the most important natural characteristics of the desert depressions selected for agricultural investment especially those related to the nature of their geological formation and characteristics of the surface and soil as they have a direct impact on agricultural operations and chemical and physical properties of soil and groundwater. These two most important variables is affecting agricultural production in terms of water quality and the amount of water and its content of salts, mineral elements, as well as the texture and nature of the soil composition. Al-Hadithi and Al-Dabag (2008) classified the desert depression soils according to the modern American system within the scope of young or newly formed. These soils were affected by drought conditions which were reflected in the lack of moisture necessary for the activity of biological and chemical weathering processes as has negative effects on its diagnostic horizon. Al-Mohsen (2015) classified depression soils in southern desert from Muthanna province to Aridisols order, Argids sub-order, Calciargids great group and Vertic Calciargid sub-great group. The justifications and reasons for choosing the depressions for the study are the investment of desert areas especially the lowland areas in Najaf desert for agriculture which are characterized by good soils that increases the agricultural lands and thus reflects on the national economy and reduces the state of land degradation. Current study aims to classify and characterize the soils of desert depressions in Najaf province.

MATERIAL AND METHODS

Three pedons were selected based on the area of the depression in the south desert of Najaf province as the area of big depression between 600 to 1000 ha, medium size depression between 100 to 300 ha and the small depression is less than 100 ha (Fig. 1). Soil samples were obtained from each horizon and were air dried and sieved with 2mm sieve and kept for laboratory analysis. Undisturbed soil samples were obtained to study the micro-morphological characteristics.

Physical measures: The particle size distribution of soil samples was estimated using Hydrometer method described in Richards (1954).

Fig. 1. Study area of southern desert from Google earth

Chemical estimations: pH in soil water extract (1:1) was estimated following Mckeague (1978) mentioned in Raein et al (2003). Electric conductivity of soil water extract (1:1) was measured using conductivity bridge following Richards (1954) method which described in USDA (1954). Calcium carbonate was estimated using Jackson (1958) procedure. Gypsum was estimated using spectrophotometer (Richards 1954). Cation exchangeable capacity was measured according to Page et al (1982), while, the organic matter was estimated following Black and Walkely which described in Jackson (1958).

Micro-morphological characteristics: Micro-morphological characteristics were studied for undisturbed soil samples of horizon pedons by using thin section (Brewer (978).

RESULTS AND DISCUSSION

Morphological properties of study horizons: Thef morphological description indicated a variation in some morphological properties of each pedon of study area due to the influence of local factors particularly the topographic location, the area of depressions, the conditions of sedimentation and geomorphological processes. These factors helped to determine difference in the nature of the great morphological characteristics which are the type, thickness and arrangement of horizons that make each pedon and the accompanying distinctive characteristics of each horizon.

Pedon number (1) Al-Hayadia depression: This pedon is located in Al-Hayadia depression and rises 68 meters above sea level and has high content of lime and a lower content of gypsum as well as the presence of small pebbles were also observed within the horizons of this pedon. The depression area was about 5 ha located 40 km from Najaf city. The surface of the land is flat and has dry climate with lack of rain. This pedon is exploited by cultivation wheat, eggplant and maize. The description of morphological characteristics showed that the arrangement of horizons in this pedon was Ap, B_{tk}, B_t and C as indicated by presence of gain horizons type B, a process of transferring colloidal materials including clay and calcium carbonate from the upper horizons towards the lower horizons to the level at which the conditions for the formation of calcic horizon. Therefore, the soil of this pedon is considered developed soil as it affected by the condition of the torrential waters in this area and their movement within the soil body during the drought period as well as the agricultural use which helped in the movement of soil components towards the sub horizons by improving soil permeability and increasing porosity. The thickness of surface horizon was 12cm and the thickness of alluvial horizons reached 68cm.

The texture of Ap horizon was loamy-sandy, loamy-clay-sandy for B_{tk} horizon and loamy-sandy for B_t and C horizons. The variation of texture types in horizons of this pedon may be attributed to the effect of alluvial and loss processes that worked on the movement of the clay separated inside horizons (West 2000). This pedon showed morphological characteristics that reflect desert conditions in terms of lack of moisture and high temperatures which was reflected in the color of the soil as the wavelength of horizons Ap and B_{tk} was light yellowish brown (d, 4/6 YR 10), while, the color in B_t and C horizons was changed to very pale brown (d,4/7 YR 10). The reason for the change of colors in these horizons is due to the high content of calcium carbonate in them which act as a diluting agent for dark colors or the nature of mineral composition, the lack of organic matter, moisture and the accumulation of lime and gypsum in these horizons. Many white spots were found on horizon B_{tk} especially at 44cm depth in the form of gypsum nodes and calcareous spots and on C horizon at 70cm depth. In addition to a complete layer of limestone in the form of powder in this horizon. The difference in the color of the soil between different pedons and horizons in the same pedon reflects the state of variance that exists between the components of the soil and the nature of the internal conditions of those horizons especially the type and quantity of soil particles as well as its content of organic matter (Soil Survey Staff 1999). The soil was of a block type with sharp angles in horizons Ap and C and stability was medium due to the increase in the proportion of sand and the lack of organic matter with an increase in the content of calcium carbonate. In B_{tk} and B_t horizons, the construction of soil was of a block type with sharp angles with great clarity or stability and this is due to the high content of the separated clay in this horizon, in addition to the increase in loss and alluvial processes. There are many medium-sized pores in all horizons of this pedon andfor roots, were very fine and numerous in horizon Ap, and medium and few in horizon B_{tk}, fine and few in B_t horizon and rootless in horizon C. The texture of the soil in all horizons was little to very hard in the dry state, very brittle in the wet state and low in viscosity in very wet state, and the boundaries between horizons were clear and flat (Fig. 2 and Table 1).

Morphological description of pedon1

Soil classification: Typic Calciargide

Date: October 24,2020

Location: The middle of Al-Hayadia depression 40 km from Najaf city

Vegetation: Wheat, barley, maize and palm trees

Climate: Desert

Physiography: Najaf desert/Western plateau

Topography: Flat

Height: 68 meters above sea level

Origin matter: Calcareous sedimentary

Land use: Exploited for cultivation of wheat, barley, maize and palm trees

Describer: Sarah H. A. Al-ameedee and Ayad K. Ali

Additional notes: The presence of small pebbles in small amounts within horizons

Pedon number 2 Farea Alsalam depression: This pedon is located in the middle of Farea Alsalam depression as its area about 300 ha and it is 66.6 km from Najaf city and it rises 207 meters above sea level, unexploited agriculturally but has natural vegetation cover. The origin matter is calcareous and has a high content of calcium carbonate. The forth horizon in this pedon consists of a layer of stone and limestone blocks, the surface of the land is flat and has dry climate with lack of rain and the soil is shallow because of the rocky cut. The arrangement of horizons in this pedon was A, B_{tk}, and B_t and the color of soil was strong brown (d,6/5 YR 7.5) for A and B_{tk} horizons, while, it was light brown (d,4/6 YR 7.5) in B_t horizon. There was large variation in the texture where it was loamy-clay-sandy in horizon A, clay-sandy in B_{tk} and loamy-sandy in B_t horizon. The variation in texture in the vertical direction came as a result of the effect of sedimentation process from floods. In addition to the effect of alluvial and loss processes which in turn helped in variation in the distribution of soil separations and the difference in texture (Al-Mushhady 2003). The construction of the soil was of a block type with no angles and medium stability in horizons A and large in other horizons, the size of soil construction was fine. The predominance of few coarse roots were observed in horizon A and decreased significantly with depth, as for the pores, they were numerous and of precise size. The texture of the soil in all horizons was little to very hard in the dry state, very brittle in the wet state and low in viscosity in very wet state, and the boundaries between horizons were clear and flat (Fig. 3, Table 2).

Fig. 2. Morphological of pedon1

Morphological description of pedon2

Soil classification: Typic Calciargide

Date: October 29,2020

Location: The middle of Farea Alsalam depression 66.6 km from Najaf city

Vegetation: Natural vegetation cover

Climate: Desert

Physiography: Najaf desert/Western plateau

Topography: Flat

Height: 207 meters above sea level

Origin matter: Calcareous sedimentary

Land use: Non-exploited for cultivation (desert land)

Describer: Sarah H. A. Al-ameedee and Ayad K. Ali

Additional notes: The soil is shallow because of the rocky cut

Pedon number 3 Om Al-Habara depression: This pedon is located in the middle of Om Al-Habara depression with an estimated area of 1000 ha and it is 157.52km from Najaf city and it rises 268 meters above sea level, the surface of the

Table 1. Physical and chemical characteristics of pedon 1

Horizon	Depth /cm	Description
Ap	0-12	Light yellowish brown (10 YR 6/4 , d), sandy loam, moderate fine angular blocky, slight hard (d) very friable (m) slightly sticky and slightly plastic (w). Common medium pores. Many fine roots, clear smooth boundary.
B_{tk}	12- 50	Light yellowish brown (10 YR 6/4, d), sandy clay loam, strong fine angular blocky, hard (d) very friable (m) slightly sticky and slightly plastic (w), common medium pores, few medium roots, many accumulation of calcium carbonate and nodules gypsum at the depth of (44)cm, clear smooth boundary .
B_t	50 – 80	Very pale brown (10 YR 7/4,d), sandy loam, and common fine white mottles, strong fine angular blocky, slight hard (d) very friable (m) slightly sticky and slightly plastic (w), common medium pores, few fine roots, common fin white mottle and an entire layer of lime in the form of a powder at the depth of (70)cm, Clear smooth boundary.
C	+80	Very pale brown (10 YR 7/4,d) sandy loam, moderate fine angular blocky , slight hard (d) very friable (m) slightly sticky and slightly plastic (w), common medium pores, no roots, clear smooth boundary.

land is flat and it has dry climate with lack of rain, the land unexploited agriculturally but has natural vegetation cover. The arrangement of horizons in this pedon was A, B_{t1}, $B_{t2}$and B_{t3} and this pattern of arrangement indicates the presence of developed soils as a result of the nature of locational conditions of this pedon which helped to activate alluvial and loss processes in it. The thickness of A horizon was 14cm and 56cm in horizon B. The texture of horizons did not differ so much as horizon A texture was loamy-clay-sandy, while was clay in B_{t1}, $B_{t2}$and B_{t3} horizons. The appearance of soft texture in most horizons of this pedon may be attributed mainly to the sedimentary origin material rich in fine particles, in addition to gain and loss processes that helped in redistributing it within horizons of pedon (Al-Mohsen 2015). The color of all horizons soil was brown (d,4/5 YR 7.5), the construction of the soil was of a block type with no angles and medium stability in horizons A and strong stability in other horizons.The size of soil construction was very large and there was a large variation in roots and pores from A to B_{t1}. The texture of the soil in all horizons was little to very hard in the dry state, very brittle in the wet state and low in viscosity in very wet state The boundaries between A and B_{t1} horizons were interlaced wavy and between B_{t2} and B_{t3} horizons were clear and flat (Fig 4.,Table 3).

Morphological description of pedon3

Soil classification: Typic Haploargids

Date: October 29, 2020

Location: The middle of Om Al-Habara depression 157.52 km from Najaf city

Vegetation: Natural vegetation cover

Climate: Desert

Physiography: Najaf desert/Western plateau

Topography: Flat

Height: 268 meters above sea level

Origin matter: Sedimentary

Land use: Non-exploited for cultivation (desert land)

Describer: Sarah H. A. Al-ameedee and Ayad K. Ali

Physical properties: The predominance of clay and silt particles in all pedons as the clay percentage reached between 13.5 to 45.5%, when the lowest as in horizons 1 and 2 of first pedon and the highest was in the third horizon of third pedon (Table 4). This may be attributed to the conditions of sedimentation and the location of the pedon (Ndewy 1983), in addition to the low topographical location and the wide area of the depression.The effect of area and topographical location on the distribution of soil particles, where there was a dominance in clay particles with depth and exceeding of other depressions in which the area is less as a result of receiving large amounts of torrential water. Similarly, the proportion of sand increased in the depression with a smaller area, while, the depression that had a medium area increased it contains clay, silt followed by sand. Results also showed the presence of Argillic horizon in all study pedons in the depressions either has large, medium or small area due to the locational conditions and loss and alluvial processes activities.

Chemical characteristics: The f pH of most of study horizons ranged between 7.01 to 8.19, and the lowest was in the surface horizon of first pedon which located in the depression that has small area, while, the highest was in third

Fig. 3. Morphological of pedon number 2 and the natural vegetation cover

Fig. 4. Morphological of pedon number 3 and the natural vegetation cover

Table 2. Physical and chemical characteristics of.pedon 2

Horizon	Depth /cm	Description
A	0-15	Strong brown (7.5 YR 5/6,d), sandy clay loam, moderate fine Sub angular blocky. Slightly hard (d) very friable (m) slightly plastic and slightly sticky (w). Common fine pores, few coarse roots, clear smooth boundary.
B_{tk}	15-30	Strong brown (7.5 YR 5/6,d), sandy-clay, strong fine sub angular blocky, hard (d) very friable (m) slightly plastic and slightly sticky (w). Common fine pores, no roots, common fin white mottle and an entire layer of lime in the form of a powder, clear smooth boundary.
B_t	30-60	Light brown (7.5 YR 6/4,d), clay loam, strong fine sub angular Blocky, slightly hard (d) very friable (m) slightly plastic and slightly sticky (w). Common fine pores, no roots, clear smooth boundary.

horizon of third pedon within the depression of large area. These values are in the natural level of pH of Iraqi soils and it identical to what Bready (1974) indicated that the degree of pH in soils of dry and semi-dry areas ranges between 7-8. The salinity values ranged between 0.09 to 1.24ds.m^{-1}. This may be due to increasing of salinity level in studied soils is attributed to the good natural drainage condition of study soil which helped to dissolve and wash salts out of the soil (Al-Husayni 2010).

The content of calcium carbonate of pedons of depression soils was very high with a status of homogeneity in its vertical distribution and the proportions of those carbonate ranged between 35.75 to 66.75%. This may be attributed to the nature of the calcareous material, in addition to the lack of rainfall which leads to a weak redistribution of carbonate in the soil (Ibrahem 2007), and to the addition operations as a result of the sedimentation of transported materials from other sites by transporting factors such as water and its sedimentation in the subsurface horizons, causing an increase in calcium carbonate. All study pedons showed the quantitative and descriptive criteria required for the formation of lime horizon for calcium carbonate represented by calcic horizon as stated in Soil Survey staff (2010, 2014). As the accumulation of carbonate minerals is considered one of important processes in dry and semi-dry areas and is important indicator for soil classification (Khresat 2001; Pal et al 2003).

CEC values ranged between 5.00 to 40.60cmol.kg^{-1} as the highest value recorded in the second horizon of second pedon and the lowest in the second horizon of third pedon (Table 5). The reduction of cation exchangeable capacity in these pedons may be attributed to the decreasing of organic matter, the presence of calcium carbonate and its increase with depth as well as the presence of clay minerals of low ECE.This is in agreement with Al-Rawi (2005) and Sleman and Abd Al-Jabar (2012). The clay particles contribute actively in increasing cation exchangeable capacity in these soils . There was a decreasing in the content of organic matter in all study pedons as it ranged between 0.11 to 0.68%, where the lowest value was in 1, 2 and 4 horizons of first pedon, and the highest in the second horizon of second pedon. The reduction may be attributed to the lack of vegetation cover and dry climate desert with high temperatures which play significant role in the oxidation of organic matter (Konen et al 2003).There was a decreasing in gypsum content in surface horizons in general with little

Table 3. Physical and chemical characteristics of pedon 3

Horizon	Depth /cm	Description
A	0-14	Brown (7.5 YR 5/4,d), sandy clay loam ,moderate medium sub angular blocky. Slightly hard (d) friable (m) plastic and slightly sticky (w). Many fine pores, many fine and few coarse roots, interlaced wavy boundary.
B_{t1}	14-48	Brown (7.5 YR 5/4,d),clay, strong coarse sub angular blocky. Hard (d) friable (m) plastic and slightly sticky (w). Few fine pores, few coarse roots, interlaced wavy boundary.
B_{t2}	48-70	Brown (7.5 YR 5/4,d(, clay, strong very coarse sub angular blocky, hard (d) friable (m) plastic and slightly sticky (w). very few very fine pores, no roots. Clear smooth boundary .
B_{t3}	+70	Brown (7.5 YR 5/4,d), clay, strong very coarse sub angular blocky, hard (d) friable (m) plastic and slightly sticky (w). Very few very fine pores, no roots. Clear smooth boundary.

Table 4. Physical characteristics of pedons

Pedon No.	Location	Land Use	Land area	Horizon	Depth (cm)	Percent			Texture
						Sand	Silt	Clay	
1	Al-Hayadia	Exploited agriculturally	5 ha	Ap	0 - 12	64	22.5	13.5	Sandy loam
				B_{tk}	Dec-50	66.5	10	23.5	Sandy clay loam
				B_t	50 - 80	76.5	5	18.5	loam Sandy
				C	80+	74	12.5	13.5	loam Sandy
2	Farea Alsalam	Unexploited agriculturally	300 ha	A	0-15	71.5	7.5	21	Sandy clay loam
				B_{tk}	15-30	51.5	12.5	36	Sandy clay
				B_t	30+	41.5	20	38.5	Clay loam
3	Om Al-Habara	Unexploited agriculturally	1000 ha	A	0-14	59	15.5	25.5	Sandy clay loam
				B_{t1}	14-48	44	13	43	Clay
				B_{t2}	48-70	44	10.5	45.5	Clay
				B_{t3}	70	39	13	48	Clay

increasing in the subsurface horizons. The gypsum percentage in pedons ranged between 1.55 to 13.38% as the lowest value was recorded in the third horizons of second pedon, and the highest value in the second horizon of first pedon. This may be attributed to the increasing of calcium sulphate in the water of wells that irrigates the soil of this pedon as this area is exploited agriculturally unlike other pedons, or the dissolved of some minerals that contain calcium sulphate which leads to release sulphate and calcium the exchange with sodium ions (Sancho et al 2008, Silvera et al 2009, Vyshpolsky et al 2010, Al-Ganmy 2015).

Micro morphological features: The third horizon of first pedon consists of quartz, feldspar and rock pieces, in addition to clay and iron oxides in small percentage (Fig. 5). The porosity was presented as wholes between grains and gaps type bugs due to dissolution. The clays appeared in the form of round clay films linked to the system of pores. The pedons in medium and large depressions showed some micro morphological evidences that refer to the movement of part of soil contains from surface horizons toward subsurface horizons as a result of alluvial and loss processes, and one of these evidences is the presence of Argillic in second and third pedons (Fig. 6, 7). The second horizon of third pedon showed some gain and loss appearances (Ferri-Argillans, Orgaargillans), in addition to quartz, rock pieces, while its porosity was presented as gaps type vugs (Fig. 7).

Classification of study soils: Soils of study area were classified according to the modern American system (Soil Survey staff 2009) to sub great group level, as these soils are under Aridisols order. The determination of this order depends on the presence of diagnostic horizons and soil properties.

Aridisols order: Soils in this order are distinguished by Aridic moisture system as the average of water loss through evaporation and transpiration more than the average of rainfall in most months of the year in study area which ranged between 90 t0 100ml annually when the soil is dry with no moisture for long time. The soil temperature system was very hot (hyperthermic) in the study area.

Sub order Argids: This included soils that contain clay

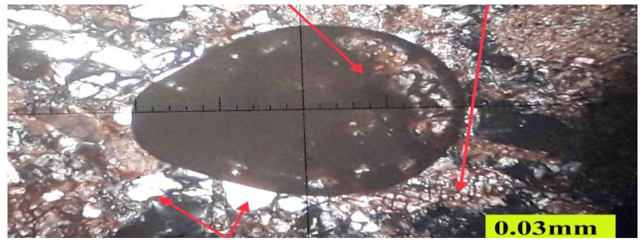

Fig. 5. Clay films and quartz in second horizon of first pedon

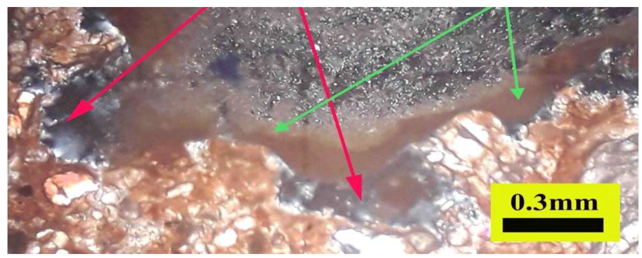

Fig. 6. Sediment clay films in a crescent shape

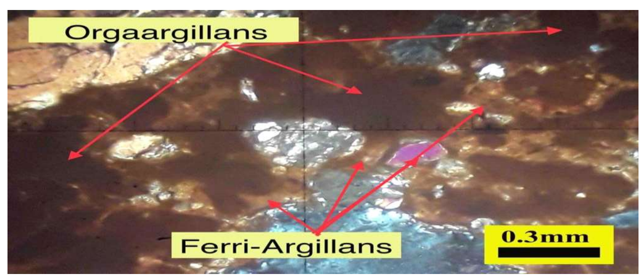

Fig. 7. Iron oxides and organic matter mixed with clay in second horizon of third pedon

Table 5. Chemical characteristics of pedons

Pedon No.	Location	Land Use	Land area (ha)	Horizon	Depth (cm)	PH	EC ds.m^{-1}	Caco3 (%)	Gypsum (%)	CEC cmolc. kg^{-1}	O.M (%)
1	Al-Hayadia	Unexploited agriculturally	5	Ap	0-12	7.01	1.18	56.25	13.07	23.27	0.11
				B_{tk}	Dec-50	7.19	1.08	61.75	13.38	18.49	0.11
				B_t	50-80	7.12	0.94	50	12.3	7.82	0.34
				C	80	7.16	1.24	58.75	12.11	22.01	0.11
2	Farea Alsalam	Unexploited agriculturally	300	A	0-15	7.97	0.09	48	5.09	31.22	0.34
				B_{tk}	15-30	7.98	0.09	53.5	1.65	40.6	0.68
				B_t	30	8.01	0.13	35.75	1.55	23.43	0.45
3	Om Al-Habara	Unexploited agriculturally	1000	A	0-14	7.53	0.15	60.5	6.6	28.57	0.11
				B_{t1}	14-48	7.91	0.09	60.5	4.79	5	0.45
				B_{t2}	48-70	8.07	0.09	62.75	6.39	26.54	0.34
				B_{t3}	70	8.19	0.09	66.75	4.22	23.76	0.45

horizon especially Argillic, decreasing of gypsum content, organic matter, salt content and locational factors was helped in the movement of some soil contains to the down such as clay which leads to increase subsurface horizons content of clay compared to surface horizons (Soil Taxonomy 1999).

Calciargids group: The most important great groups diagnosed within the sub order Calciargids and contain calcic horizon within the 150cm from soil surface. The great group Haploargids that represented other soils of Argids order was not present great group characteristics. The characteristics of sub great group were identical with the great group thus classified as Typic Calciargids and Typic Haploargids.

CONCLUSIONS

Characteristics of studied depressions soils are good for agriculture with low salinity level and acceptable drainage. The area of depression and water staying period was determined the main soil properties. All study pedons were affected by alluvial and loss processes of clay and lime, as well as the presence of argillic and calcic horizons. Morphological, chemical and physical properties indicated that most study soils are belong to Aridisols order, Argids sub order, Calciargids and Haploargids great groups and Typic Calciargids and Typic Haploargids sub great groups.

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Received 22 December, 2023; Accepted 22 April, 2024

Indian Journal of Ecology (2024) 51(4): 828-836
DOI: https://doi.org/10.55362/IJE/2024/4317

Manuscript Number: 4317
NAAS Rating: 5.38

Estimation of Monthly Evaporation in Hilly Regions of Uttarakhand using Machine Learning Techniques

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Abstract: Evaporation estimation is one of the complicated and important measures of the hydrological cycle due to its complex behavior for planning, management, and development of water resources. In this study, the Multivariate Adaptive Regression Splines (MARS) and Random Forest (RF) models were utilized to estimate mean monthly evaporation at Ranichauri. The mean monthly meteorological variables as, maximum and minimum temperature, morning and afternoon relative humidity, rainfall, morning and afternoon vapor pressure, wind speed, morning and afternoon wind direction, solar radiation, and evaporation were used for the development of the models. The results obtained by MARS and RF models were compared based on statistical indices root mean square error (RMSE), correlation coefficient (r), percent bias (PBIAS), and Nash-Sutcliffe efficiency (NSE). The results indicated that the performance of the RF model is better than the MARS model during the training period and the MARS model is better than the RF model during the testing period with nine input variables in estimating mean monthly evaporation at Ranichauri. Based on the present results when compared with the previous study's results done by many researchers, reveal that the methods can easily be implemented in hilly regions with greater accuracy.

Keywords: Gamma Test, Evaporation, Multivariate adaptive regression splines, Random forest

Evaporation is a nonlinear process that converts a liquid state into a gaseous state under different kinds of atmospheric processes. The meteorological variables (Temperature, wind speed, solar radiation, vapor pressure, humidity etc.) have a great association with the formation of evaporation. Due to the conversion of liquid into a gaseous form, the clouds are formed and then precipitation may occur. Evaporation is a major kind of water loss from the water bodies and water channels. Evaporation is considered a time-dependent function and a cumulative process, further, the estimation of isotopic evaporation is reliable during the dry season while estimations of isotopic loss fraction in the wet season behave as an isotopic mixing model of evaporated water-precipitation-runoff (Perez et al 2020). Evaporation estimation is one of the complicated measures of the hydrological cycle due to its complex behavior. For improving the development and management plans of the water resources the evaporation should be well estimated. Therefore, proper estimation and prediction of evaporation especially in arid and semiarid areas is of great importance to integrated water resources management and modeling studies (Ribot et al 2005, Nourani and Fard 2012, Malik and Kumar 2015). Modern hydrology is concerned with the distribution of water on the surface of the earth and its movement over and beneath the surface, and through the atmosphere (Davie 2008). The rate of evaporation depends upon the temperature variation, wind speed, atmospheric pressure, relative humidity, size of the water body, etc. Estimation of the water loss by evaporation is important for modeling, surveying and management of many projects related to hydrology and water resources systems (Shrisath and Singh 2010).

The direct and indirect methods can be used for estimation and evaluation of evaporation loss of any region. One of the direct methods for evaporation measurement is pan evaporation (Ep) (Eslamian et al 2008, Goyal and Ojha 2011). By using different types of techniques, the statistical parameters can be defined easily with a high degree of accuracy. Several studies have emphasized the need for accurate estimates of evaporation in hydrologic modeling studies (Sudheer et al 2002, Szilagyi and Jozsa 2009). Machine learning algorithms build a mathematical model based on sample data. For this, machine learning techniques are widely used in the estimation of time series, rainfall-runoff modeling, hydro informatics, and trend analysis. Machine learning is a computational statistics, that focuses on predictions and estimations using computers. It is a sub-area of artificial intelligence. Evaporation is one of the common examples, as it exhibits unique characteristics of complexity in nature and chaotic patterns so the estimation of evaporation is complex. Using machine learning techniques such as linear regression, decision tree, wavelet artificial neural network (WANN), random forest (RF), clustering algorithms, support vector regression (SVR), multivariate adaptive regression splines (MARS), artificial neural network (ANN) are well adapted for evaporation estimation (Cramer et al 2017, Dodla et al 2017, Khan et al 2018, Pham et al 2020). Recently for the monthly pan evaporation prediction the MARS, M5 model tree (MT) was coupled with a maximum overlap discrete wavelet transform (MODWT) for Turkey's Siirt and Diyarbakir stations (Ghaemi et al 2019), results revealed that the hybrid MARS model improves the accuracy for both the stations compared with the standalone models. The random forest (RF), which is tree-based simple, and robust to the outliers, has been widely used for pan evaporation and evapotranspiration estimation. It can easily deal with small and large datasets.

The CAT Boost was found to be the best and the RF model was the second best-performing model to map weekly pan evaporation with higher accuracy and effectiveness, followed by MLR, MARS, MNLSR, and M5Tree (Vishwakarma et al 2024).The daily pan evaporation modeling of Poyang lake, China was performed by four different models (M5 model tree, random forest, and gradient boosting decision tree) using daily meteorological variables out of which the gradient boosting decision tree is superior to the random forest model (Lu et al 2018). The machine learning techniques indicated that MARS model is superior to the LSSVM and M5 Tree for the modeling of daily evaporation of coastal cities of Turkey with a lack of input variables (Kisi 2015). The weekly evaporation prediction of different regions of India as Raipur, Karnal, Pattambi, and Anantapur using discriminant analysis, logistic regression, and random forest demonstrates that the random forest model predicts weekly evaporation accurately than the logistic regression, discriminant analysis (Rakhee et al 2020). The performance of the hybrid artificial neural network (ANN) models may be affected by importing meteorological variables such as solar radiation and deficit vapor pressure as inputs for daily evaporation estimation (Seifi *et al*., 2020 and Dumka *et al*., 2018). Among the four models (MLR, SVR, MARS, and RF) the RF model outperformed in both training and testing phases for weekly rainfall prediction (Markuna et al 2023).

Based on the above reviews, this study was conducted to analyze the potential of machine learning techniques (MARS, and RF) for the estimation of mean monthly evaporation of Ranichauri located at the foothills of the Himalayas in the Uttarakhand state of India. The combination of input variables was selected using the Gamma test to improve the performance of the models. A comparison between the models was described using statistical indices such as root mean square error (RMSE), correlation coefficient (r), Percent bias (PBIAS), and Nash Sutcliffe efficiency (NSE).

MATERIAL AND METHODS

Study area and data: Ranichauri is a hill station located in the Northern Indian state of Uttarakhand, in the Tehri Garhwal district. The altitudinal expansion of the study area is 1827 meters above sea level, the latitude is 30°18'40" N and the longitude is 78°24'35" E. The historically available meteorological data obtained for the analysis from 2008-2017 from the College of Forestry, Agromet Field Unit (AMFU), V.C.S.G. Uttarakhand University of Horticulture and Forestry, Ranichauri, Uttarakhand. The total data points were 120, out of the total data 75% (90 data points) were used in training, and the remaining 25% (30 data points) were used in testing periods. The mean monthly meteorological data of maximum and minimum temperatures (T_{max} and T_{min}), morning and afternoon relative humidity (RH_m, RH_a), evaporation (E), wind speed (W_s), morning & afternoon wind direction (Wd_m and Wd_a), solar radiation (SR), morning and afternoon vapor pressure (Vp_m and Vp_a) and rainfall (Rf) were collected from the study area. The warmest month of the study area was June with the highest mean monthly temperature of 29.6 °C, while the coolest month of the study area was January with the lowest temperature -0.551°C.

Gamma test (GT): The gamma test is a non-parametric approach and is based on the minimization of mean square error in the modeling (Agalbjorn et al 1997) and selects the combination of the most appropriate input variables from the original dataset to model the output with greater accuracy. The limitation of the GT is the input and output variables should be continuous to form a smooth system. The test can be achieved using win Gamma software and is efficient in evaluating the error present in the dataset. The combination of the most appropriate input variables is selected based on the obtained minimum value of Gamma static and V_{ratio}. The value of V_{ratio} is between 0 and 1, when its value is closer to 0 means the forecast ability of input combinations is high (achieved smooth system). Mathematically it can be elaborated as:

The estimate for Gamma static (Γ) is as follows:

$$y = A\delta + \Gamma \quad \ldots(2.1)$$

Where, y= output variable, A=Gradient, and Γ = Intercept (when $\delta = 0$)

$$V_{ratio} = \frac{\Gamma}{\sigma^2} \quad \ldots(2.2)$$

Where, σ^2 is the variance of output.

Multivariate adaptive regression splines (MARS): The Multivariate adaptive regression splines (MARS) model is the statistical technique and is a nonlinear and nonparametric approach that considers the separation of the datasets into splines. The MARS model is used for high dimensional analysis and non-linear multiple variable modeling. It can identify the nonlinear pattern with greater variables in the datasets. The MARS model was used as a regression method for high dimensional data and produced the appropriate results. It is based on the forward pass and backward pass approach. Using forward pass in the model results in potential knots to enhance the accuracy and better performance of the model. The backward pass is used to prune the modeling by eliminating the basis functions that do not significantly contribute to the best fit of the model.

The two parameters are the maximum number of basis functions and the maximum interaction level considered in the algorithm. Some other kinds of parameters are observed which can affect the generalized cross-validation (GCV), type of cross-validation, and degree of optimization in the modeling. The flexibility of the model was enhanced while selecting the adaptive knot in the data-fitting procedure. The appropriate knot selection method is the minimization of the least square method. The model generally constructs a pair of matrices for model fit representation in the analysis. The advantage of the MARS model to co-operate with the huge variety of predictors naturally includes continuous and categorical variables. The criteria for the selection of the model is that it evaluates the corresponding future lack-of-fit on the dataset.

The general form of the MARS model is as:

$$y = \beta_o + \sum_{i=1}^{m} \beta_i Y_i(x) \ldots (2.3)$$

Where, x = function of explanatory variables and their interactions, m= number of spline functions, Y_i (x) = basis function, β_i = set of coefficients and β_0= constant

The GCV method was developed in 1979 by spline pioneer Grace Wahba. In the MARS technique, the optimum model is selected based on the lowest value of GCV as well in the analysis and it does not correspond to the cross-validation. The GCV is a less expansive approach used to compare the subsets of the model. The GCV for the v^{th} model can be evaluated using the following formula:

$$GCV = \frac{1}{n} \frac{\sum_{i=1}^{n} [y_i - f_v(x_i)]^2}{(1-\frac{c_v}{n})^2} \ldots (2.4)$$

Where, $f_v(x_i)$= evaluated model in v^{th} step of the backward stage, C_v= cost-complexity = (1+ϕ) b+1, Φ= smoothing parameters value varies between 2-4,b= number of basis functions

Random forest (RF): Random Forest (RF) is a nonparametric approach in which explanatory variables may be either continuous or categorical (Leo Breiman in 2001). It is used for both regression and classification. The basic difference between the regression and classification in the model is that the correlation enhances with the number of features. In the regression approach of the RF model, the output is numerically identified and the training set is derived by the selection of random distribution of input and output features. It is an unsupervised learning model and helps to minimize the generalization error and detect the outliers in the analysis and is a tree-based approach and each tree depends on the selection of variables randomly from the dataset and the trees are selected in the model based on the binary recursive partitioning.

The classification and regression tree (CART) based approach uses the binary tree data algorithm for modeling and further the decision tree approach is improved by increasing the number of trees for better generalization of model (Breiman 2001. The selection of the variables is based on the minimum residual sum of the square error of the explanatory variables for the section of the split. The RF model contained a collection of tree predictors (Yu et al 2017). The out-of-bag (OOB) estimates are defined as the rate of error of the out-of-bag classifier used in the training set. The bagging concept is used in the model to increase the accuracy when features are randomly selected and to evaluate the generalization error, strength, and correlation in the model. For complex problems, this model is used to identify the analysis by making trees. The number of trees (n tree) and the number of variables on each node (mtry) are important terms that can easily affect the accuracy and performance of the model. There are some parameters like the total number of explanatory variables that are selected randomly, the total number of trees in the model, and the size of trees that are required to be tuned to improve the accuracy of the model for its better performance. The error in regression is defined as follows:

$$MSE_{oob} = \frac{1}{N} \sum_{i=1}^{N} y_i - f_{oob}\ (x_i)^2 \ldots (2.5)$$

Where, $f_{oob}\ (x_i)$= OOB forecasting for i^{th} observations.

Performance evaluation of models: The performance evaluation of the models is based on the graphical comparison between the observed and estimated evaporation. The quantitative performance evaluation is based on statistical parameters such as root mean square error (RMSE), correlation coefficient (r), percent bias (PBIAS), and Nash-Sutcliffe efficiency (NSE).

Root Mean Square Error (RMSE): It is defined as the square root of the mean of the squared difference between the observed and estimated values. The lower value elaborates on the evaluation accuracy of the model.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (E_{oi} - E_{pi})^2}{n}} \ldots (2.6)$$

Correlation coefficient (r): The correlation coefficient evaluates the variance and proximity between the observed and estimated values. It varies between -1 and 1 and zero value represents that there is no relationship between observed and estimated values.

$$r = \frac{\sum_{i=1}^{n}(E_{oi}-\overline{E_{oi}})(E_{pi}-\overline{E_{pi}})}{\sqrt{\sum_{i=1}^{n}(E_{oi}-\overline{E_{oi}})^2}\sqrt{\sum_{i=1}^{n}(E_{pi}-\overline{E_{pi}})^2}} \quad ...(2.7)$$

Percent Bias (PBIAS): The PBIAS evaluates the average tendency of estimated values to be larger or smaller than the observed values. The desirable value of PBIAS is zero. The model with low-magnitude values indicates the modeling accuracy. The positive and negative values of PBIAS indicate the over-evaluation bias and under-evaluation bias.

$$PBIAS = \frac{\sum_{i=1}^{n}(E_{pi}-E_{oi})}{\sum_{i=1}^{n}(E_{oi})} \times 100 \quad ...(2.8)$$

Nash Sutcliffe efficiency (NSE): It was introduced by Nash and Sutcliffe (1970) and value varies between –∞ to 1. The NSE was used to define the accuracy and precision of the model. Its value near 1 represents the perfectness of the model and sensitivity to the outliers present in the dataset. It results in the variance of the observation for models and is used widely in the field of hydrology.

$$NSE = 1 - \frac{\sum_{i=1}^{n}(E_{oi}-E_{pi})}{\sum_{i=1}^{n}(E_{oi}-\overline{E_{oi}})^2} \quad ...(2.9)$$

Where E_{oi}= i^{th} observed evaporation, E_{pi} = i^{th} predicted evaporation, E_{oi} = mean of i^{th} observed evaporation, E_{pi} = mean of i^{th} predicted evaporation and n= total observations.

RESULTS AND DISCUSSION

Input variables selection using GT: The selection of a combination of appropriate input variables for evaporation estimation is a complex process when the data is non-linear. In the present study, combinations of appropriate input variables were selected using the Gamma test to map mean monthly evaporation at Ranichauri for MARS and RF models. The combination of best input variables was selected with the minimum value of gamma (0.00095), gradient (0.10541), standard error (SE) (0.00700), and V_{ratio}(0.00382). Therefore, the combination of appropriate input of nine variables as maximum temperature (T_{max}), minimum temperature (T_{min}), rainfall (Rf), morning relative humidity (RH_m), morning vapor pressure (Vp_m), wind speed (W_s), morning wind direction (Wd_m), afternoon wind direction (Wd_a), and solar radiation (SR) was used for the MARS and RF models to estimate mean monthly evaporation for Ranichauri. The maximum mean monthly evaporation was found 5.65 mm and the minimum mean monthly evaporation was 0.93 mm (Table 1 and Fig. 1). The GT performed on a different set of input variables and parameters estimated for Ranichauri (Table 2).

Estimation of mean monthly evaporation using MARS and RF Models at Ranichauri: According to the GT results, the best combination of input variables was selected as T_{max}, T_{min}, Rf, RH_m, Vp_m, W_s, Wd_m, Wd_a, and SR with a minimum value of Gamma and V_{ratio} which indicates that these variables have a significant effect on evaporation. The mean monthly evaporation for the study area was estimated using MARS and RF models based on historically available data. The data is divided into training (75%) and testing periods (25%) for the validation of models. Twelve meteorological input variables were used to estimate daily pan evaporation of summer maize using MARS model with empirical Shuttleworth-Wallace, Priestley-Taylor, back-propagation neural networks and, Two-Patch models (Shan et al 2020). The values of statistical indices for the MARS model during training and testing periods are RMSE=0.32 and 0.17, r=0.97 and 0.98, PBIAS=0.00 and 0.00 (the value of PBIAS is desirable to 0, it means the estimation of mean monthly evaporation using MARS model is accurate), and NSE=0.93 and 0.96. Similarly, the values of statistical indices for the RF model during training and testing periods are RMSE=0.20 and 0.23, r=0.99 and 0.98, PBIAS=0.10 and 0.80, and NSE=0.97 and 0.90, respectively (Table 3). Thus, the performance of the MARS and RF models was different according to the statistical indices for the estimation of evaporation.

The scatter plot between observed and estimated values of mean monthly evaporation for the MARS and RF models are plotted during the training and testing period (Figs. 2, 4, 6

Table 1. Basic statistics of the selected input variables

Statistical parameter	Input variables (2008-2017)									
	T_{max} (℃)	T_{min} (℃)	Rf (mm)	RH_m (%)	Vp_m (mm Hg)	W_s (Km/h)	Wd_m (◦)	Wd_a (◦)	SR (h)	E (mm)
Maximum	29.06	17.8	559.5	97.74	16.34	12.56	198.4	220.6	10.15	5.65
Minimum	9.3	-0.55	0	45.1	4.22	1.28	2.58	4.90	2.38	0.93
Mean	19.90	10.02	83.87	78.7	9.71	4.01	62.4	102.6	6.612	2.53
Median	21.19	10.00	28.1	78.26	8.78	4.14	29.37	80.55	6.89	2.25
Variance	20.51	28.18	1680	158.0	16.97	1.98	3532	7269	3.35	1.34
S. D.	4.52	5.31	129.6	12.57	4.12	1.41	59.43	85.26	1.83	1.16

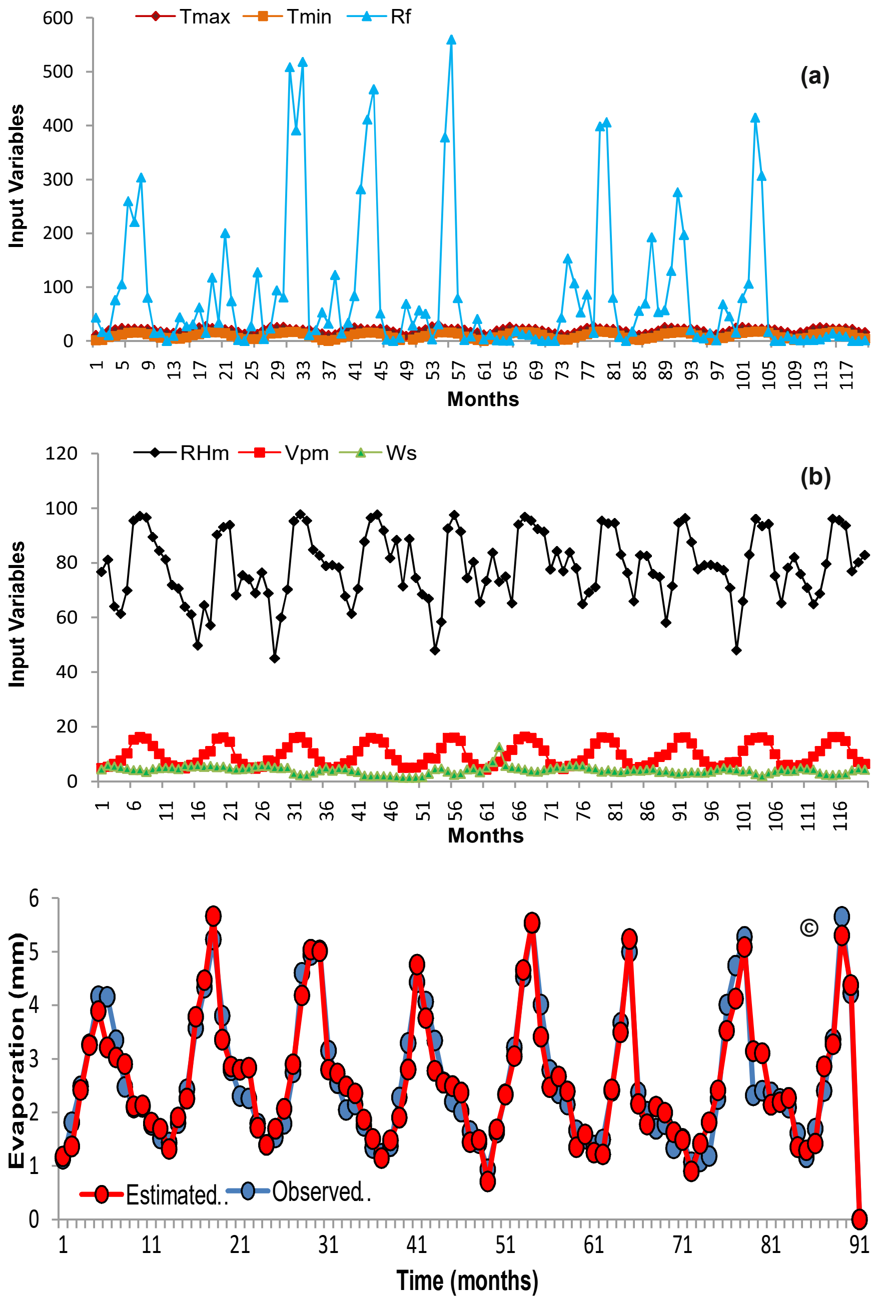

Fig. 1. (a), (b), (c). Time series plot of monthly input variables at Ranichauri

Table 2. Gamma test for input variable selection of Ranichauri

Output	Input combination	Mask	Gamma	Gradient	SE	V_{ratio}
E	T_{max}, T_{min}, Rf, RH_m, RH_a, Vp_m,Vp_a, W_s, Wd_m,Wd_a, SR	11111111111	0.001	0.091	0.008	0.006
E	T_{max}, T_{min}, Rf, RH_m,RH_a, Wd_m,Wd_a, SR	11111000111	0.011	0.011	0.009	0.045
E	T_{max}, RH_m, RH_a, Vp_m	10011100000	0.032	0.021	0.004	0.131
E	T_{max}, Rf, RH_a, W_s	10101001000	0.036	0.068	0.004	0.144
E	T_{min}, Rf, Vp_a,Wd_m,Wd_a, SR	01100010111	0.010	0.249	0.009	0.040
E	Vp_m, Wd_a	00000100010	0.145	-0.267	0.016	0.583
E	T_{max}, T_{min}, Vp_m,Vp_a,W_s, Wd_m,Wd_a	11000111110	0.006	0.227	0.007	0.025
E	T_{max}, Vp_m,Wd_m	10000100100	0.027	0.583	0.005	0.108
E	T_{max}, T_{min}, Rf, RH_m, Vp_m,W_s, Wd_m,Wd_a, SR	11110101111	0.001	0.105	0.007	0.003
E	T_{max}, T_{min}, Rf, RH_m, Vp_m,W_s, Wd_m	11110101100	0.014	0.093	0.004	0.057
E	T_{max}, T_{min}, Rf, Vp_m,Vp_a,W_s, Wd_m,Wd_a, SR	11100111110	0.008	0.119	0.006	0.035

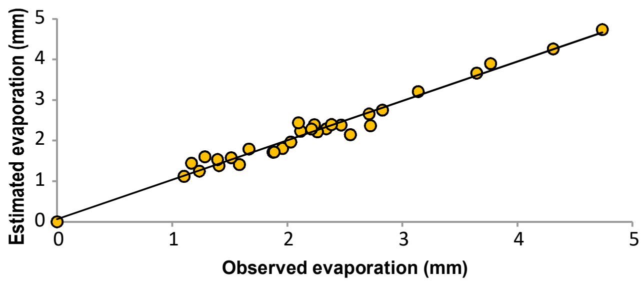

Fig. 2. Scatter plot between observed and estimated mean monthly evaporation using the MARS model for the training period

Table 3. Statistical indices for MARS and RF Models

Statistical indices	Training period		Testing period	
	MARS	RF	MARS	RF
RMSE	0.32	0.20	0.17	0.23
r	0.97	0.99	0.98	0.98
PBIAS	0.00	0.10	0.00	0.80
NSE	0.93	0.97	0.96	0.90

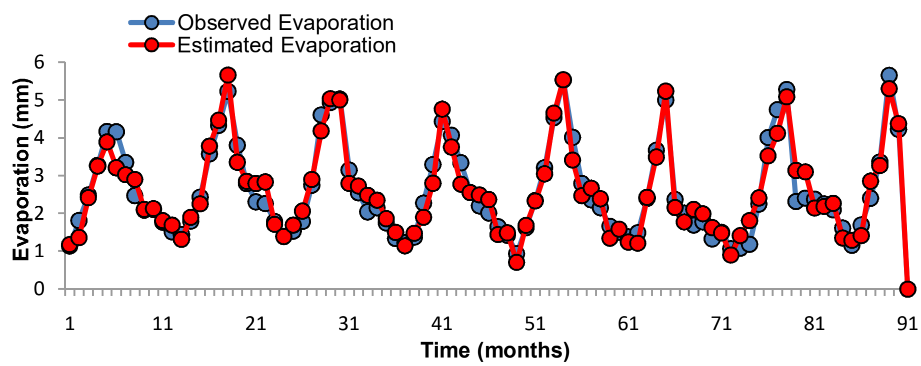

Fig. 3. Temporal variation between observed and estimated mean monthly evaporation by MARS model for the training period

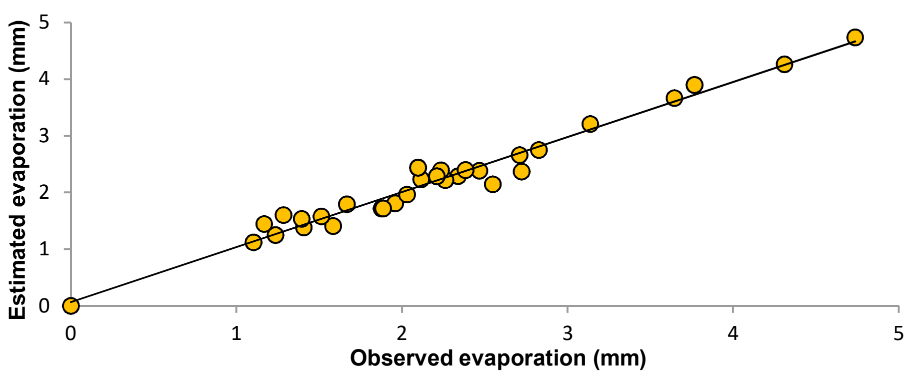

Fig. 4. Scatter plot between observed and estimated mean monthly evaporation using MARS model for the testing period

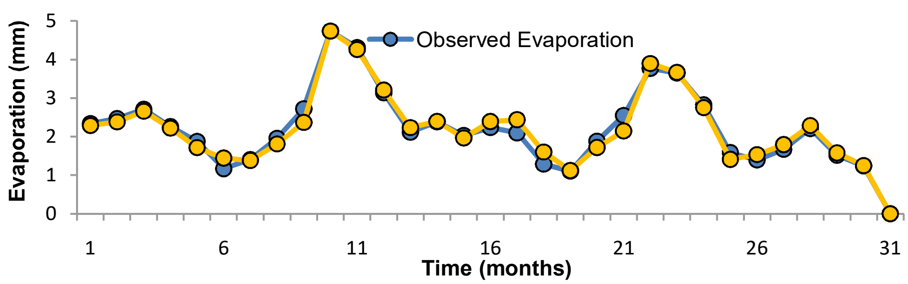

Fig. 5. Temporal variation between observed and estimated mean monthly evaporation by MARS model for the testing period

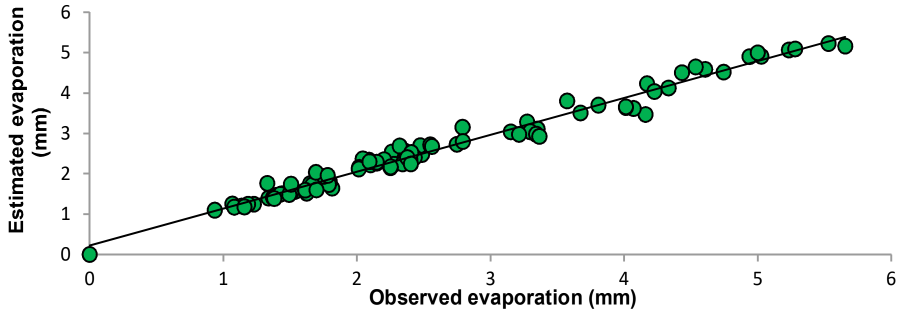

Fig. 6. Scatter plot between observed and estimated mean monthly evaporation using RF model for the training period

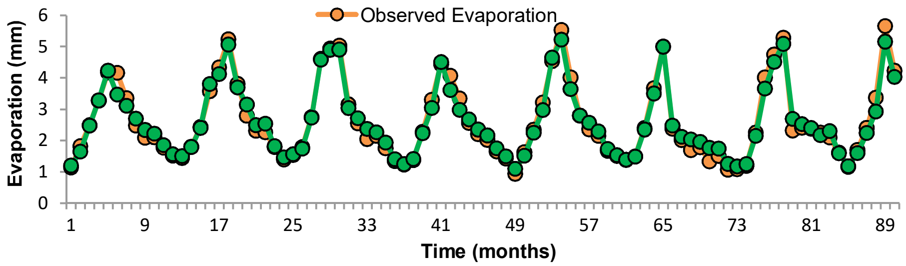

Fig. 7. Temporal variation between observed and estimated mean monthly evaporation by RF model for the training period

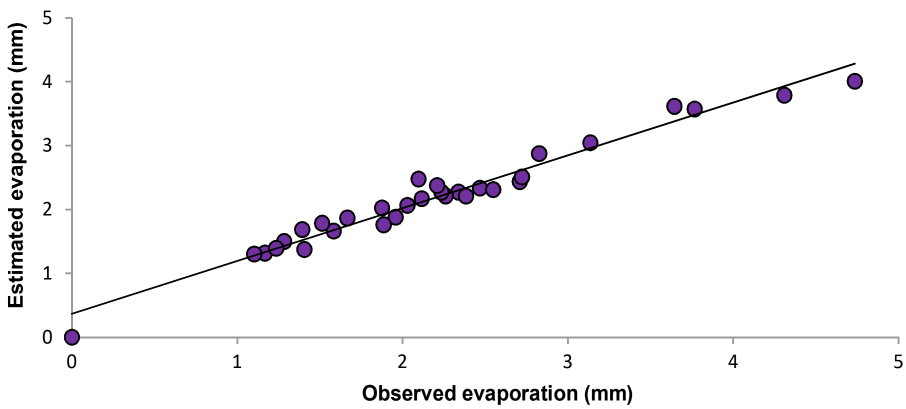

Fig. 8. Scatter plot between observed and estimated mean monthly evaporation using RF model for the testing period

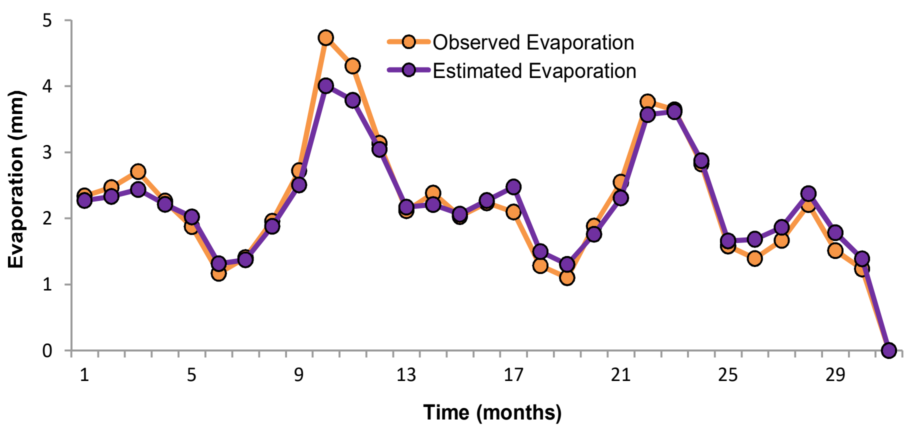

Fig. 9. Temporal variation between observed and estimated mean monthly evaporation by RF model for the testing period

and 8, respectively). The temporal variation between observed and estimated mean monthly evaporation by MARS and RF model for the training and testing period are plotted (Figs. 4, 5, 8, 7 and 9, respective). The observed and estimated values of mean monthly evaporation match closely for the RF model in the training period and the MARS model in the testing period. The value of R^2 and RMSE of approximately (0.950 and 0.910) for training phase and for testing phase (0.62 and 0.910) respectively using RF and MARS models which shows model simulation accuracy for evaporation (Wang et al 2023). The performance of the models with respect to the statistical parameters can be easily identified from Figure 11 for the training set and Figure 12 for the testing set.

Comparison of statistical indices (RMSE, r, and NSE) indicates that the MARS model performs better during the testing period and the RF model performs better during the training period. The models perform with better accuracy concerning RMSE, r, and NSE. According to the given values of PBIAS, the MARS model performs better for both training and testing periods as compared to the RF model. Furthermore, the comparison between our models and the MLR, MNLSR, MARS RF, CAT Boost, M5Tree proposed by Vishwakarma et al (2024) for estimation of evaporation revealed significant findings.

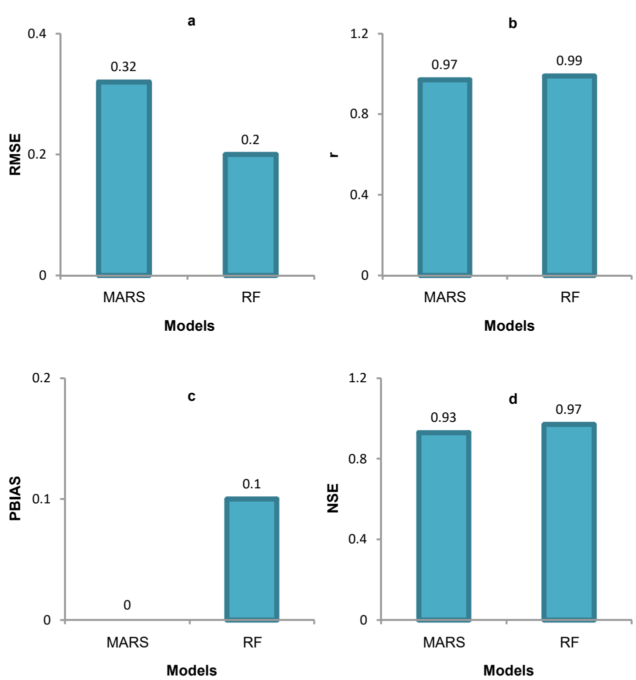

Fig. 10. Comparison of different performance measures between MARS and RF models for training set: (a) RMSEvs. models, (b) rvs. models, (c) PBIASvs. models, (d) NSEvs. models

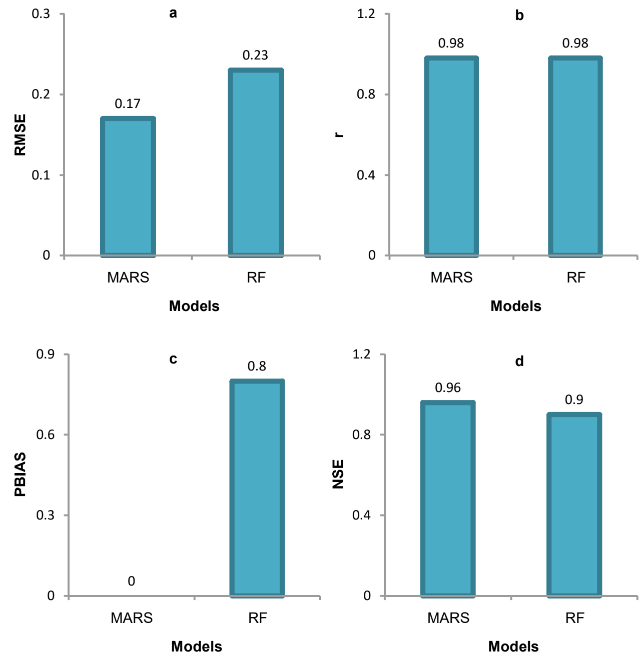

Fig. 11. Comparison of different performance measures between MARS and RF models for testing set: (a) RMSEvs. models, (b) rvs. models, (c) PBIASvs. models, (d) NSEvs. models

CONCLUSIONS

This study evaluates the performance of the machine learning models (MARS, and RF) for the estimation of mean monthly evaporation at Ranichauri. The combination of appropriate input variables was selected using the Gamma test to map evaporation for MARS and RF models. The combination of nine input variables as T_{max}, T_{min}, Rf, RH_m, Vp_m, W_s, Wd_m, Wd_a, and SR based on GT was identified as the most significant for mean monthly evaporation estimation of the study area. The performance of the RF model was found to be better than the MARS model in the training period and the MARS model was found to be better than the RF model in the testing period for the estimation of mean monthly evaporation at Ranichauri. So the performance of both the models was found to be significant for mean monthly evaporation estimation during the study period.

ACKNOWLEDGEMENT

The authors thank AMFU, V.C.S.G. Uttarakhand University of Horticulture and Forestry, Ranichauri, Tehri Garhwal district, Uttarakhand for providing support to collect the dataset to make the present study possible.

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Indian Journal of Ecology (2024) 51(4): 837-841
DOI: https://doi.org/10.55362/IJE/2024/4318

Manuscript Number: 4318
NAAS Rating: 5.38

Impact of Crop Phenology and Environmental Factors on Rice Leaf Folder Infestation in Middle Gangetic Plains of India

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Abstract: The present study was an attempt to examine the impact of crop growth stages and environmental factors on rice leaf folder infestation in middle Gangetic plains. Crop phenology was the most significant biotic factor influencing pest population density. Rice leaf folder infestation was highest during the crop's booting stage, with 11.15and 13.16 percent leaf damage per hill in *kharif* 2018-19 and 2019-20, respectively. During *kharif* 2018-19, the rice leaf folder infestation began in 31st SMW with 1.90 percent damaged leaves per hill and peaked at 38th SMW with 11.60 percent damaged leaves per hill In *kharif* 2019-20, pest infestation began in 31st SMW with 1.00 percent leaf damage per hill in the field and increased to a peak during the 39th SMW with 14.66± percent leaf damage per hill. The abiotic factors such as rainfall, morning relative humidity, average relative humidity and maximum temperature had a significant positive influence on rice leaf folder infestation. These findings could be used to create precise management strategies to keep pest infestation in the rice ecosystem below the economic threshold level.

Keywords: Rice, *Cnaphalocrocis medinalis*, Pest infestation, Crop phenology, Abiotic factors

In Asia's rice ecosystem, over 250 insect pests and 350 beneficial arthropod species have been recorded (Ali et al 2020). In India, out of more than 100 total insect pests, twenty insect pests species are considered economically important because they cause severe damage to rice production (Heinrichs et al 2017, Ali et al 2020). In the last two decades, rice crop yield losses have increased due to widespread outbreaks of certain insect pests of rice in the Indian subcontinent, among which rice leaf folder (*Cnaphalocrocis medinalis* Güenée) (Lepidoptera; Pyralidae) is the major one (Kumar et al 2023), which causes significant yield loss in India, China, and other Asian countries (Fahad et al 2021). Rice in yield losses of up to 20-30% in general (Sharma and Raju 2018) and under epidemic conditions yield losses can be up to 80% (Sachin et al 2023). Relied heavily on insecticides to manage rice insect pests, sometimes using indiscriminate doses of chemicals pesticides with similar modes of action, resulting in insecticide resistance, pest resurgence, outbreaks of secondary or minor insects, health hazards, environmental pollution, destruction of natural enemies and beneficial fauna of the rice ecosystem, and so on (Möhring et al 2020, Ali et al 2021).

The relationship between the insect pest and its host is an important factor in determining whether the insect develops and reproduces. On the other hand, the plant's susceptibility to insect attacks is determined by its chemical constituents and morphological features (Faruq et al 2018). Thus, selecting a stage-specific pest management strategy is an important step in pest management because pest-host interactions determine the species level of infestation and crop stage. Climate variables are also recognised as significant factors in the abundance and distribution of insects (Lantschner et al 2024). Regular observations of pest populations in the field useful to determine the incidence of insect pests in relation to several environmental factors such as rainfall, relative humidity, temperature, wind direction, and sunshine hour also helps to investigate the impact on the rise and fall of insect populations, as well as their survival, growth, multiplicative potential, and tritrophic interactions (Tomar 2010, Yang et al 2024). It is also useful in the development of prediction and forecasting models, which could help in a decision support system for plant infestation and pest dynamics is used to ensure timely pest management preparation and crop losses are avoided (Sharma et al 2018). With these considerations in mind designed study to show the incidence pattern of rice leaf folder in relation to crop growth stages and weather variables over two consecutive *kharif* seasons, 2018-19 and 2019-20.

MATERIAL AND METHODS

Pure seeds of the test variety (cv. Swarna sub-1) were procured from the University's Agricultural Research Farm (24° 56' N to 25° 35' N latitude and 82° 14' E to 83° 24' E longitude) and sown in nursery beds on the 5th and 9th of July in *kharif* 2018-19 and 2019-20, respectively. Twenty-one-day-old seedlings were transplanted at a rate of 2-3 seedlings per hill on a 50-square-meter plot in four replications. All recommended agronomic practises were implemented. Throughout the experiment, no plant protection measures were used for any of the insect pests.

Rice leaf folder infestation was recorded in unprotected plot at 7-day intervals beginning with the first occurrence or initiation of pest infestation and continuing until crop maturity. The observations were made by counting the number of damaged and total leaves on 10 randomly selected hills in each replication. Meteorological data (temperature, relative humidity, precipitation, wind speed, and sunshine time) were collected concurrently from the meteorological observatory at the Agricultural Research Farm, Institute of Agricultural Sciences, BHU, Varanasi.

The effect of abiotic factors on rice leaf folder infestation was assessed using Pearson's correlation test. The same test was used to compare the infestation of rice leaf folder at the phenological stages of the plant (seedling, tillering, booting, flowering, and ripening) in both cropping years. Means were compared using Tukey's test ($p < 0.05$) using SPSS Pearson's correlation and Tukey tests (Version 27).

RESULTS AND DISCUSSION

Impact of crop phenology on the infestation of rice leaf folder: The phenological stages of rice plants had a significant impact on rice leaf folder infestation. During *kharif* 2018-19, larvae feeding on different stage plant leaves showed effects of crop growth stages (Table 1). All rice-growing stages had a significant impact on rice leaf folder damage. There were no damaged leaves found on the plant during its seedling stage. The crop's booting stage had the highest percentage of damaged leaves (11.15 percent per hill), followed by the tillering stage (6.95 percent per hill) and did not differ significantly from the flowering stage (6.86 percent per hill).

Table 1. Infestation of rice leaf folder during different phenological stages of rice (*Kharif* 2018-19 and 2019-20)

Phenological stage	Rice leaf folder infestation (% leaf damage)	
	Kharif 2018-2019	*Kharif* 2019-20
Seedling	0.00^c	0.00^c
Tillering	6.95^b	7.66^b
Booting	11.15^a	13.16^a
Flowering	6.86^b	8.77^b
Ripening	2.50^c	1.83^c
$F_{(4/15)}$	57.78	51.66

Mean followed by the same alphabets in columns were not statistically different by the Tukey test ($p < 0.05$)

The crop experienced the least damage during the ripening stage (2.50 % damaged leaves per hill). Similar results were observed in *kharif* 2019-20 and leaf damage caused by the rice leaf folder differed significantly along all rice growing stages (Table 1). The booting stage had the most damaged leaves (13.16percent per hill), followed by the flowering stage, which was not significantly different from the crop's tillering stage. The crop showed minimal damage during the ripening stage (1.83± percent damaged leaves per hill), with no damaging symptoms observed during the seedling stage.

The pest infestation began in rice fields during the early tillering stage, and the population was expected to grow gradually over generations. The highest infestation of rice leaf folder occurred during the crop's booting stage. The leaf folder infestation was more detrimental at the grain filling stage. Chakraborty and Deb (2011) also observed the most leaf folder damage during the crop's maximum tillering stage. The leaf folders consumed the majority of leaf mass when feeding on crop booting stage leaves. Previous studies reveal that the abundance of chemical compounds in leaves changes with the rice growth stage (Sun et al 2013), particularly, the nitrogen content was highest in the leaves of the plants during the tillering and booting stages (Chang et al 2018). The high nitrogen nutritional level of tillering and booting stage leaves, combined with increased consumption of these leaves by rice leaf folder larvae, may have contributed to their superior performance. Although secondary metabolites in rice change dramatically during development (Hu et al 2016). Sharma et al (2023) also observed that the tillering and booting stages of the rice crop are more susceptible to pest infestation. Thus, crop growth stages significantly influenced rice leaf folder infestation.

Impact of weather variables on the infestation of rice leaf folder: Rice leaf folder infestations ranged from 1.90 percent damaged leaves per in first week of August (31^{st} SMW) to 11.60 percent damaged leaves per in third week of September (38^{th} SMW) during *kharif* 2018-19 (Table 2). The rice leaf folder infestation began and reached its peak infestation after that, the percentage of damaged leaves steadily decreased, eventually reaching zero when the crop reached maturity (Figure 1). In *kharif* 2019–20, rice leaf folder infestations ranged from 1.00 percent damaged leaves per hill in the first week of August (31^{st} SMW) to 14.66 percent damaged leaves per hill in the fourth week of September (39^{th} SMW) (Table 3). The rice leaf folder infestation began and reached its peak, after that infestation gradually decreased and reached zero levels at the harvesting stage of the crop (Fig. 1). The incidence of the leaf folder was slightly higher during the second-year trial, which could be attributed to seasonal differences between years.

Earlier, studies on the rice leaf folder, *C. medinalis* revealed that the infestation began during the 31st SMW and reached peak infestation in the 37th SMW (Nirala et al 2015). However, Vanitha et al (2015) observed that the peak of rice leaf folder activity occurred between August and September, and then declined from October onward, whereas Rasul et al. (2019) confirmed that peak population of *C. medinalis* occurred during the fourth week of September. Shyamrao and Raghuraman (2019) also observed maximum damage at tillering stage. Chatterjee et al (2021) reported *C. medinalis* activity beginning in the second week of August and remaining low to moderate throughout the tillering stage. The infestation increased in October and peaked at the end of the month. The slight variation that could be attributed to location changes, but they confirm the similar seasonal occurrence pattern. These reports strongly support the current finding.

The correlation co-efficient study during *kharif* 2018-19 and 2019-20 (Table 4), the pooled data revealed that maximum temperature (r = 0.527), morning relative humidity (r = 0.465), average relative humidity (r = 0.541) all had significant positive relationship with *C. medinalis* infestation and evening relative humidity (r = 0.278), sunshine hours (r = 0.182) had non-significant positive relationship with *C. medinalis* infestation. While, rainfall had significant negative (r = - 0.501) and minimum temperature non-significant negative (r = - 0.255) association with the infestation of *C. medinalis.* Increase in leaf folder infestation was associated to rising temperatures and morning relative humidity. This could support the finding that warming conditions caused by global climate change have a significant impact on the abundance of

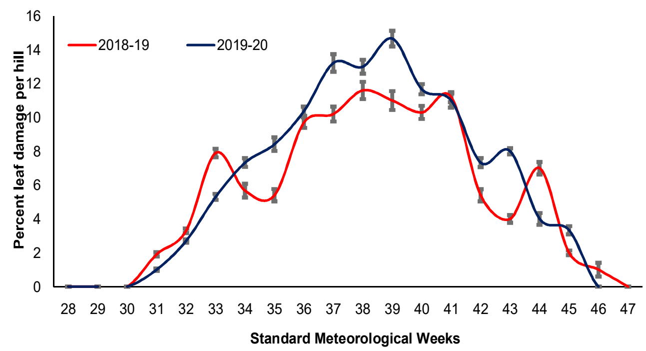

Fig. 1. Fluctuation of rice leaf folder infestation during *kharif* 2018-19 and 2019-20 (from 28th to 47th SMW). Standard errors are indicated (n = 10)

Table 2. Influence of abiotic factors on the rice leaf folder infestation during *kharif* 2018-2019

SMW	RF	T_{max}	T_{min}	T_{avg}	RH_M	RH_E	RH_A	SSH	RLF
28	11.60	35.50	26.00	30.75	83.00	58.00	70.50	7.80	0.00±0.00
29	78.40	33.30	25.40	29.35	86.00	66.00	76.00	4.90	0.00±0.00
30	91.40	28.40	23.60	26.00	88.00	87.00	87.50	0.30	0.00±0.00
31	86.80	28.10	22.80	25.45	93.00	88.00	90.50	0.10	1.90±0.12
32	26.60	31.80	24.70	28.25	92.00	77.00	84.50	4.80	3.30±0.13
33	20.40	33.30	25.30	29.30	88.00	70.00	79.00	5.90	7.90±0.25
34	154.80	31.10	24.00	27.55	91.00	81.00	86.00	2.60	5.67±0.40
35	118.40	32.00	24.30	28.15	93.00	77.00	85.00	4.40	5.40±0.36
36	94.60	30.60	23.60	27.10	91.00	79.00	85.00	4.70	9.70±0.31
37	0.00	32.40	23.60	28.00	88.00	68.00	78.00	7.80	10.20±0.44
38	53.40	32.50	22.80	27.65	88.00	65.00	76.50	6.80	11.60±0.51
39	0.00	33.40	25.90	29.65	92.00	63.00	77.50	8.50	11.00±0.55
40	0.00	34.20	20.80	27.50	83.00	51.00	67.00	9.10	10.30±0.38
41	0.00	31.00	20.00	25.50	89.00	61.00	75.00	6.00	11.20±0.29
42	0.00	33.40	16.50	24.95	84.00	40.00	62.00	9.60	5.40±0.36
43	0.00	31.50	14.40	22.95	89.00	41.00	65.00	9.10	4.00±0.22
44	0.00	31.10	16.70	23.90	91.00	48.00	69.50	8.70	7.00±0.36
45	0.00	28.20	12.20	20.20	87.00	44.00	65.50	7.70	2.00±0.13
46	0.00	29.00	11.70	20.35	89.00	45.00	67.00	7.90	1.00±0.16
47	0.00	27.90	10.10	19.00	88.00	44.00	66.00	8.70	0.00±0.00

Note: SMW (Standard Meteorological Week), RF (Rainfall, mm), T_{max} (Maximum temperature °C), T_{min} (Minimum temperature °C), T_{avg} (Average temperature °C), RH_M (Morning relative humidity, %), RH_E (Evening relative humidity, %), RH_A (Average relative humidity, %), SSH (Sunshine hours), RLF (Rice leaf folder, % incidence per hills) insect pest species (Ali et al. 2019). Kumar et al. (2023) also observed that relative humidity was positively correlated with rice leaf folder damage. Shyamrao and Raghuraman (2019) found a significant positive correlation between leaf folder population and maximum temperature, as well as a highly significant negative correlation with rainfall. Rasul et al. (2019) reported that average temperature had a negative effect on leaf folder population while relative humidity and rainfall had a positive effect on *C. medinalis* prevalence. Zainab et al. (2017) found that the rice leaf folder significantly and negatively correlated with mean temperature, but positively correlated with mean relative humidity and rainfall. Other parameters did not have a significant positive or negative relationship with the leaf folder population

Table 3. Influence of abiotic factors on the rice leaf folder infestation during *kharif* 2019-2020

SMW	RF	T_{max}	T_{min}	T_{avg}	RH_M	RH_E	RH_A	SSH	RLF
28	194.80	31.40	22.80	27.10	87.00	76.00	81.50	5.30	0.00±0.00
29	0.00	36.40	25.10	30.75	82.00	54.00	68.00	0.50	0.00±0.00
30	25.80	31.90	23.50	27.70	89.00	72.00	80.50	1.90	0.00±0.00
31	2.00	32.30	23.80	28.05	85.00	72.00	78.50	4.40	1.00±0.08
32	61.00	31.00	23.20	27.10	89.00	79.00	84.00	4.50	2.70±0.11
33	56.90	32.80	23.10	27.95	89.00	74.00	81.50	2.40	5.30±0.18
34	115.40	31.20	21.70	26.45	94.00	80.00	87.00	4.70	7.33±0.26
35	11.40	34.20	24.60	29.40	90.00	69.00	79.50	5.10	8.42±0.40
36	11.60	32.10	24.00	28.05	87.00	77.00	82.00	3.10	10.37±0.27
37	48.20	33.20	23.30	28.25	89.00	71.00	80.00	2.90	13.22±0.52
38	164.00	30.80	21.60	26.20	93.00	82.00	87.50	2.70	13.00±0.41
39	532.20	27.80	20.40	24.10	95.00	87.00	91.00	2.30	14.66±0.46
40	39.00	30.00	20.40	25.20	94.00	78.00	86.00	5.80	11.67±0.30
41	0.00	32.20	19.20	25.70	91.00	59.00	75.00	6.50	11.00±0.42
42	3.80	29.60	19.10	24.35	91.00	68.00	79.50	8.70	7.33±0.27
43	0.00	28.50	17.20	22.85	84.00	60.00	72.00	7.70	8.00±0.18
44	0.00	30.20	16.60	23.40	92.00	62.00	77.00	8.00	4.00±0.35
45	0.00	29.50	14.20	21.85	91.00	56.00	73.50	3.90	3.33±0.24
46	0.00	29.00	11.20	20.10	90.00	41.00	65.50	6.60	0.00±0.00
47	0.00	27.30	11.30	19.30	90.00	52.00	71.00	4.70	0.00±0.00

See Table 2 for details

Table 4. Correlation matrix (Pearson's) for weather-based observations with rice leaf folder infestation in rice ecosystem during pool data (*Kharif* 2018-19 and 2019-20)

Variables	RF	T_{max}	T_{min}	T_{avg}	RH_M	RH_E	RH_A	SSH	RLF
RF	1	0.173	0.504*	0.437	0.442	0.588**	0.625**	-0.330	-0.501*
T_{max}		1	0.779**	0.871**	-0.340	0.387	0.301	-0.219	0.527*
T_{min}			1.000	0.983**	-0.029	0.864**	0.799**	-0.631**	-0.255
T_{avg}				1.000	-0.121	0.773**	0.698**	-0.566**	0.252
RH_M					1.000	0.313	0.468*	-0.034	0.465*
RH_E						1.000	0.986**	-0.726**	0.278
RH_A							1.000	-0.681**	0.541*
SSH								1.000	0.182
RLF									1.000

'*' Significant correlation at P< 0.05 and data followed by '**' significant correlation at P< 0.01

Note: RF (Rainfall, mm), T_{max} (Maximum temperature °C), T_{min} (Minimum temperature °C), T_{avg} (Average temperature °C), RH_M (Morning relative humidity, %), RH_E (Evening relative humidity), RH_A (Average relative humidity), SSH (Sunshine hours), RLF (Rice leaf folder infestation)

CONCLUSION

The population of rice leaf folder were observed at the start of the season, from the early tillering stage, and peaked at booting stage of crop with more or less population fluctuation until the rice crop matured. Among the abiotic factors, morning temperature, evening relative humidity, average relative humidity and rainfall had a significant impact on rice leaf folder infestation in rice ecosystems. Pest population dynamics and crop phenology are critical factors in implementing management strategies in the rice ecosystem. It can be used to create a prediction and forecasting model that will help understand infestation and pest dynamics in rice fields, as well as ensure readiness to deal with pest problems quickly while avoiding crop losses.

ACKNOWLEDGMENT

The authors would like to express their gratitude to the University Grant Commission (UGC) of New Delhi for its fellowship and financial support in carrying out the experiments.

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Received 28 April, 2024; Accepted 20 June, 2024

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Indian Journal of Ecology (2024) 51(4): 842-850
DOI: https://doi.org/10.55362/IJE/2024/4319

Manuscript Number: 4319
NAAS Rating: 5.38

Moths of Superfamily Pyraloidea (Lepidoptera) from Western Ghats (India)

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Abstract: Twenty-three species belonging to twenty-one genera i.e., *Nomophila* Hübner, *Palpita* Hübner, *Glyphodes* Guenée, *Botyodes* Guenée, *Tyspanodes* Warren, *Dichocrocis* Lederer, *Agrotera* Schrank, *Cnaphalocrocis* Lederer, *Syngamia* Guenée, *Terastia* Guenée, *Meroctena* Lederer, *Polythlipta* Lederer of subfamily Spilomelinae; *Agathodes* Guenée, *Phlyctaenia* Hübner, *Nausinoe* Hübner, *Syllepte* Hübner, *Aetholix* Lederer, *Filodes* Guenée, *Nevrina* Guenée of subfamily Pyraustinae and *Nymphula* Schrank subfamily Nymphulinae and *Eoophila* Swinhoe of subfamily Acentropinae of family Crambidae of Superfamily Pyraloidea has been collected from the different localities of Western ghats.

Keywords: India, Lepidoptera, Moths, Pyraloidea, Western ghats

The Western Ghats are quite diverse and unique due to their topography and climatic conditions. It cover an area of about 160,000 Km^2 and stretches for 1600 km from the mouth of river Tapti in the North to Cape Camorin in the South. Due to great diversity in flora and fauna, it is one of the hot biodiversity spots of India. The mountain ranges are with an average height of about 1200MSL running parallel to the Western coast of Southern India in the six states i.e., Maharashtra, Goa, Karnataka, Gujarat, Tamil Nadu and Kerala. Except single major gap of about 24 km called as 'PalGhat gap' alongwith some small passes like 'Goa gap', 'Bhor Ghat' and 'ThalGhat', these ranges of the Western Ghats are almost continuous upto the last end. The Western Ghats are also known by different states i.e., as the Sahyadri mountains in Maharashtra and Karnataka, Nilagirimalai in Tamil Nadu and Sahyaparvatam in Kerala. The highest peak (2,695 MSL) Anaimudi peak of the Western Ghats which lies in the ranges of the state of Kerala. The Anaimudi peak act as a central point from where three ranges radiate to different directions viz., the Anaimalai hills (North), the Palni hills (North-East) and the Cardamom hills (South). The order Lepidoptera is divided into primitive Lepidoptera, Early Heteroneura, Lower Ditrysia and Higher Ditrysia. Further, the Lower Ditrysia, the larvae of which are often concealed rather than external feeders, includes the Superfamilies *viz.,* Tineoidea, Gracillarioidea, Yponomeutoidea, Gelechioidea, Cossoidea, Tortricoidea, Castnioidea, Sesioidea, Zygaenoidea, Immoidea, Copromorphoidea, Schreckensteinoidea, Urodoidea, Epermenioidea, Alucitoidea, Pterophoroidea, Hyblaeioidea, Thyridoidea and Pyraloidea (Scoble 1995). Four subfamilies i.e., Spilomemelinae, Pyraustiinae, Nymphulinae and Acentropinae moths belonging to family Crambidae of Superfamily Pyraloidea were collected and have been deal with during the present investigations from the area, under reference.

MATERIAL AND METHODS

Survey-cum-collection tours were conducted from different localities of states Goa, Maharashtra, Karnataka, Tamil Nadu and Kerala falling in the jurisdiction of Western Ghats during March 2003 to October 2006 (Map attached). The details of the localities and their coordinates are provided (Table 1). Due to nocturnal behaviour, adult moth diversity referable to family Crambidae, the adults has been collected with the help of a portable light trap (Photo 1). The portable trap comprises a funnel (diameter top 30 cm, bottom 6 cm, height 30 cm) fitted with baffle plates so that the moths once visiting the light get trapped around the lamp. The source of light to attract the moths was a 125w Mercury Vapour lamp fixed in the funnel. The funnel is fixed on the top of a collecting chamber (30cm x 30cm x 12 cm) fitted with a sliding collecting trays (29cm x 29cm). The collecting chamber used to be charged/fumigated with 1, 1, 2, 2- Tetrachloroethane as a killing agent for the adult moth. The petri dish containing cotton soaked with the aforesaid chemical was placed in one of the corners of the tray. Some of moths were captured individually in glass killing tubes of various sizes (2cm x 7cm to 5cm x 15cm) charged with ethyl acetate poured over the plaster of Paris dried at the bottom of the tube from near the

Restaurants, Hotels, Forest Rest Houses, Bus Depots and Railway Stations around the localities being visited. Besides the portable light trap, some collection was also made by hanging the source of light (125w Mercury Vapour lamp) on a white sheet or a whitewashed wall. As per techniques being used in Lepidopterology (Lindquist 1956, Hodges 1958, Tagestad 1974, Zimmerman 1978, Nielson 1980, Sokoloff 1980, Mikkola 1986, Landry and Landry 1994), the entire collected specimens were processed for further biosystematics studies.

RESULTS AND DISCUSSION

Twenty-three species belonging to 21 genera of moths family Crambidae were collected and identified from the available literature (Hampson 1896, Roonwal et al 1964, Singh 1976, Pajni and Rose 1977, Nielson 1980, Mandal and Bhattacharya 1980, Sokoloff 1980, Singh 1984, Rose and Singh 1985, 1988, Kirti and Rose 1987, 1989, 1990, 1992, Nayar et al 1990, Rose and Kirti 1989, Srivastava 1996, Atwal and Dhaliwal 2008) and also with the reference collections housed in the National Pusa Collection, Division of Entomology, IARI, New Delhi and also from the Museum of Department of Zoology & Environmental Sciences, Punjabi University, Patiala. All the colections are deposited in the Museum of Department of Zoology & Environmental Sciences, Punjabi University, Patiala. The details are provided below:

Higher Classification:

Phylum: Arthropoda

Subphylum: Hexapoda

Class: Insecta

Order: Lepidoptera

Superfamily: Pyraloidea

Family: Crambidae

The presently studied genera and number of species are provided (Table 2).

Superfamily Pyraloidea

Forewing with vein 1A vestigial or absent. Hindwing with vein Rs partly fused with or approximated to vein $Sc+R_1$ beyond cell for some distance, vein M_1 stalked with or approximated to vein vein Rs, vein 1A always present.

Family Crambidae

Subfamily spilomelinae

I. *Nomophila* hübner

Nomophilla Hübner 1825, Verz.: 368 (Type- species: *noctuella* Schiffermuller and Denis)

***Nomophila noctuella* (Schiffermüller & Denis)**

Nomophila noctuella Schiffermuller & Denis, syst. Verz. Schm. Wien, p. 136 (1775) (*Tinea*).

Material examined: India: Karnataka: Dist. Kodagu, Medikeri, 1100mASL, 25.ix.2003, 03♂♂; Dist. Kodagu, Baghamandala, 900mASL, 01.viii.2004, 01♂; Dist. Uttar Kannada, Ganeshgudi, 480mASL, 14.x.2005, 03♂♂; Dist. Uttar Kannada, Jog Falls, 480mASL, 08.viii.2006, 01♂; Maharashtra: Dist. Sindhudurg, Amboli, 850mASL, 11.x.2005, 04♂♂; Gujarat: Dist. The Dangs, Saputara, 970mASL, 30.ix.2005, 01♂; Dist. The Dangs, Waghai, 180mASL, 31.viii.2005, 02♂♂, coll. A. Katewa.

Distribution: Universal distribution (Hampson 1896); Himachal Pradesh, Uttar Pradesh, Jammu and Kashmir, Chandigarh, Punjab, Haryana (Singh 1976).

Remarks: Though, the species *Nomophila noctuella* (Schiffermüller & Denis) has been considered to be universal in distribution, yet knowing the precise localities will define

Table 1. Visited states/localities

State	Visited localities (Coordinates)
Goa	Keri (15.4593°N, 73.9977°E), Mollem (15.3758°N, 74.2269°E), Ponda (15.4027°N, 74.0078°E)
Gujarat	Dharmpur (20.5401°N, 73.1792°E), Vaghai (20.7737°N, 73.4976° E) , Ahava (20.7606°N, 73.6912°E), Saputara (20.5786°N, 73.7507° E).
Maharashtra	Allefata (19.1766°N, 74.1108°E), Malshej Ghat (19.3406°N, 73.7746°E), Sanjay Gandhi National Park Bombay (19.2205° N, 72.9128°E), Satara (17.6805°N, 74.0183°E), Mahableshwar (17.9307°N, 73.6477°E), Amboli (15.9647°N, 74.0036°E)
Karnataka	Londa (15.4567° N, 74.4936° E), Ganeshgudi (15.2843° N, 74.5302° E), Khanapur (15.6407° N, 74.5170° E), Ramnagar (12.7209° N, 77.2799° E), Nagargalli (15.4163° N, 74.6119° E), Karwar (14.8074° N, 74.1299° E), Kasarkod (14.2687° N, 74.4335° E), Shimoga (13.9299° N, 75.5681° E), Shettihalli (13.7955° N, 76.1719° E), Honnawar (14.2798° N, 74.4439° E), Jog Falls (14.2004° N, 74.7922° E), Bhagwati (15.1553° N, 74.7615° E), Chickmaglur (13.3161° N, 75.7720° E), Kemangundi (13.5500° N, 75.7500° E), Kallatgiri Falls (13°33'0"N 75°47'17"E), Medikeri (12.4244° N, 75.7382° E), Kulgi (15.1664° N, 74.6373° E), Dandeli (15.2361° N, 74.6173° E) Gundya (12.5218° N, 76.8951° E), Baghamandala (12.3866° N, 75.5287° E).
Tamil Nadu	Ooty (11.4102°N,76.6950°E), Coonoor(11.3439°N, 76.7945°E), Dodabetta (11.4007°N, 76.7358°E), Kanyakumari (8.0844°N, 77.5495°E), Coimbatore (11.0168°N, 76.9558°E).
Kerala	Mukkali (11.0587°N, 76.5402°E), Agli (11.1014° N, 76.6471° E), Neyyar WLS (8.5341°N, 77.1503°E), Shendurni WLS (8.8578°N, 77.2175°E), Vithura (8.6753°N, 77.0852°E), Rani (9.3866° N, 76.7856° E), Vadasarikera (11.6084°N,, ***75.5917***°E), Kumli (9.6037°N, 77.1675°E), Periyar WLS (9.4631°N, 77.2287°E), Vallakadavu (8.4750°N, 76.9195°E), Deviculam (10.0564° N, 77.1198° E), Maryur (10.2762° N, 77.1615°E) and Parambiculam WLS (10.4667° N, 76.8333°E).

exact limits of its distribution. Accordingly, the collection of the species, under reference, are first additional records from the Western Ghats.

II. *PALPITA* HÜBNER

Hübner 1808, Erste Zut. Zur. Samm. Exotisch. Schmetterlinge, 1808, Augsburg (monotype: *Palpita normalis unionalis* Hübner).

Type- species : *Pyralis unionalis* Hübner.

(2) *Palpita unionalis* (Hübner)

Hübner 1796, Samml. Eur. Schm. Horde **6**: 21, t. 20, f. 132 (*Pyralis*); 1806-24, Samml. Exot. Schm. Pyr., 2, C, a, f. 4; 1826, Verz. bek. Schm., 1826: 358 (*Margaronia*).

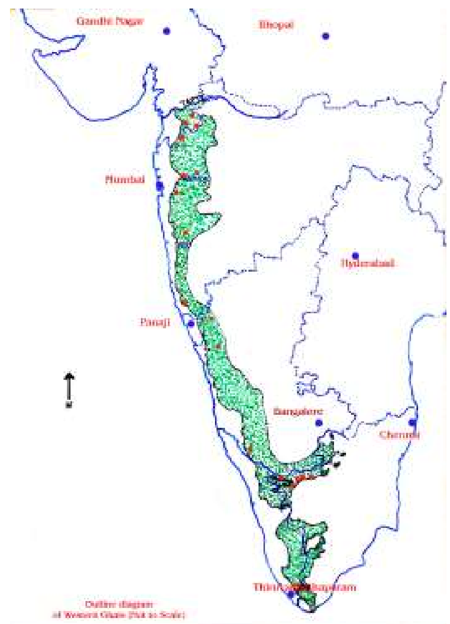
Material examined: India: Karnataka: Dist. Belgaum, FRH, Khanapur, 370mASL, 21.iii.2003. 01♂; Dist. Kodagu, Medikeri, 1100mASL, 16.xi.2002, 01♂; Dist. Uttar Kannada, Ganeshgudi, 480mASL, 13.xi.2003, 05♂♂, 22.vii.2004, 01♂, 16.x.2005, 01♂; Dist. Dakshin Kannada, Gundya, 40mASL, 28.vii.2004, 04♂♂, Dist. Shimoga, Shettihalli WLS, 320mASL, 10.vi.2003, 01♂; Dist. Kodagu, Nisergdhama, 1080mASL, 17.xi.2002, 02♂♂; Kerala: Dist. Kollam, Chendruni, 70mASL, 03.ix.2004, 02♂♂,01♀; Gujarat: Dist. The Dangs, Hawa, 520mASL, 29.ix.2005, 04♂♂, coll. Amit Katewa.

Distribution: South Europe, South and West Africa, Madagaskar, Mauritius, Aden, throughout India, Ceylon, Australia (Hampson 1896); Chandigarh, Punjab, Haryana, Jammu and Kashmir (Kirti and Rose, 1992).

Remarks: Though the species, under reference, is widely distributed in many parts of world, including India yet the same is reported from the states of Karnataka, Kerala and Gujarat with precise localities for the first time.

Table 2. Number of Subfamilies/genera and number of species

Superfamily	Pyraloidea	
Family	Crambidae	
Subfamily	Genera	No of species
Spilomelinae	*Nomophila* Hübner	01
	Palpita Hübner	01
	Glyphodes Guenée	01
	Botyodes Guenée	01
	Tyspanodes Warren	01
	Dichocrocis Lederer	02
	Agrotera Schrank	01
	Cnaphalocrocis Lederer	01
	Syngamia Guenée	02
	Terastia Guenée	01
	Meroctina Lederer	01
	Polythlipta Lederer	01
Pyraustinae	*Agathodes* Guenée	01
	Phlyctaenia Hübner	01
	Nausinoe Hübner	01
	Syllepte Hübner	01
	Aetholix Lederer	01
	Filodes Guenée	01
	Nevrina Guenée	01
Nymphulinae	*Nymphula* Schrank	01
Acentropinae	*Eoophila* Swinhoe	01



Map: Area surveyed

Photo 1. Portable light trap

III. *GLYPHODES* GUENÉE

Guenée, Delt. & Pyral., p. 292 (1854) - Lederer, Wien. Ent. Monatschr., Z, p. 401 (1863. -Meyrick, Trans. Ent. Soc. London, p. 297 (1884).

Type-species: *stolalis* Guenée

(3) *Glyphodes stolalis* Guenée

Guenée 1854, Delt. & Pyral., 1854: 293, t. 3, f. 11 (male) (Glyphodes) (India?). – Walker, 1859, Car. Lep. Het. Brit. Mus., **17**: 497 (Glyphodes).

Material examined India: Gujarat: Dist. The Dangs, Saputara, 970mASL, 30.ix.2005, 04♂♂; Dist. The Dangs, Ahwa, 520mASL, 27.xi.2005, 01♂; Karnataka: Dist. Belgaum, FRH, Londa, 420mASL, 24.iii.2003, 01♂; Dist. Kodagu, Baghamandala, 900mASL, 25.xi.2003, 03♂♂; Dist. Uttar Kannada, Ganeshgudi, 480mASL, 13.xi.2003, 01♂, 21.vii.2004, 01♂, 16.x.2005, 01♂; Dist. Kodagu, Sampaje, 100mASL, 13.xi.2002, 01♂, coll. Amit Katewa.

Distribution: Nepal, Sikkim, Assam, Borneo, Ceylon, Australia (Hampson, 1896); Assam, Sikkim, Meghalaya, Nagaland, Manipur and Arunachal Pradesh (Rose and Kirti, 1989).

Remarks: *Glyphodes stolalis* Guenée is being reported for the first time from the Western Ghats.

(IV) *Botyodes* guenée

Guenée, delt. & Pyral., p. 320 (1854)., - Walker, Cat. Lep. Het. Brit., Mus., **18**, p. 550 (1859).

Type- species: *asialis* Guenée.

(4). *Botyodes asialis* Guenée

Guenée, Delt. & Pyral., p. 321 (female) (1854) (*Botyodes*) (India). - Walker, Cat. Lep. Het. Brit. Mus., **18**, p. 551 (1859).

Material examined: India: Karnataka: Dist. Belgaum, FRH, Londa, 420mASL, 24.iii.2003, 03♂♂; Dist. Kodagu, Baghamandala, 900mASL, 25.xi.2003, 06♂♂; Dist. Uttar Kannada, Ganeshgudi, 480mASL, 13.xi.2003, 1♂, 16.x.2005, 01♂; Gujarat: Dist. The Dangs, Saputara, 970mASL, 30.ix.2005, 04♂♂; Dist. The Dangs, Ahwa, 520mASL, 29.ix.2005, 01♂, coll. Amit Katewa.

Distribution: Throughout India, Ceylon, Burma (Hampson, 1896); Dehradun, Chakrata, Chandigarh (Kirti and Rose, 1990).

Remarks: Though *Botyodes asialis* Guenée is known to occur throughout India (Hampson, 1896), yet could be collected from only two other states (Karnataka and Gujarat) comprising this area/ hot biodiversity spot.

(V) *Tyspanodes* Warren

Tyspanodes Warren 1891, A. M. N. H. (6) 7: 425 (Type-species: *nigrilinealis* Moore).

(5) *Tyspanodes linealis* Moore

Propachys linealis Moore, 1867, P.Z.S., 1867: 665, pl. 33. f. 17. Moore, Proc. Zool. Soc. London, p. 665,t. 33, f. 14 (1867) (*Tyspanodes*).

Material examined: India: Kerala: Dist. Kollam, Chendruni, 70mASL, 03.ix.2004, 01♂; Karnataka: Dist. Belgaum, FRH, Khanapur, 370mASL, 21.iii.2003. 01♂; Dist. Kodagu, Medikeri, 1100mASL, 16.xi.2002, 01♂; Dist. Uttar Kannada, Ganeshgudi, 480mASL, 22.vii.2004, 02♂♂, 16.x.2005, 01♂; Dist. Dakshin Kannada, Gundya, 40mASL, 28.vii.2004, 04♂♂; Dist. Shimoga, Shettihalli WLS, 320mASL, 10.vi.2003, 01♂; Dist. Kodagu, Nisergdhama, 1080mASL, 17.xi.2002, 01♂; Maharashtra: Dist. Sindhudurg, Amboli, 850mASL, 11.x.2005, 02♂♂, coll. Amit Katewa.

Distribution: Dharamshala, Sikkim, Ceylon, Andamans (Hampson 1896); Assam, Mizoram (Singh 1984).

Remarks: During the present studies, the collection of the species *Tyspanodes linealis* Moore the Western Ghats becomes new record from this hot biodiversity spot in India.

(VI) *Dichocrocis* Lederer

Lederer, Wien, Ent. Monatschr., **7**, p. 477 (1863). - Hampson, Fauna Brit. India, **4**, p. 305 (1896);

Type- species: *frenatalis* Lederer = *pandamalis* Walker

(6) *Dichocrocis leptalis* Hampson

Hampson 1892, *Fauna Br. India* (Moths) **1**: 383 (nom. Preocc.).

Material examined: India: Karnataka: Dist. Kodagu, Medikeri, 1100mASL, 25.ix.2003, 04♂♂; Dist. Kodagu, Baghamandala, 900mASL, 01.viii.2004, 01♂; Dist. Uttar Kannada, Ganeshgudi, 480mASL, 14.x.2005, 02♂♂; Dist. Uttar Kannada, Jog Falls, 480mASL, 08.viii.2006, 03♂♂; Dist. Chikmaglur, Kallathy Falls, 960mASL, 26.vii.2004, 01♂; Gujarat: Dist. The Dangs, Waghai, 180mASL, 31.viii.2005, 02♂♂; Maharashtra: Dist. Sindhudurg, Amboli, 850mASL, 11.x.2005, 01♂, coll. Amit Katewa.

Distribution: Throughtout India (Hampson 1896); Dehradun, Shimla, Solan (Singh 1976).

Remarks: Contrary to the information that the species *Dichocrocis leptalis* Hampson is available throughout in India (Hampson 1896), yet the same has been reported from only three localities in Western Himalaya (Pajani and Rose 1977). The present collection data of the species, under reference, further explores its distribution in the Western Ghats.

(7) *Dichocrocis nilusalis* Walker

Walker 1859, Cat. Lep. Het. Brit. Mus., **18**: 685 (male) (*Botys*) (Borneo). – Swinhoe, 1900, Cat. Lep. Het. Oxford Mus., **2**: 484.

Material Examined: India: Kerala:Dist. Idukki, Vallakadavu, 780mASL, 09.ix.2004, 01♂, 10.ix.2004, 02♂♂, 12.ix.2004, 01♂; Dist. Idukki, Maryur, 960mASL, 15.ix.2004, 01♂; Dist. Kollam, Chendruni, 70mASL, 03.ix.2004, 01♂; Karnataka:Dist. Uttar Kannada, Ganeshgudi, 480mASL, 20.vii.2004, 01♂, 21.vii.2004, 03♂♂, 16.xi.2005, 02♂♂; Dist. Uttar Kannada, Jog Falls, 480mASL, 24.vii.2004, 01♂; Maharashtra: Dist. Pune, Malshej Ghat, 690m, 02.x.2005, 01♂; Gujarat :Dist. The Dangs, FRH, Ahwa, 520mASL, 29.ix.2005, 01♂, coll. Amit Katewa.

Distribution: Nagas, Khasis, Ceylon, Borneo, Java (Hampson, 1896); Jatinga, North Cachaar Hills, Khasi Hills (Pajni and Rose, 1977).

Remarks: *Dichocrocis nilusalis* Walker is being collected from the aforesaid localities of the Western Ghats for the first time. Accordingly, it becomes new record from this hot biodiversity spot in India.

(VII) *Agrotera* Schrank

Schrank, Fauna Boica, **2** (2), p. 163 (1802). - Guenée, Delt. & Pyral., p. 217 (1854).

Type- species: *nemoralis* Scopelodes

(8) *Agrotera scissalis* (Walker)

Walker, Cat. Lep. Het. Brit. Mus., **34**, p. 1526 (male) (1865) (*Aediodes*) (Java).

Material examined: India: Kerala: Dist. Thiruvananthapuram, FRH, Vithura, 120mASL, 04.ix.2004 01♂; 05.ix.2004, 01♂; Dist. Idukki, Vallakadavu, 780mASL, 12.ix.2004, 01♂; Tamil Nadu : Dist. Nilgiris, Dodabetta, 2640mASL, 01.x.2003, 02♂♂; Gujarat: Dist. The Dangs, Saputara, 970mASL, 30.ix.2005, 03♂♂, coll. Amit Katewa.

Distribution: Sikkim, Khasis, Nagas, Ceylon, Java (Hampson, 1896) ; Hardwar, Garhwal, Dehradun (Rose and Singh, 1988).

Remarks: The aforesaid distribution record of *Agrotera scissalis* (Walker) reveals that it has been recorded from only three states of the Western Gats is not only additional distribution record but also new from this hot biodiversity spot.

(VIII) *Cnaphalocrocis* Lederer

Lederer, Wien. Ent. Monatschr., 7, p. 384 (1963). - Meyrick, Trans. Ent. Soc. London, p. 303 (1884). Type-species : *medinalis* Guenée

(9) *Cnaphalocrocis medinalis* (Guenée)

Guenée, Delt. & Pyral., p. 201 (female) (1854) (*Salbia*) (E. India). - Walker, Cat. Lep. Het. Brit. Mus., **17**, p. 361 (1859) (*Salbiar*).

Material examined: India: Kerala: Dist. Thiruvananthapuram, FRH, Vithura, 120mASL, 05.ix.2004, 01♂; Dist. Palakkad, Mukkali, 560mASL, 19.ix.2004, 01♂, 21.ix.2004, 01♂, 22.ix.2004, 04♂♂; Dist. Idduki, Maryur, 960mASL, 15.ix.2004, 03♂♂; Karnataka: Dist. Kodagu, Medikeri, 1100mASL, 16.xi.2002, 01♂, 25.ix.2003, 01♂; Dist. Uttar Kannada, Ganeshgudi, 480mASL, 16.x.2005, 02♂♂; Dist. Kodagu, Sampaje, 100mASL, 14.xi.2002, 01♂; Dist. Kodagu, Nisergdhama, 1080mASL, 17.xi.2002, 01♂; Dist. Uttar Kannada, Kulgi, 360mASL, 16.vii.2004, 01♂, coll. Amit Katewa.

Distribution: Japan, Throughout Oriental, India, Russia (Hampson 1896); Dehradun, Kalka, Kurukshetra, Srinagar, Punjab, Chandigarh (Singh 1976).

Remarks: *Cnaphalocrocis medinalis* (Guenée) is a minor pest of rice and commonly known as rice leaf roller (Nayar and David 1990, Srivastava 1996, Atwal and Dhaliwal 2002). The above distributional data shows its prevalance in two states of the Western Ghats, as well.

(IX) *Syngamia* Guenée

Guenée, Delt. & Pyral., p. 187 (1854). - Walker, Cat. Lep. Het. Brit. Mus., 17, p. 333 (1859). Type- species : *florellalis* Guenée = *florella* Cramer

(10) *Syngamia abruptalis* (Walker)

Walker, Cat. Lep. Het. Brit. Mus., **17**, p. 371 (1859) (*Asopia* ?) (Cylon). - Felder & Rognhofer, Reise Novara, Lep. (Het.), p. 4, t. 135, f. 10 (1874) (*Botys*) (Bengal).

Material examined: India: Karnataka: Dist. Uttar Kannada, Ganeshgudi, 480mASL, 20.vii.2004, 03♂♂, 21.vii.2004, 04♂♂; Dist. Uttar Kannada, Jog Falls, 480mASL, 24.vii.2004, 01♂; Dist. Uttar Kannada, Kulgi, 360mASL, 17.vii.2004, 01♂; Kerala: Dist. Idukki, Vallakadavu, 780mASL, 10.ix.2004, 03♂♂, coll. Amit Katewa.

Distribution: North Africa, Throughout India, Ceylon, Burma, Andamans, Java, Australia, Fizi (Hampson 1896); Meghalaya, Assam, Mizoram, Uttar Pradesh (Singh 1984).

Remarks: Except fro three-four states, no precise distribution record of *Syngamia abruptalis* (Walker) is available in India (Hampson 1896). Its collection from the states of Karnataka and Kerala in the Western Ghats proves its extended distribution.

(11) *Syngamia falsidicalis* (Walker)

Guen, 1854, *Delt & Pyr*.: 187.

Material examined: India: Karnataka: Dist. Kodagu, Baghamandala, 900mASL, 31.vii.2004, 01♂; Dist. Uttar Kannada, Ganeshgudi, 480mASL, 20.vii.2004, 02♂♂, 21.vii.2004, 01♂, coll. Amit Katewa.

Distribution: North- Western Himalaya, Khasis, Nilgiris, Ceylon (Hampson 1896) ; Assam, Meghalaya, Arunachal Pradesh, Mizoram (Singh 1984).

Remarks: Hampson (1892) reported *Syngamia falsidicalis* (Walker) from the Nilgiris in South India and its collection from the aforesaid localities in the state of Karnataka enriches the distributional data of the species, under reference. As such, the species is being reported for the first time from the state of Karnataka.

(X) *Terastia* Guenée

Guenée, Delt. & Pyral., p. 211 (1854). - Walker, Cat. Lep.

Het. Brit Mus., **17**, p. 379 (1859).

Type- species: *meticulosalis* Guenée.

(12) *Terastia egialiealis* (Walker)

Walker, Cat. Lep. Het. Brit. Mus., **17**, p. 383 (1859) (*Megaphsa*) (India). - Swinhoe & Cotes, Cat. Moths India, **5**, p. 632 (1888) (*Megaphysa*)

Material examined: India: Karnataka:Dist. Uttar Kannada, Ganeshgudi, 480m, 16.x.2005, 01♂; Gujarat: Dist. The Dangs, Saputara, 970mASL, 30.ix.2005, 01♂, Dist. The Dangs, Ahwa, 520mASL, 29.ix.2005, 03♂♂, 02♀♀, coll. Amit Katewa.

Distribution: Dharamshala, Sikkim, Java (Hampson, 1896); Dehradun, Dharamshala (Singh, 1976).

Remarks: *Terastia egialiealis* (Walker) is being reported for the first time from the Western Ghats.

(XI) *Meroctena* Lederer

Lederer, 1863, Wien. Ent. Monatschr., **7**: 392 (type-species: *staintoni* Lederer). – Hampson 1896, 1896, fauna Brit. India Moths, **4**: 376.

Type-species: *Botys tullalis* Walker.

(13) *Meroctena tullalis* (Walker)

Walker 1859. *Cat Lep.* 18: 649; Meroctena. Hampson, *Ill Het* 9. Pl.172, f.11.

Material Examined: India: Tamil Nadu:Dist. Nilgiris, Dodabetta, 2640mASL, 1.x.2003, 01♀, coll. Amit Katewa.

Distribution: Sikkim, Assam, Nilgiri hills (Hampson 1896); Assam, Meghalaya (Singh 1984).

Remarks: The species *i.e., tullalis* Walker is the type-species of monotypic genus *Meroctena* Lederer. Hampson (1896) reported this species from the Nilgiris and during the course of present surveys a single female specimen could be collected from another locality *i.e.,* Dodabetta in Nilgiris. The species has restricted distribution in the Western Ghats.

(XII) *Polythlipta* Lederer

Lederer 1863, *Wien. Ent. Monatschr*., **7**: 389, t. 5, f. 20. – Moore, 1886, *Lep. Ceylon*, **3**: 310.

Type-species: *Polythlipta macralis* Lederer.

(14) *Polythlipta macralis* Lederer

Lederer 1863, Wien. Ent. Monatschr., **7**: 389, 477 (*maceratalis* err.), t. 12, f. 14 (male) (*Polythlipta*) (Amboina).

Material examined: India: Kerala: Dist. Idukki, Vallakadavu, 780mASL, 11.ix.2004, 02♂♂, coll. Amit Katewa.

Distribution: Sikkim, Khasis, Nilgiris, Ceylon (Hampson 1896); Assam (Rose and Singh 1985).

Remarks: The species *Polythlipta macralis* Lederer is being reported for the first time from the state of Kerala in the Western Ghats in India. As per its collecion, it appears to be quite rare.

Subfamily Pyraustinae

(XIII) *Agathodes* Guenée

Guenée, Delt. & Pyral., p. 207 (1854).- Moore, Lep. Ceylon, **3**, p. 555 (1887).- Meyrick, Trans. Ent. Soc. Lond., p. 218 (1887). **Type-species**: *ostentalis* Hübner.

(15) *Agathodes ostentalis* (Hübner)

Hübner, Zutrage Samml. Exot. Schm., **5**, p. 11, f. 833, 834 (1837) (*Perinephela*) (Java). - Walker, Cat. Lep. Het. Brit. Mus., **17**, p. 378 (1859) (*Agathodes*).

Material examined: India: Karnataka: Dist. Kodagu, Medikeri, 1100mASL, 25.ix.2003, 06♂♂; Dist. Uttar Kannada, Jog Falls, 480mASL, 08.viii.2006, 01♂; Dist. Chikmaglur, Kallathy Falls, 960mASL, 26.vii.2004, 04♂♂; Dist. Kodagu, Baghamandala, 900mASL, 01.viii.2004, 01♂; Dist. Uttar Kannada, Ganeshgudi, 480mASL, 14.x.2005, 03♂♂; Maharashtra: Dist. Sindhudurg, Amboli, 850mASL, 11.x.2005, 03♂♂; Gujarat: Dist. The Dangs, Saputara, 970mASL, 30.ix.2005, 01♂; Dist. The Dangs, Waghai, 180mASL, 31.viii.2005, 05♂♂, coll.Amit Katewa.

Distribution: Throughout India, Ceylon, Burma (Hampson, 1896); Uttaranchal (Singh, 1976).

Remarks: On the basis of present surveys, twenty four individuals of the aforesaid species have been collected from the Western Ghats and accordingly, it can be inferred that the species is quite common to this hot biodiversity spot.

(XIV) *Phlyctaenia* Hübner

Hübner, Verz. bek. Schm., p. 359 (1825) (Sine fixat. typi generis; 2 sp.). - De Joannis, Ann. Soc. Ent. Fr., 98 (1928), p. 686 (1930).

Type-species: *tyres* Cramer

(16) *Phlyctaenia tyres* (Cramer)

Cramer, Pap. Exot., **3**, p. 124, t. 263, f. C (1782) ((*Phalaena*) (*Pyralis*)) (Coromandel). - Lederer, Wien. Ent. Monat-schr., **7**, p. 404 (1863) (*Pygosspila*).

Material examined: Kerala: Dist. Thiruvananthapuram, FRH, Vithura, 120mASL, 04.ix.2004 01♂; 05.ix.2004, 02♂♂; Dist. Idukki, Vallakadavu, 780mASL, 12.ix.2004, 05♂♂; Karnataka: Dist. Uttar Kannada, Ganeshgudi, 480mASL, 21.vii.2004, 02♂♂; 16.x.2005, 01♂; Dist. Kodagu, Sampaje, 100mASL, 13.xi.2002, 01♂; Maharashtra: Dist. Pune, Malshej Ghat, 690mASL, 02.x.2005, 01♂; Dist. Satara, FRH, Mahableshwar, 1320m, 09.x.2005, 11♂♂, 06♀♀; Tamil Nadu: Dist. Nilgiris, Dodabetta, 2640mASL, 01.x.2003, 02♂♂; Gujarat : Dist. The Dangs, Saputara, 970mASL, 30.ix.2005, 03♂♂, 08♀♀; Dist. The Dangs Dharmpur, 150mASL, 27.ix.2005, 02♂♂, coll. Amit Katewa.

Distribution: Throughout India, Ceylon, Burma, Java (Hampson 1896); Shimla, Dehradun, Pahalgam (Singh 1976).

Remarks: *Phlyctaenia tyres* (Cramer) is widely distributed in India (Hampson 1896) and during the course of present studies, it has been collected from all the states of the Western Ghats except Goa.

(XV) *Nausinoe* Hübner

Hübner, Verz. bek. Schm., p. 362 (1825) (since fixat, typi generis; 2 sp.).- Moore, Lep. Ceylong, **3**, p. 309 (1886).

Type- species: *neptalis* Hübner

(17) *Nausinoe geometralis* (Guenée)

Guenée, Delt. & Pyral., p. 278, t. 8, f. 6 (1854) (*Lepyrodes*) (Central India). - Walker, cAt. Lep. Het. Brit. Mus., **17**, p. 465 (1859) (*Lepyrodes*).

Material examined: India: Karnataka: Dist. Uttar Kannada, Jog Falls, 480mASL, 08.viii.2006, 03♂♂; Dist. Chikmaglur, Kallathy Falls, 960mASL, 26.vii.2004, 01♂; Gujarat : Dist. The Dangs, Saputara, 970mASL, 30.ix.2005, 01♂; Dist. The Dangs, Waghai, 180mASL, 31.viii.2005, 06♂♂, coll. Amit Katewa.

Distribution: China, Formosa, throughout India, Ceylon, Burma, Java, Australia, West Africa (Hampson 1896); Dehradun, Nainital, Jammu, Chandigarh, Hoshiarpur, Solan (Singh and Rose 1992).

Remarks: The collection of the species *Nausinoe geometralis* (Guenée) from the aforesaid localities in the Western Ghats will definitely enriches its distributional record which could be useful to study its life history and applied aspects (Nayar and David 1990, Srivastava 1996, Atwal and Dhaliwal 2008).

(XVI) *Syllepte* Hübner

Syllepte Hübner 1823, Zutrage Samml. Exot. Schmett. 2 : 18, figs. 285-286 (Type-species: *incomptalis* Hübner). (Type-species: *occlusalis* Dognin).

(18) *Syllepte derogata* (Fabricius)

Phalaena derogata Fabricius, 1779, Syst. Ent. : 641

Material examined: India: Karnataka: Dist. Kodagu, Medikeri, 1100mASL, 25.ix.2003, 01♂; Dist. Kodagu, Baghamandala, 900mASL, 01.viii.2004, 01♂; Dist. Uttar Kannada, Ganeshgudi, 480mASL, 14.x.2005, 01♂; Dist. Chikmaglur, Kallathy Falls, 960mASL, 26.vii.2004, 01♂; Maharashtra: Dist. Sindhudurg, Amboli, 850mASL, 11.x.2005, 02♂♂; Gujarat: Dist. The Dangs, Saputara, 970mASL, 30.ix.2005, 06♂♂; Dist. The Dangs, Waghai, 180mASL, 31.viii.2005, 07♂♂, coll. Amit Katewa.

Distribution: Throughout India (Hampson 1896); Himachal Pradesh, Uttar Pradesh, Haryana (Singh 1976).

Remarks: The species *Syllepte derogata* (Fabricius) is a most common pest of cotton and is generally called as cotton leaf roller (Srivastava, 1996; Atwal and Dhaliwal 2002). On the basis of present surveys, it appears that it is moderately common in the Western Ghats.

(XVII) *Aetholix* Lederer

Lederer, 1863, Wien. Ent. Monatschr., **7**: 437.- Hampson, 1896, Fauna Brit. India Moths, **4**: 286.

Type-species: *Aediodes flavibasalis* Guenée.

(19) *Aetholix flavibasalis* (Guenée)

Guenée 1854, Delt. & Pyral., 1854: 193 (male) (*Aediodes*) (Bombay) Walker 1859, Cat. Lep. Het. Brit. Mus., **17**: 347 (female) (*Aediodes*).

Material examined: India: Kerala: Dist. Palakkad, Mukkali, 560mASL, 19.ix.2004, 02♀♀, coll. Amit Katewa.

Distribution: Bombay, Andamans and Kalimpong (Hampson 1896, Roonwal et al 1963, Mandal and Bhattacharya 1980), Assam (Singh 1984).

Remarks *flavibasalis* (Guenée) is the type-species of the genus *Aetholix* Lederer and has limited distribution data available in literature. The collection of only two female specimens from the Western Ghats shows that it quite rare in the Western Ghats.

(XVIII) *Filodes* Guenée

Guenée 1854, Delt. & Pyral 1854: 317. – Lederer 1863, Wien. Ent. Monatschr. **7**: 390.

Type- species: *Pinacia fulvidorsalis* Geyer.

(20) *Filodes fulvidorsalis* (Geyer)

Geyer in Hübner 1832, Zutrage Samml. Exot. Schm., **4**: 15 nr. 322, f. 643, 644 (*Pinacia*) (Java). – Guenée, 1854, Delt. & Pyral., 1854 : 317 (*Filodes*).

Material Examined: India: Kerala: Dist. Thiruvananthapuram, FRH, Vithura, 120mASL, 05.ix.2004, 04♂♂; Dist. Palakkad, Mukkali, 560mASL, 22.ix.2004, 02♂♂; Dist. Pathanmthitta, Vadaserikera, 30mASL, 7.ix.2004, 01♂; Dist. Kollam, Chendruni, 70mASL, 03.ix.2004, 02♂♂, coll. Amit Katewa.

Distribution: Assam and Sikkim (Hampson 1896), Meghalaya, Assam, Nagaland (Singh 1984).

Remarks: *Pinacia fulvidorsalis* (Geyer) is the type-species of the genus *Filodes* Guenée. The present and earlier collection record reveals that it occurs only in either of the biodiversity hot spots in India. It is a new report from the Western Ghats.

(XIX) *Nevrina* Guenée

Guenée 1854, Delt. & Pyral 1854: 313. –Lederer 1863, Wien. Ent. Monatschr., **7** :395.

Type-species: *Phalaena* (= *Pyralis*) *procopia* Stoll.

(21) *Nevrina procopia* (Stoll)

Stoll in Cramer 1781, Pap. Exot. , **4**: 152, t. 368, f. E. (*Phalaena Pyralis*). – Guenée, 1854, Delt. & Pyaral., 1854:317 (*Nevrina*).- Lederer, 1863, Wein. Ent. Monatschr., **7**: 396 (*Neverina*).

Material examined: India: Kerala: Dist. Idukki, Vallakadavu, 780mASL, 09.ix.2004, 01♂; Dist. Palakkad, Mukkali, 560mASL, 21.ix.2004, 01♂; Dist. Idukki, Maryur, 960mASL, 15.ix.2004, 01♂; Tamil Nadu: Dist. Nilgiris, Dodabetta, 2640mASL, 01.x.2003, 01♂, coll. Amit Katewa.

Distribution: Throughout India (Hampson 1896); Assam, Mizoram (Singh 1984).

Remarks: It has already been precisely reported from one of the hot biodiversity spot *i.e.,* North Eastern Himalaya of this megadiversity nation. The present report becomes the second one from the other hot biodiversity spot *i.e.,* the Western Ghats.

Subfamily Nymphulinae

(XX) *Nymphula* Schrank

Schrank, Fauna boica, **2**, (2), p. 162 (1802). - Hübner, Verz. bek. Schmett., p. 362, no. 3465 (1816) (1827) (Type-species: *N. potamogalis*).

Type-species: *nymphaeata* Linnaeus.

(22) *Nymphula depunctalis* (Guenée)

Guenée, Delt. & Pyral., p. 274 (1884) (*Hydrocampa*) (E. India). - Walker, Cat. Lep. Het. Brit. Mus., **17**, p. 461 (1859) (*Hydrocampa*).

Material examined: India: Kerala: Dist. Idukki, Vallakadavu, 780mASL, 09.ix.2004. 02♂♂, 10.ix.2004, 03♂♂, 11.ix.2004, 02♂♂; Dist. Idukki, Maryur, 780mASL, 15.ix.2004, 04♂♂; Karnataka: Dist. Kodagu, Medikeri, 1100mASL, 26.ix.2003, 01♂, 29.vii.2004, 01♂; Dist. Kodagu, Baghamandala, 900mASL, 25.xi.2003, 01♂, 31.vii.2004, 02♂♂, 01.viii.2004, 01♂; Dist. Kodagu, Sampaje, 100mASL, 27.ix.2003, 01♂; Dist. Uttar Kannada, Ganeshgudi, 480m, 21.vii.2004, 02♂♂, 14.x.2005, 02♂♂, 16.x.2005, 08♂♂; Gujarat : Dist. The Dangs, Ahwa, 520mASL, 29.ix.2005, 02♀♀; Maharashtra: Dist. Sindhudurg, Amboli, 850mASL, 13.x.2005, 01♂, coll. Amit Katewa.

Distribution: South Africa, Throughout India, Java, Australia (Hampson 1896); Mussorrie, Dehradun, Chakrata, Hardwar, Solan, Hoshiarpur, Kurukshetra (Rose and Pajni 1985).

Remarks: Rather than from throughout India (Hampson, 1896), the species *Nymphula depunctalis* (Guenée) has been reported from the aforesaid localities in North-West India only. The present collection data of the species enriches its distribution from the Western Ghats.

Subfamily Acentropinae

(XXI) *Eoophila* Swinhoe

Swinohe, Cat. East. Austral. Lep. Het. Oxford Mus., **2**, p. 442 (1900). - Shibuya, Journ. Fac. Agr. Hokkaido Imp. Univ., **22**, p. 152 (1928).

Type- species: *peribocalis* Walker

(23) *Eoophila gibbosalis* (Guenée)

Guenée, Delt. & Pyral., p. 262 (1854) (*Oligostigma*) (E. India). - Walker, Cat. Lep. Het. Brit. Mus., **17**, p. 431 (1859) (*Oligostigma*).

Material examined: India: Kerala: Dist. Idukki, Vallakadavu, 780mASL, 10.ix.2004, 01♂; Dist. Palakkad, Mukkali, 560mASL, 22.ix.2004, 02♂♂; Dist. Kollam, Chendruni, 70mASL, 03.ix.2004, 01♂; Karnataka: Dist. Uttar Kannada, Ganeshgudi, 480mASL, 21.vii.2004, 01♂; Dist. Uttar kannada, Jog Falls, 480mASL, 29.vii.2004, 01♂; Dist. Uttar Kannada, Kulgi, 360mASL, 17.vii.2004, 02♂♂; Dist. Dakshin Kannada, Gundya, 40mASL, 28.vii.2004, 04♂♂, coll. Amit Katewa.

Distribution: Java, Celebes (Hampson 1896); Dharamshala, Kullu (Singh 1976).

Remarks: This species is only known from two localities in the state of Himachal Pradesh from India. Accordingly, this species is being reported for the first time from the Western Ghats.

CONCLUSIONS

Twenty-three species belonging to twenty-one genera of moths family Crambidae of the order Lepidoptera were collected and identified from the six states. Highest number of species were reported in Subfamilies Spilomelinae with fourteen, Pyraustinae with seven and Nymphulinae and Acentropinae with one each species.

ACKNOWLEDGEMENTS

We are grateful to MoEFCC (GoI), New Delhi for funding the project on Microlepidoptera. Thanks are also due to Dr. V.V. Ramamurthy, Principal Scientist (Retd.), Division of Entomology, for giving permission to consult reference collections housed at NPC, IARI, New Delhi.

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Received 12 May, 2024; Accepted 15 July, 2024

Indian Journal of Ecology (2024) 51(4): 851-859
DOI: https://doi.org/10.55362/IJE/2024/4320

Manuscript Number: 4320
NAAS Rating: 5.38

Biosystematics Studies on Lepidopteran Pests of Rice (*Oryza Sativa* L.) (Insecta: Lepidoptera) in Nagaland, India

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Abstract: In the rice crop, lepidopterans such as stem borers, leaf folders, caseworm, rice butterfly, skipper, *etc.* are some of the most devastating pests found all over the world. The present communication deals with the field survey conducted in the farmer's field, Chumukedima, Nagaland from July-November, 2022 by using portable light traps to document various lepidopteran pests occurring in rice. The study reveals that four lepidopteran insect pests such as *Cnaphalocrocis medinalis* (Guenée 1854), *Leucania loreyi* (Duponchel 1827), *Melanitis leda* (Linnaeus 1758), and *Scirpophaga incertulas* (Walker 1863) were reported as the major insect pests infesting rice crop in the area under reference. Out of these species, *L. loreyi* is the new record from Nagaland. Besides this, morphological and genital characters of adults and photographs and keys of these species are also described.

Keywords: Taxonomic studies, Survey, Lepidopteran pests, Rice, Nagaland

Rice is the most important staple cereal food crop across the globe, cultivated in almost all tropical, sub-tropical, and temperate parts of the world (Pathak et al 2020). Asian countries such as India, China, Japan, Indonesia, Thailand, Burma, the Philippines, and Bangladesh are the major rice-growing countries (Das 2020). Among these countries, India ranks first in rice production contributing more than 40% of the total country's food grain production (Anonymous 2018). However, rice crop is affected by several biotic and abiotic factors such as pests, diseases, soil fertility, rainfall, water logging, and climatic conditions (Das 2020). Among these, insect pests are the major yield-limiting factor. Rice crop is attacked by more than 100 species of insects belonging to various orders such as Lepidoptera, Hemiptera, Coleoptera, Diptera, etc. (Pathak and Khan 1994). After a decade, Pasalu and Katti (2006) reported nearly 300 species of insect pests attacking paddy crops at various stages, with only 23 among these causing significant damage. Lepidopterans are the most destructive of all the orders due to the majority of them being stem borers, leaf folders, leaf webbers, and defoliators (Khan 2000).

Rani et al (2007) documented three species of leaf folders viz., *C. medinalis*, *Marasmia patnalis* (Bradley 1981), and *Marasmia ruralis* (Walker, 1859) affecting rice crop in Madurai, Tamil Nadu. Srivastava et al (2009) reported three lepidopterans such as *C. medinalis*, *Parapoynx stagnalis* (Zeller 1852), and *Scirpophaga innotata* (Walker, 1863) as the most common pests of rice in Himachal Pradesh. Ane and Hussain (2015) recorded 13 lepidopteran pest species infesting rice from all over India. Varun et al (2017) recorded nine species of lepidoptera viz., *C. medinalis*, *M. patnalis* (= *C. patnalis*), *M. ruralis* (= *C. ruralis*), *Marsmia trapezalis* (Guenée 1854) (= *C. trapezalis*), *Marasmia exigua* (Butler 1879) (= *. exigua*), *Marasmia poeyalis* (Boisduval 1833) (=*C. poeyalis*), *S. incertulas*, *Scirpophaga fusciflua* (Hampson 1893) and *Scirpophaga virginia* (Schultze 1908) infesting rice in Tamil Nadu. Among these, *C. medinalis*, *M. patnalis,* and *S. incertulas* were the dominant pests. Nagaraj et al (2018) documented five species viz., *C. medinalis*, *P. stagnalis*, *S. incertulas*, *Cnaphalocrocis* sp. 1, and *Cnaphalocrocis* sp. 2 as the lepidopteran pests infesting rice in Hyderabad-Karnataka region. Das (2020) reported three lepidopterans viz., *C. medinalis*, *S. incertulas,* and *Mythimna separata* (Walker 1865) as the major pests of rice crop in Assam. Valluri et al (2022) reported two lepidopterans such as *C. medinalis* and *S. incertulas* as the major pests of rice in Guntur, Andhra Pradesh. It is estimated that yield loss due to yellow stem borer and leaf folder ranges from 25-30% and 10-15%, respectively (Khan 2000 and Krishnaiah and Varma 2011).

In India, taxonomic studies on lepidopteran pests of rice were carried out by Hampson (1896), Bradley (1981), Khan (2000), Mathew and Soumya (2013), Nagaraj (2014), Shankaramurthy et al (2015b), Varun et al (2017), Athulya et al (2022), Dey and Shashank (2021) and Pasam et al (2023). However, the primary and most important step in integrated pest control is the correct identification of a pest species that is impacting any crop. It is particularly challenging to find literature on the taxonomy of lepidopterous pests of rice in Nagaland, as it is dispersed throughout many books, periodicals, and monographs printed in several languages over a long era of time. Intensive studies on the taxonomy of a variety of lepidopterous pests connected with the rice ecosystem are necessary to provide a thorough description of the morphological and genital characteristics and to present a key that will be of use for scientists and research scholars to recognize these pests without any ambiguity. The significance of the morphological and genital characters in resolving the taxonomic identities is very well recognized (Miller 1968). Considering the above facts, the present investigation was undertaken with the objective of studying the morphological and genital characters to confirm the identities of the adult lepidopteran pests of rice in Nagaland.

MATERIAL AND METHODS

The survey was carried out at the farmer's field located in Chumukedima district, Nagaland during the *kharif* season from July 2022 to November 2022. Two portable light traps comprised of a funnel with a 125W mercury vapour lamp fitted with baffle plates were placed in between the open rice fields. The light trap was used for four to five hours and the pests trapped were collected at fortnight intervals. The trapped adult specimens were killed, pinned, and then preserved in well-fumigated wooden boxes and were utilized for morphological and genital studies. The morphological characters of these adult specimens were studied following Hampson (1896), Clark (1941), Robinson (1976), Thomas (2007), Nagaraj (2014), and Pasam et al (2023) with slight modifications. The general terminology has been drawn from Diakonoff (1954) and terminology for male and female genitalia have been followed from Klots (1970) and Scoble (1992). The classification of studied specimens was done following Regier et al (2012), Mitter et al (2017), Keegan et al (2019), Leger et al (2021) and Chen et al (2022).

For the preparation of wing slides, the method described by Common (1970) and Zimmerman (1978) was followed with slight modifications. The right-side wings, i.e., both forewings and hind wings were detached with the help of forceps held close to the base by applying a little jerk and dipped in 70% ethyl alcohol. Then, the wings were transferred to sodium hypochloride solution for bleaching for 2-3 min. After bleaching, the wings were washed 3-4 times in distilled water and stained using acid fuchsin for about twenty-four hours. After staining, wings were transferred to 90% alcohol to rinse off excess stain and then transferred to absolute alcohol for complete dehydration. Then, the wing s were mounted on a glass slide in Canada Balsam/DPX, centered and properly oriented in the required direction with the help of needles. A cover slip was placed on the slide gently. The mounted slides were kept on a leveled surface at room temperature (25°C) to dry for 24-36 hours. For the preparation of genitalia, the methods proposed by Robinson (1976) and Zimmerman (1978) were followed with slight modifications. The abdomen of moths was detached from the thorax with the help of a fine needle by exerting upward/downward pressure. The detached abdomen was then transferred to 30% alcohol for wetting. Later, it was shifted to 10% and 5% caustic potash (KOH) in the case of male and female specimens respectively, as the parts of the female genitalia are more membranous than the male genitalia. This was heated slowly in a water bath till the convection currents were observed in the solution and kept for cooling. After cooling, the abdomen was transferred to a glass cavity dish containing water, and the macerated soft tissues were pressed out with the help of a pair of bent needles. After repeated washings in water, the abdomen was transferred to glycerin in a glass cavity dish for further dissection, and observation was made under a stereoscopic microscope.

Before dissection of genitalia, adult specimens were photographed using Nikon D7000 camera body attached with Nikon 90mm macro lens. Adult characters such as maxillary palpi, labial palpi, head, thorax, proboscis, forewing, hindwing, and male and female genitalia were photographed using a DEBRO DSZ 55 stereo zoom trinocular microscope.

RESULTS AND DISCUSSION

One hundred and eighty nine specimens of the adult lepidopteran pests of rice were collected and examined in detail. The studied specimens have shown variations with respect to morphological as well as genital characters. These variations were utilized for classifying them into different genera and species. All the characterized specimens were assigned to four genera with one species each viz., *C. medinalis*), *S. incertulas* belonging to Crambidae, night feeding *L. loreyi* belonging to Noctuidae, and *M. leda* belonging to Nymphalidae (Table 1 & Plates 1-4). Besides, egg, larval, and pupal stages of these pests were observed in the field at different stages of the crop starting from vegetative till harvesting stage (Fig. 1-2).

Family Crambidae Latreille 1810

***Cnaphalocrocis medinalis* (Guenée 1854) *Guen. Delt. & Pyr. p. 201; C & S.no. 4118* (Plate 1)**

Salbia medinalis Guenee 1854, *Delt. et Pyral*., p. 201

Cnaphalocrocis medinalis (Guenee); Lederer 1863, *Z Wiener entomologische Monatschrift*., 7: 384

Botys nurscialis Walker 1859, *List of the Specimens Insects in the Collection of the British Museum*, 18: 724

Botys acerrimalis Walker, 1866: Wlk. Cat. xxxiv, p. 1449

Botys fasciculatalis Walker, 1866: 1431

Botys nurscialis Walker, 1859: Wlk. Cat. xviii, p. 724

Materials examined: India: Nagaland: Chumukedima, (190m ASL), 13.Viii.2022, 4♀; 27. viii. 2022, 4♂, 2♀; 10. ix. 2022, 8♂, 6♀; 24. ix. 2022, 5♂, 7♀; 8. x. 2022, 6♀; 22.x. 2022, 1♂, 4♀, light trap, coll. Imtienla.

Distribution: Afghanistan, Australia, Bangladesh, Bhutan, Cambodia, China, Fiji, Hong Kong, India (Andhra Pradesh, Assam, Haryana, Karnataka, Kerala, Maharashtra, Madhya Pradesh, Manipur, Meghalaya, Punjab, Nagaland, Tripura, Tamil Nadu and West Bengal), Indonesia, Java, Japan, Korea, Malaysia, Madagascar, Myanmar, Nepal, Pakistan, Papua New Guinea, Philippines, Singapore, Solomon Islands, Sri Lanka, Taiwan, Thailand and Vietnam (Varun et al (2017), Reddy and Shankaramurthy (2021) and Pasam et al (2023)).

Host range: *Avena sativa* L., *Pennisetum glaucum* L., *Hordeum vulgare* L., *Saccharum officinarum* L., *Sorghum bicolor* (L.), *Zea mays* L. *Triticum sp.* L. (Shankaramurthy et al (2015a) and Pasam et al (2023))

Description: Medium-sized moth. Presence of basally scaled proboscis. Labial palpi porrect. Adult golden yellow with dark brown markings on the wings. Forewing with sub-terminal, anti-median, and post-median lines prominent in both males and females. In the male, the forewing triangular with a dark brown patch and androconial scales along mid costa; in the female, the forewing triangular with coastal and outer areas brownish yellow; In the female, the forewing postmedian line diagonal and comma-like; the hindwing median line very short, comma like and curved outside. In the male, the abdomen ochreous, covered with scales, and white towards the extremity. In both sexes, legs covered with white scales. Fore tibia with spur-like protrusion called epiphysis.

Wing venation: Forewing with vein R_1 confluent with R_2; R_5 straight and well separated from R_{3+4}; Cu_1, M_3, and M_2 from angle of cell; Hindwing with the cell short; veins Cu_1, M_3 and M_2 from angle; M_1, R_s from upper angle, R_5 anastomosing with $Sc + R_1$ almost to apex.

Male genitalia: Uncus is faintly sclerotized and short. Tegumen is short and densely setose. Valva is semi-membranous, ovate and the internal surface is lightly clothed with fine setae. Vinculum with prominent coremata and very long hair-like setae. Sacculus is less sclerotized and Saccus U-shaped. Aedeagus short, slender, and sclerotized with dense cornuti spiked on vesica apically.

Female genitalia: In female genitalia, anal papillae are thickly setose and slightly sclerotized. Apophyses weak, posterior pair approximately twice the length of the anterior pair. Ostium is broad and slightly sclerotized. Ostium bursae is strongly spiculated. Bursa copulatrix is elongated and spiculated with a thorn-like signum bounded by strong granular scobination.

Remarks: In rice ecosystem, this is one of the most important leaf folder species (Chakraborty and Deb (2011), Padmavathi et al (2013), Kadke and Patel (2015) and Soomro et al (2020)) and has become widespread (Rautaray et al 2019) throughout the major rice growing areas.

Family Noctuidae Latreille, 1809

***Leucania loreyi* (Duponchel1827) (Plate 2)**

Acantholeucania loreyi (Duponchel 1827, Calora 1966, 665; Holloway 1976:

Noctua loreyi Duponchel, 1827, *Lep. France 7:81*

Leucania caricis Treitschke, 1835, *Schmett. Europe., 10.2:91*

Leucania collecta Walker, 1856*, List of the Specimens of*

Table 1. Lepidopteran pests of rice collected through a survey using light traps from Nagaland, India

Common name	Scientific name	Family	Sub-family	Damaged parts	Earlier reports cited as a pest on rice across the globe
Rice leaf folder	*Cnaphalocrocis medinalis* (Guenée)	Crambidae	Spilomelinae	Leaves	Srivastava et al (2009), Nagaraj (2014), Shankaramurthy et al (2015a), Shankaramurthy et al (2015b), David and Ramamurthy (2017), Varun et al (2017), Nagaraj et al (2018), Mally et al (2019), Das (2020), Somoro et al (2020), Reddy and Shankaramurthy (2021), Valluri et al (2022) and Pasam et al (2023)
Night feeding rice armyworm	*Leucania loreyi* (Duponchel)	Noctuidae	Hadeninae	Leaves	Fibiger and Legrain (2009), Walters (2015) and Jalaeian et al (2017)
Rice yellow stem borer	*Scirpophaga incertulas* (Walker)	Crambidae	Schoenobiinae	Leaves	Nagaraj (2014), Ane and Hussain (2015), Shankaramurthy et al (2015a), Varun et al (2017), Nagaraj et al (2018) and Dey and Shashank (2021)
Rice butterfly	*Melanitis leda* (Linnaeus)	Nymphalidae	Satyrinae	Leaves	Ane and Hussain (2015), Mishra et al (2017), Pradeepa et al (2017), Nitin et al (2018) and Sanjay et al (2021)

Lepidopterous Insects in the Collection of the British Museum., 9: 105

Leucania exterior walker, 1856. *Ibid. 9: 106*

Leucania curvula Walker, 1856

Leucania denotata Walker, 1856, *Ibid. 9:107*

Leucania designata Walker, 1856

Leucania pseudoloreyi Rungs, 1953.

Materials examined: India: Nagaland: Chumukedima, (190 m - ASL), 10. ix. 2022, 3♂; 24. ix. 2022, 3♂; 8. x. 2022, 4♂; 22. x. 2022, 3♂; 5. xi. 2022, 2♂; 9. xi. 2022, 1♂, light trap. coll. Imtienla.

Distribution: Algeria, Bangladesh, Cape Verde, Central African Republic, DR Congo, Egypt, Ethiopia, Fiji, Gambia, India (Chhattisgarh, Gujarat, Himachal Pradesh, Maharashtra, Uttarakhand, and Rajasthan), Israel, Ivory Coast, Kenya, Libya, Mauritius, Morocco, Myanmar, New Caledonia, South Africa, Sri Lanka, Sudan, Tanzania, Tonga, Turkey, United Arab Emirates, Uganda and Zimbabwe (Fibiger and Legrain (2009), Holloway (2012), Walters (2015), Sambath and Farooqui (2017), Seven (2019) and Farooqui and Parwez (2022)).

Host range: *Oryza sativa*, *Sorghum bicolor*, *Triticum aestivum*, *Hordeum vulgare*, *Avenasativa*, *Allium cepa*, *Zea mays and Saccharum Officinarum*, *S. ravennae*, *Arundo*

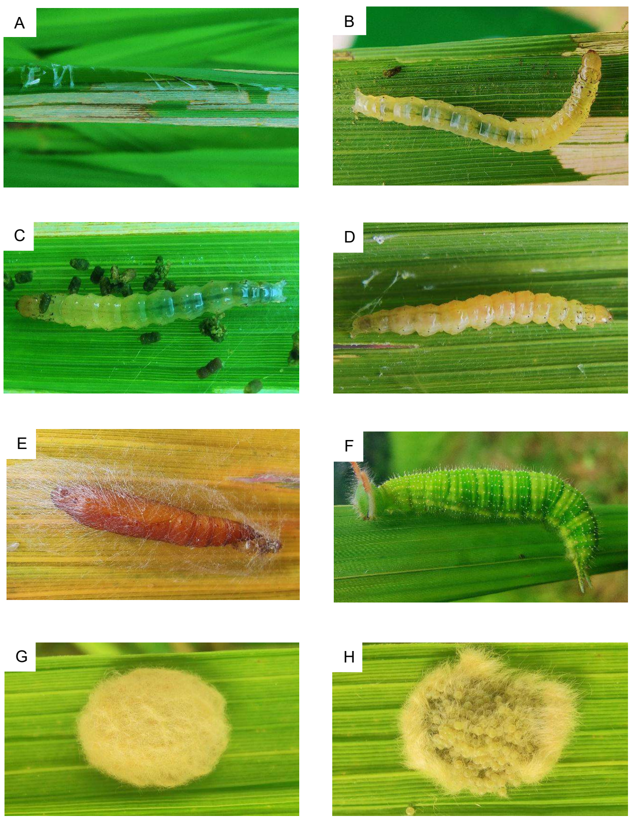

Fig. 1. A-F. *C. medinalis*; A. Larva folds the leaves longitudinally, scrapes the green tissue, and remain inside; B & C. Early and late instar larvae; D. Larva before pupation; E. Pupa F. *M. leda* late instar larva; G-H. *Scirpophaga incertulas*; G & H. Egg mass covered with hairs

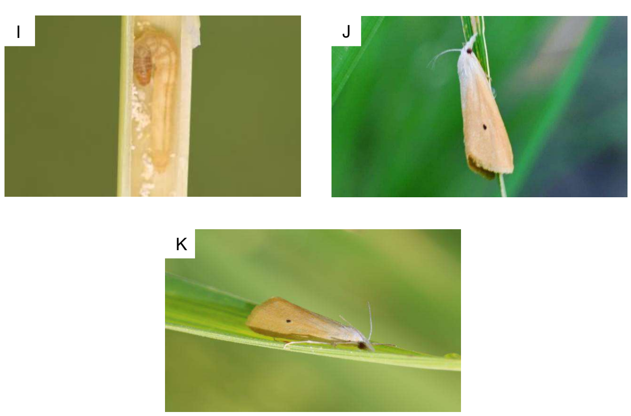

Fig. 2. I-K. *Scirpophaga incertulas*; I. Larva; J & K. Adult resting on the leaf

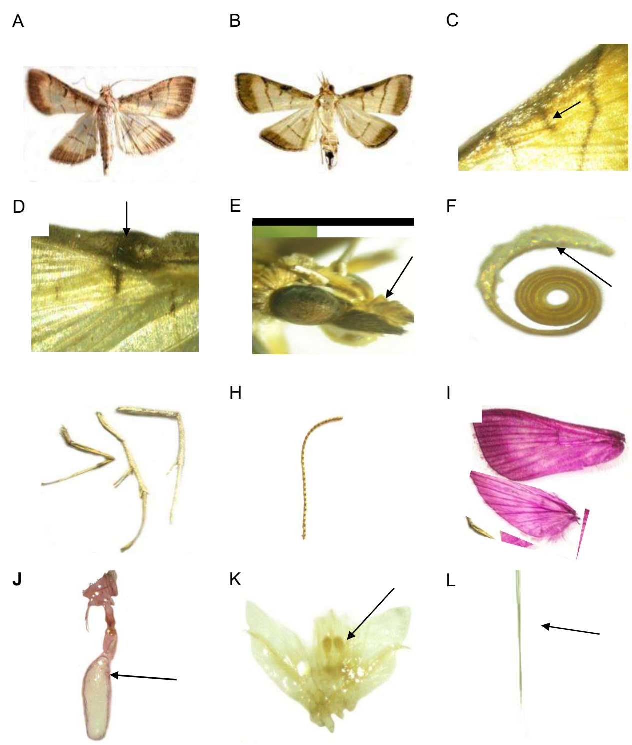

Plate 1. Morphological and genital characteristics of *Cnaphalocrocis medinalis* (Guenee)
(A. female; B. male; C. forewing with subterminal, anti-median and post-median lines; D. androconial scales in male forewing; E. labial palpi porrect; F. basally scaled proboscis; G. spur-like projection on foretibia; H. antennae; I. wing venation; J. Female genitalia, thorn-like signum; K. male genitalia, bifurcate uncus; L. aedeagus)

donax, *Panicum maximum*, *Phragmites australis* (Fibiger and Legrain (2009), Walters (2015) and Jalaeian et al (2017)).

Description: Adult wingspan is about 34-44 mm. Moths are usually brown or straw-coloured with a tiny white spot near the middle. The proboscis is dented. Labial palpi is slightly porrect. The forewing is greyish in colour, the veins are paler lined with brown lines. A series of narrow longitudinal dark stripes and a submarginal arc of black dots are present on each forewing. Hindwings are lighter than the forewings, usually white in colour. Abdominal tufts are scale-like, with brown black hairs.

Wing venation: In the forewing, C and Sc are unbranched reaching towards the costal margin. R separated into R_1 and R_S (R_2, R_3, R_4 and R_5); R1 and R_2 reaches towards coastal margin; R_3 and R_4 branched: R_5 branched to R_4. M_1, M_2 and M_3 present. M_2 closer to M_3 than M_4. CuA_1, CuA_2 present. A_1 reaches towards the posterior margin, A_2 present and highly reduced. In the hindwing, Sc and R_1 arise near the base of the wing. Sc and R_1 is separated from R_S.

Male genitalia: Uncus is long, curved, and beak-like with hair-like structures on the mid-dorsal portion. Valva with two harpe-like structures and a distal portion is equipped with hair-like structures. Gnathos is highly reduced. Tegumen is broad and sclerotized. Juxta sub-triangular in shape. Saccus is U-shaped. Aedeagus short and robust with stout cornutus and numerous cornuti.

Female genitalia: Not examined

Remarks: It is a noctuid pest of grain crops like rice, wheat, maize, sugarcane, barley, sorghum etc. (Nam et al 2020).

Family Nymphalidae Rafinesque, 1815

***Melanitis leda* (Linnaeus, 1758), *Sys. Nat. 1(2): 773* (Plate 3)**

Papilio ismene Cramer, *Pap*. *Exot*., 1: 40, pl. 26, figs.

Melanitis leda ismene Talbot, *Fauna of Brit*. *India*, Butterflies, 2: 366-369.

Melanitis leda ismene Gupta & Shukla, *Rec*. *Zool*. *Surv*. *India*, *Occ*. *Pap*. *No*. 106: 23

Materials examined: India: Nagaland: Chumukedima, (190m ASL), 13. viii. 2022, 4♂,6♀; 27. viii. 2022, 6♂, 6♀; 10. ix. 2022, 13♂, 9♀; 24. ix. 2022, 5♂; 8. x. 2022, 5♂6♀; 22.x. 2022, 3♂; 5. xi. 2022, 1♀, light trap, coll. Imtienla.

Distribution: India (Andaman & Nicobar Islands, Andhra Pradesh, Arunachal Pradesh, Assam, Bihar, Chhattisgarh, Delhi, Goa, Gujarat, Himachal Pradesh, Jammu and Kashmir, Jharkhand, Karnataka, Kerala, Lakshadweep, Madhya Pradesh, Maharashtra, Meghalaya, Nagaland, Orissa, Rajasthan, Sikkim, Tamil Nadu, Tripura, Uttarakhand, Uttar Pradesh and West Bengal), Afghanistan, Africa, Australia, Bangladesh, Bhutan, Brunei, Cambodia,

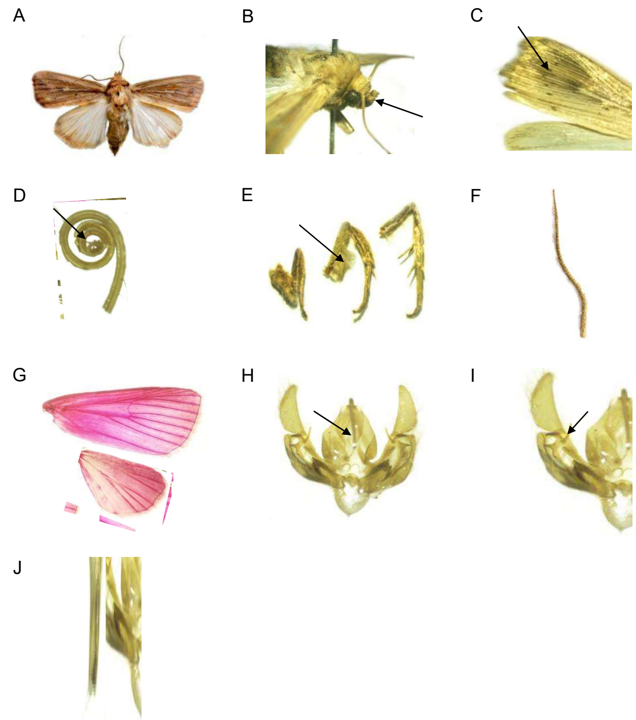

Plate 2. Morphological and genital characteristics of *Leucania loreyi* (Duponchel)
(A. male; B. labial palpi porrect; C. arc of black spots on forewing; D. dented proboscis; E. legs; F. antennae; G. wing venation; H. male genitalia, uncus beak-like; I. harpe or clasper on the valve of male genitalia; J. aedeagus)

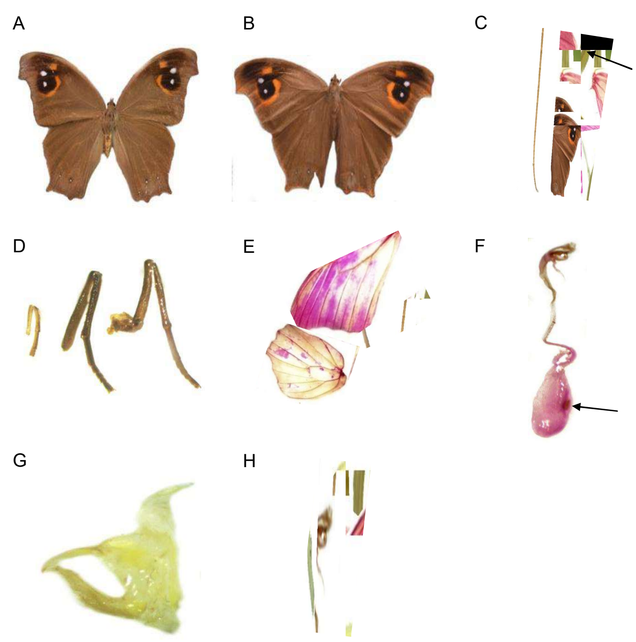

Plate 3. Morphological and genital characteristics of *Melanitis leda* (Linnaeus)
(A. female; B. male; C. antennae apically swollen; D. forelegs reduced; E. wing venation; F. female genitalia, signum present; G. male genitalia; H. aedeagus)

China, East Timor, Indonesia, Laos, Malaysia, Maldives, Myanmar, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Thailand and Vietnam (Gupta and Majumdar (2012), Sambath (2014), Sharma and Goswami (2020) and Irungbam (2022)).

Host range: *Oryza sativa*, *Eleusine indica*, *Panicum maximum*, *Sorghum bicolor*, *S. vulgare*, *Zea mays*, *Axonopus compressus*, *Bambusa arundinacea*, *Brachiaria mutica*, *Cyanodon dactylon*, *Eleusine indica*, *Ficus reliogiosa*, *Paspalidium geminatum*, *Pennisetum setaceum*, *Rotboellia cochinchinensis, Sorghum halepensis* and *Triticum aestivum* (Gupta and Majumdar (2012), Mishra et al (2017), Pradeepa et al (2017), Roy et al (2021) and Sanjay et al (2021)).

Description: The adult is dark brown in colour. The head, thorax, and antennae are brown or greyish-brown in colour. Antennae annulated with white, ochraceous at apex. Wings are broad. The forewing is falcate with subapical white pupilled black spots surrounded by orange borders. The hindwing is caudate and three ocelli are present and more prominent in females. Tail is present in females. In male, the forewing is angled and falcate in female. In the hindwing of male, presence of a single white spot above the tail as well as three spots in female. The female is usually larger and light coloured and the forewing significantly sloping at vein 5.

Wing venation: In the forewing, the costal vein is present, Sc reaches towards the anterior margin of the costa; R_1 and R_2 stalked. R_3 reaches towards the posterior margin of the wing. Cu_1 and Cu_2 present and A_1 and A_2 present.

Male genitalia: Uncus with an elongate, slender, and blunt lobe. Vinculum and tegument with elongate narrow arms. Valva is short and swollen in the middle and basal part. Apex is round and blunt. The inner margin of the valve is fringed with a row of tiny, stiff hairs. Saccus with an exceptionally elongate lobe having a blunt tip. Aedeagus is short, robust, and fairly bent in the middle; the proximal portion broad and appears like the grip of a sword. The distal end broadly blunt.

Female genitalia: Bursa is vesicular and appears as a hood-shaped structure. Ductus bursae is narrow and long and consist of uniform width. The basal portion is swollen.

Remarks: It is an important pest of rice (Pradeepa et al (2017)). **Family Crambidae Latreille, 1809**

***Scirpophaga incertulas* (Walker, 1863), *Wlk. Cat. xxvii,143* (Plate 4)**

Chilo incertulas Walker 1863, *List Spec Lep. Ins. Coll. Brit. Mus*., 27: 143

Schoenobins incertellus (Walker); Hampson, 1895. *Proc. zool. Soc. Lond*., p. 916

Tryporyza incertulas (Walker); Common 1960, *Aust. J. Zool*., 8 (2); 340

Scirpophaga incertulas (Walker); Lewvanich 1981, *Bull. Brit. Mus.* (*Nat. Hist.*), (Entomology), London, 42 (4); 243

Catagela adonotalis Walker 1863, *List. Spec- Lep. Ins. Coll. Brit. Mus*., 27: 192 (Synonymised by Hampson 1895)

Schoenobins punctellus Zeller 1863, *Chilonidarum et. Crambidarum genera et species*, (Synoymised by Shiraki, 1917)

Schoenobins minutellus Zeller 1863, *Chilonidarum Crambidarum genera et species*, (Synonymised by Hampson,1895)

Tipanaea bipunctifera Walker 1863, *List. Spec. Lep. Ins. Coll. Brit. Mus*., 28: 523. (Synonymised by Shiraki 1917)

Chilo gratiosellus Walker 1864, *List Spec. Lep. Ins. Coll. Brit. Mus*., 30: 967 (Synonymised by Shiraki 1917)

Schoenobius bipunctifer ab. *quadripunctellus* Strand 1918, *Stettin ent. Ztg*., 79: 263 (Synonymised by Lewvanich 1981)

Materials examined: India: Nagaland: Chumukedima, (190 mASL), 16. vii. 2022, 4♀; 30. vii. 2022, 4♂, 2♀; 13.Viii.2022, 3♂, 5♀; 27. viii. 2022, 6♂, 2♀; 10. ix. 2022, 7♂, 5♀; 24. ix.

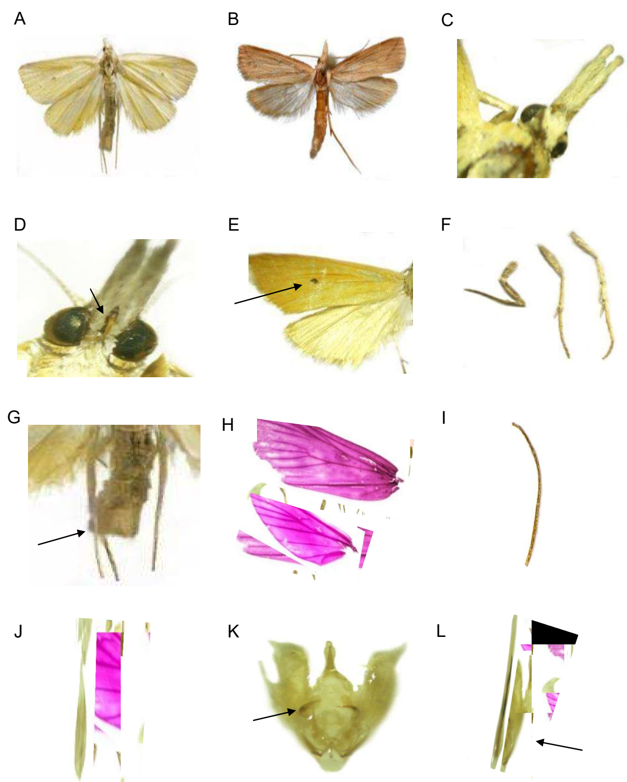

Plate 4. Morphological and genital characteristics of *Scirpophaga incertulas* (Walker)
(A. female; B. male; C. labial palpi porrect, 3 times the diameter of the compound eyes; D. proboscis reduced; E. single black spot on the forewing; F. legs; G. anal tuft; H. wing venation; I. antennae; J. Female genitalia; K. male genitalia, presence of spine; L. aedeagus, presence of curved spined cornuti)

2022, 5♂, 2♀; 08. x. 2022, 2♂, 2♀; 22. x. 2022, 2♀,light trap, coll. Imtienla.

Distribution: Afghanistan, Bangladesh, Bhutan, Borneo, Burma, China, Hong Kong, India (Andaman and Nicobar Islands, Andhra Pradesh, Assam, Bihar, Chhattisgarh, Delhi, Haryana, Indonesia, Karnataka, Kerala, Maharashtra, Nagaland, Orissa, Pakistan, Punjab, Sikkim, Tamil Nadu, Tripura, Uttar Pradesh, West Bengal), Japan, Java, Malaysia, Myanmar, Nepal, Philippines, Vietnam, Singapore, Sri Lanka, Sulawesi, Sumatra, Sumba, Taiwan, Thailand, Vietnam (Chen et al (2014), Chen and Wu (2014), Raha et al (2017), Sanyal et al (2018), Kathirvelu *et al* (2019), Singh (2019) Rao and Sivaperuman (2020)).

Host range: *Oryza sativa* L. (Shankaramurthy et al (2015a)).

Description: Male brownish ochreous. Head and thorax pale ochreous, with smooth frons. Labial palpi is porrect and is about 3 times the length of the compound eyes. Maxillary palpi not well developed in male while well developed and longer than in male. Antennae minutely serrate, profusely ciliated in male, and sparsely ciliated in female. Male forewing is ochreous irrorated with dark scales and the veins slightly streaked with fuscous, black spot at the lower angle of the cell not conspicuous. In females, the forewing is bright yellowish with a clear, single spot at lower angle of the cell. In the male, the hindwing ochreous white, with a double frenulum whereas, in the female, the hindwing white, slightly tinged with yellow towards the outer margin, with single frenulum. In the male, the abdomen is slender and the anal end with thin hairs dorsally. Whereas in female, the abdomen is wide with the tip covered with a tuft of yellowish hairs.

Wing Venation: Forewing with Sc and R_1 close or anastomosed; R_2 free; R_{3+4} stalked; R_5, M_1 free, from below the 'upper angle of cell; M_2-M_3 close to each other, from lower angle of cell; Cu_{1a} close to the lower angle, nearer to M_3 than to Cu_{1b}, the three veins, *i.e.,* M_2, M_1 and Cu_{1a} equidistantly placed; Cu_{lb} much before the cell angle, about thrice as far from Cu_{1a} as the latter from M_3, and nearly in line with origin of R_1 above. Other features as given for the genus. Hindwing venation as given for the genus; M_2 and M_3 close to each other.

Male genitalia: Uncus is long and slender. Gnathos is sclerotized and shorter than the uncus. Valva is rectangular with costal and saccular margins more or less straight and apical margin slightly bent in the middle with setae. Vinculum and saccus V-shaped. Tegumen dorsal portion sclerotized and triangular in shape; sub-teguminal process a bifid spine; aedeagus slender, elongated with two adjacent unequal, curved spined cornuti.

Female genitalia: Anterior apophyses longer than the posterior. Ductus bursae is reduced and membranous. Corpus bursae is elongated, basal three-fourth area is spined minutely with no presence of signum.

Remarks: Rice yellow stem borer is one of the important and serious pests of rice that causes dead hearts and white ears (Shankaramurthy et al (2015a)).

Keys to different species of lepidopteran pests of rice

Keys are prepared to aid rapid and accurate identification of the different species. Based on the variation observed in the objective 'Morphotaxonomic studies on the collected adult lepidopteran pests.' an illustrated key was prepared for the species collected and studied from the rice field.

Key to lepidopteran pest's species occurring in rice ecosystem.

1. Adult is a butterfly, large sized with broad wings, adult is dark brown in colour, hindwing with 1-3 spots, front legs reduced and without tarsal claws, tail or extension on anal vein present, uncus slender, elongate, blunt lobe, aedeagus long and slender. Ductus bursae narrow and long. Presence of signum at bursa copulatrix …………………. *Melanitis leda*

1'. Adult is a moth, small to medium-sized, yellow to ocherous yellow in colour (straw coloured). Wings small to medium-sized with no spots on the hindwing, front legs not reduced, tail or extension on anal vein absent, Uncus is long and slender or short or triangular in shape. Aedeagus is long or short. Ductus bursae is broad and short or narrow and long. Signum present or absent …………………...............………….....……….2

2. Adult is small-sized moth. Male possess dark brown patch and androconial scales along mid costa of forewing. Forewing has sub-terminal, anti-median, and postmedian lines prominent both in male and female, uncus is bifurcate. In female genitalia thorn-like signum is present at bursa copulatrix. ……………………….. *Cnaphalocrocis medinalis*

2'. Adult is medium-sized, absence of androconial scales in the mid costa of forewing. Uncus is never bifurcate, bursa copulatrix is not elongate and round. Signum present or absent……………………...……………………….3

3. Adult is a medium sized moth. Adult is straw coloured, a series of narrow longitudinal dark strips and submarginal arc of more than one black spot present on each forewing…………………...……..*Leucania loreyi*

3'. Adult is a medium sized moth, Adult is ocherous yellow in colour, on the forewing presence of one dark fuscous spot on the lower angle of the cell, tegumen with dorsal sclerotized thickening triangular, ostium bursae broad and membranous, presence of dense spines in the basal three quarters of corpus bursae, Cubital vein in the hindwing not pectinated on upperside *….. Scirpophaga incertulas*

CONCLUSIONS

In the present study, based on the morphological and genital variations, the specimens were grouped into four species viz., *C. medinalis*, *L. loreyi*, *M. leda,* and *S. incertulas* found infesting on rice crops. The species i.e. *L. loreyi* is being reported for the first time from Nagaland, India. Further, an illustrated key was also prepared on the basis of various morphological and gentalic characters for easy and accurate identification of the species. Besides, the coloured photographic illustrations, valid names, and synonyms of each species is also provided.

AUTHOR CONTRIBUTION

The first author contributed in field survey, installation of light trap, collection of specimens, preparation of wing slides, dissection of male and female genetalia of collected specimens, photography and writing of manuscript. The second author contributed in field survey, dissection of male and female genetalia of collected specimens, checking of manuscript. The third author contributed in writing of description of collected specimens. The fourth author contributed in identification of collected specimens, writing of description of wings, male and female genetalia of collected specimens, checking and finalising of manuscript. The fifth author contributed in microscopy and photography of specimens.

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Received 22 January, 2024; Accepted 10 June, 2024

Indian Journal of Ecology (2024) 51(4): 860-866
DOI: https://doi.org/10.55362/IJE/2024/4321

Manuscript Number: 4321
NAAS Rating: 5.38

Optimization of Process Parameters to Manage *Callosobruchus maculatus* (Fabricius) and Maintain Quality Parameters of Green Gram Grains (*Vigna radiata*)

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Abstract: The present study conducted to optimize the effect of different process parameters *i.e.* deltamethrin (0.025-0.075%), canola oil (0.50-1.50%), kinnow peel powder (0.50-1.50%) and storage period (2-6 month) to maintain physical and quality attributes by managing *Callosobruchus maculatus* in stored green gram grains (*Vigna radiata*). Under optimized conditions, the process parameters *i.e.* deltamethrin @ 0.027% for treating jute bags, canola oil @ 1.43% and kinnow peel powder @ 0.85% for treating green gram grains and stored for 6 month showed very less grain damage (0.17%) with minimum colour change (3.96) and optimum protein content (21.92%). The grains treated with optimized parameters required 62 min for their proper cooking and for overall acceptability, these grains scored 8 points (liked very much) based on hedonic sale. Above treated green gram samples with optimized parameters when compared with other tested treatments found to be in consonance with hermetic zerofly bag and metallic drum stored green gram grains with sand layer of 7 cm, revealing all the practices were at par for the effective control of pulse beetle without affecting the physical and quality attributes of green gram grains.

Keywords: Green gram, Pulse beetle, Canola oil, Kinnow peel powder, Insecticide, Storage, Grain quality

Post-harvest losses have become a growing concern globally for the grain supply chain. Among different post-harvest losses, insects are of great threat. Legumes, including green grams, are attacked by a beetle, *Callosobruchus maculatus* (Coleoptera: Chrysomelidae) in both the field and during storage (Srivastava and Subramanian 2016), causes significant losses when stored inappropriately (Jat et al 2013). The harm to the grain, which includes weight loss, a decline in commercial value, a reduction in nutritional content, and hygienic hazards, is caused by the insect's larval stage colonizing the interior section of the grain (Akami et al 2017, Saini et al 2022). Fungi and other secondary pests are more likely to appear because of the damage to the grains, which will reduce the quantity and quality of stored grains. Fumigation is the most practical and economical way to preserve grains particularly from insect-pests. However, due to their instability and detrimental impacts on commodities and humans, most gases have been eliminated. Methyl bromide is one of them, which has been taken out from the list of fumigants since it contributes to the ozone layer's depletion. Phosphine is a cheap insecticide that spreads swiftly through fumigant action and leaves little residue on the products, which makes it a popular choice for managing storage insects. Nevertheless, utilizing a single fumigant over an extended period runs the danger of making insect populations more resistant (Tay et al 2016). Moreover, at the discriminating phosphine concentrations, certain species have already shown 100% survival (Pimentel et al 2010).

Various non-chemical approaches are there to manage green gram at farm and under storage *viz.* cultural control, sealed containers, fine ash, inter-cropping, harvesting time, alternate host, heating and freezing effect, solar treatment and radiation treatments. Use of inert gases such as CO_2 and other method like ozonation (Kaur et al 2023) has also been used to control *C. maculatus* in stored green gram. But use of these gases also poses threat beyond a particular limit. To manage insect-pest, knowledge of the host range and biology of that insect are essential. Although insecticides are the most effective way for controlling insect-pests, but their long-term and careless use has been shown to be environmentally unsound. While, plant-derived compounds are easier to employ, more easily biodegradable, more targeted mode of action, less expensive, less dangerous and easily accessible. Keeping in view the hazardous effect of chemical fumigants, the present study was planned to find out the optimized doses of insecticide and botanicals to store green gram grains for longer period of time without altering their quality attributes.

MATERIAL AND METHODS

Procurement and preparation of sample: Green gram grains (SML 668) were procured from the local market and then disinfested at 60ºC temperature for one hour to make them free from any other insect infestation. Canola oil was procured from the Department of Processing and Food Engineering (DPFE), PAU, Ludhiana, while fresh kinnow peel was obtained from local vendors. The kinnow peel was cut into small pieces, dried in shade and pulverized into fine powders using an electric grinder.

Insect specie: *Callosobruchus maculatus* was collected from infested green gram grains from farmer's house and brought to Storage Laboratory of DPFE, PAU Ludhiana. The adult beetles of *C. maculatus* were then released on disinfested green gram grains in plastic jars covered with muslin cloth and tightened with rubber bands. These jars were kept in BOD incubators maintained at 29 ± 2ºC and 70 ± 5% relative humidity. Ten pairs of adult obtained from this culture were released in another jar with green gram grains. After 48 hours these adults were removed, and the grains were kept as such for about 25 days for the emergence of adults and were used for conducting the experiments.

Treatment details: Jute bags were treated with different doses of deltamethrin 2.8 EC (A) @ 0.025-0.075%, while green gram grains were treated with canola oil (B) @ 0.50-1.50% and kinnow peel powder (C) @ 0.50-1.50% with 2-6 month of storage period (D). Experiments were designed in factorial matrix (4-factors and 3-levels) with three center points of Box-Behnken of response surface methodology (RSM) using statistical software Design Expert 9.0 (StatEase) Box and Behnken (1960) having 27 runs. Based on different combinations obtained from the software, 5 kg green gram grains were packed in each bag with release of 10 pairs (10 males and 10 females) of freshly emerged adults of *C. maculatus* in each bag including untreated control and stored for 2, 4 and 6 months. The experiments were executed to investigate and optimize the process parameters *i.e.* deltamethrin, canola oil, kinnow peel powder and storage period to maintain physical and quality attributes of stored green gram grains by managing *C. maculatus*. Regression models for different responses were developed and optimized for the responses with significant model ($p < 0.05$) and non-significant lack of fit ($p > 0.05$) along with its desirability. The stored green gram grains under optimized process parameters were compared with hermetic zerofly bags, metallic drum with 7 cm sand layer (Anonymous 2023) and untreated control stored grains. All the treatments were analyzed for grain damage, grain weight loss, colour change, moisture content, protein content, cooking quality and overall acceptability of stored green gram grains.

Physical Attributes of Grains

Grain damage: The number of insect damaged grains was counted from 1000 grains of each treatment selected randomly at different storage intervals and per cent seed damage was calculated.

Grain weight loss: Treated and untreated grains were subjected for weight loss-based on number and weight of damaged and undamaged grains. After counting and weighing, grains were analyzed for per cent weight loss (Adams and Schulten 1978).

Colour change: Colour of the fresh and stored samples was measured in terms of 'L', 'a'and 'b' value by using Colour Reader CR-10 (Konica Minolta Sensing Inc.) and calculated (Gnanasekharan et al 1992).

Colour change = $[(L\text{-}Lo)2 + (a\text{-}ao)2 + (b\text{-}bo)2]^{1/2}$

Where, Lo, ao and bo represent the respective readings of fresh sample

Moisture content: Moisture content (%) of each sample was determined by oven drying at 105 ± 1°C for 24 h (Unal et al 2008).

Quality Attributes of Grains

Protein content: To calculate the protein content (%) in the samples, nitrogen content was estimated by using Micro-kjeldhal method (AOAC 2000). Nitrogen values were converted to protein by multiplying the factor of 6.25.

Cooking time: Optimum cooking time was determined by boiling 2 g green gram grains in 20 ml distilled water in hot water bath. During boiling, initially samples were removed after 30 min. and examined for its softness by pressing them between the forefingers and the thumb to determine the cooking time (Wani et al 2017).

Overall acceptability of grains: Overall acceptability was done by using organoleptic characters based on hedonic scale. The characters which was observed under organoleptic studies were colour, visual appearance, flavor, texture, overall acceptability including remarks by a panel of 5 semi-trained judges on 9 point hedonic scale with following individual scores: liked extremely-9, liked very much-8, liked moderately-7, liked slightly-6, neither liked or disliked-5, disliked slightly-4, disliked moderately-3, disliked very much-2 and disliked extremely-1 to find out the most acceptable treated green gram grains (Amerine et al 1965).

RESULTS AND DISCUSSION

Effect on grain damage and weight loss: The grain damage after giving different treatments varied from 0.0 to 3.6 % and significantly affected by canola oil concentration (B) and storage period (D). Grain damage was reduced by the application of oil on the surface of the grains since the coating of oil have ovicidal property, which causes poor oviposition, inhibits egg laying and F_1 progeny emergence (Wanderley et al 2020), thus reduced grain damage and weight loss. There were few treatment combinations, where no grain damage and weight loss were observed at 2 and 4 month of storage (Table 1). The maximum grain damage (3.6%) and weight loss (2.04%) were observed at 6 month of storage in the treatment combinations where deltamethrin (0.050%) was used to treat jute bags, while canola oil (0.50%) and kinnow peel powder (1.00%) were used to treat green gram grains. F-values and P-values of grain damage and weight loss were calculated. The canola oil percentage witnessed the significantly higher effect in comparison to other treatments recording F value 14.19 and 9.52 for grain damage and weight loss, respectively (Table 2). However, the present study showed no grain damage and weight loss with grains treated with 1.0 and 1.5% canola oil concentration along with other variables, below which witnessed more grain damage and weight loss. Further, egg mortality may be linked with toxic components of oil and to physical characteristics. The interaction term BD had significant effect on grain damage and weight loss. The regression equation showing canola oil (B) was having significantly negative and storage period (D) significantly positive effect on grain damage and weight loss (Table 3). The increase in canola oil percentage leads to decrease in grain damage and weight loss and if there is increase in storage period causes increase in per cent grain damage and weight loss. The results are consistent with those obtained by earlier researchers showing oil coating on grains reduced the attack of pulse beetle, *C. maculatus,* (Sharma et al 2019, Sharma et al 2022).

Effect on colour change of grains: The deltamethrin and canola oil treatment as well as deltamethrin and storage period on colour change of green gram grains under varying

Table 1. Experimental data on quality of green gram grains for response surface analysis

Experimenta combinations	Process variables				Product quality responses						
	Deltamethrin 2.8 EC (%)	Canola oil (%)	Kinnow peel powder (%)	Storage methods (Months)	Grain damage (%)	Weight loss (%)	Colour Change	Moisture content (%)	Protein content (%)	Cooking time (min)	Overall acceptability
1.	0.025 (-1)	0.50 (-1)	1.00 (0)	4 (0)	1.2	0.63	4.82	10.2	24.04	69	3
2.	0.075 (+1)	0.50(-1)	1.00(0)	4 (0)	2.9	1.64	6.09	9.4	24.04	68	3
3.	0.025 (-1)	1.50 (+1)	1.00 (0)	4 (0)	0.2	0.06	3.91	10.2	22.25	62	6
4.	0.075 (+1)	1.50 (+1)	1.00(0)	4 (0)	0.2	0.06	4.51	10.4	26.94	62	5
5.	0.050 (0)	1.00 (0)	0.50 (-1)	2 (-1)	0.1	0.05	2.25	10.5	25.98	67	8
6.	0.050 (0)	1.00 (0)	1.50 (+1)	2 (-1)	0.0	0.00	2.34	10.3	26.03	66	8
7.	0.050 (0)	1.00 (0)	0.50 (-1)	6(+1)	0.2	0.17	3.22	10.4	22.10	67	8
8.	0.050 (0)	1.00 (0)	1.50 (+1)	6(+1)	1.2	0.66	4.21	10.4	23.64	66	5
9.	0.025 (-1)	1.00 (0)	1.00 (0)	2 (-1)	0.0	0.00	2.89	10.3	26.00	67	8
10.	0.075 (+1)	1.00 (0)	1.00 (0)	2 (-1)	0.0	0.00	3.26	10.1	25.83	65	8
11.	0.025 (-1)	1.00 (0)	1.00 (0)	6(+1)	0.3	0.08	3.66	10.8	24.92	66	8
12.	0.075 (+1)	1.00 (0)	1.00 (0)	6(+1)	0.3	0.11	3.09	10.8	21.08	65	4
13.	0.050 (0)	0.50 (-1)	0.50 (-1)	4 (0)	0.6	0.30	4.44	10.3	24.02	68	3
14.	0.050 (0)	1.50 (+1)	0.50 (-1)	4 (0)	0.0	0.00	5.80	10.2	21.89	62	5
15.	0.050 (0)	0.50 (-1)	1.50 (+1)	4 (0)	0.5	0.22	5.85	10.2	21.67	69	5
16.	0.050 (0)	1.50 (+1)	1.50 (+1)	4 (0)	0.2	0.15	4.92	10.1	23.95	63	5
17.	0.025 (-1)	1.00 (0)	0.50 (-1)	4 (0)	0.3	0.11	4.22	10.4	22.73	67	7
18.	0.075 (+1)	1.00 (0)	0.50 (-1)	4 (0)	0.0	0.00	4.99	10.2	21.08	67	8
19.	0.025 (-1)	1.00 (0)	1.50 (+1)	4 (0)	0.6	0.30	5.03	10.2	25.96	68	6
20.	0.075 (+1)	1.00 (0)	1.50 (+1)	4 (0)	0.3	0.16	6.05	10.0	21.51	68	5
21.	0.050 (0)	0.50 (-1)	1.00 (0)	2 (-1)	0.2	0.09	3.19	10.4	23.73	68	7
22.	0.050 (0)	1.50 (+1)	1.00 (0)	2 (-1)	0.0	0.00	4.01	10.3	26.06	64	7
23.	0.050 (0)	0.50(-1)	1.00 (0)	6(+1)	3.6	2.04	3.16	10.1	23.98	68	2
24.	0.050 (0)	1.50 (+1)	1.00 (0)	6(+1)	0.3	0.14	4.34	10.4	23.51	62	5
25.	0.050 (0)	1.00(0)	1.00 (0)	4 (0)	0.2	0.07	4.40	10.3	26.58	66	5
26.	0.050 (0)	1.00 (0)	1.00(0)	4 (0)	0.1	0.07	4.64	10.4	26.65	67	6
27.	0.050 (0)	1.00 (0)	1.00 (0)	4 (0)	0.2	0.05	4.50	10.3	24.24	66	5

process conditions ranged from 2.25 to 6.09 irrespective of the experimental combinations (Table 1). There was non-significant effect of all combinations of independent variables on colour change. The quadratic terms of D^2 was significant on colour change of green gram grains recording F value 26.92 (Tables 2, 3). Similar results were obtained on maize grains by Ogendo et al (2004) where grain colour and odour were unaffected by the botanicals.

Effect on moisture content of grains (%): The variation in moisture content was due to different combinations of independent variables and ranged from 9.4 to 10.8 % (Table 1). There was non-significant effect of all independent variables *i.e.* deltamethrin, canola oil, kinnow peel powder and storage period on moisture content. However, the interaction of AB had significant effect on moisture content (Tables 2, 3). Kadam et al (2013) also observed that moisture content in the seed stored for three years of study was non-significant and remained within the safe limit throughout the storage period. In present study, the moisture content of grains were found to be in safe limit which may be due to surface application of canola oil and kinnow peel powder on grains which cover the pores in the grain coat and prevents the entry of water and fungal mycelia and provide protection from physical damage as observed by Beedi et al (2018) in gram and Rathinavel and Raja (2007) in cotton seed.

Effect on protein content of grains (%): Various treatment combinations showed protein variability in green gram grains ranged from 21.08 to 26.65% during 6 month of storage. The storage period had negative but significant effect, while other independent variables had non-significant effect on per cent protein content. The interaction and quadratic effects of deltamethrin, canola oil and storage period for green gram used in various combinations were found to be non-significant. But the quadratic terms of C^2 was significant on protein per cent of green gram grains (Tables 2, 3).

Effect on cooking time of grains (min): The cooking time after giving different treatments varied from 62 to 69 min. The canola oil (B) had negative but significant effect on cooking time (Table 2). This witnessing that the increased canola oil percentage reduced the time required to cook the grains, which may be due to the softness of seed coat without altering the cooking quality and supported by Wanderley et al (2020). All other parameters had non-significant effect on cooking time (Table 3).

Effect on overall acceptability (OA) of grains: The overall acceptability of green gram grains was adjudged based on 9-point hedonic scale and varied from 2.0 to 8.0 points (Table 1). Canola oil and storage period had significant effect on overall acceptability of green gram grains. The results also witnessing that increase in canola oil percentage leads to

Table 2. ANOVA of process parameters for physical and quality attributes of grains

Parameters	F-value						
	Grain damage (%)	Grain Weight loss (%)	Colour Change	Moisture content (%)	Protein content (%)	Cooking time (min.)	Overall acceptability
Model	2.65**	1.15^{ns}	3.83*	1.64^{ns}	1.85^{ns}	10.70**	5.54**
A	0.26^{ns}	0.62^{ns}	2.24^{ns}	2.50^{ns}	1.05^{ns}	1.70^{ns}	2.19^{ns}
B	14.19*	9.52*	8.75 x $10^{-4\ ns}$	1.73^{ns}	0.35^{ns}	130.09*	8.76**
C	0.55^{ns}	3.68 x $10^{-3\ ns}$	2.23^{ns}	1.11^{ns}	0.88^{ns}	0.42^{ns}	2.19^{ns}
D	6.78**	2.01^{ns}	2.58^{ns}	1.73^{ns}	7.43**	0.96^{ns}	17.17*
AB	1.87^{ns}	1.94^{ns}	0.26^{ns}	5.20**	2.36^{ns}	0.32^{ns}	0.26^{ns}
AC	0.000^{ns}	1.32 x $10^{-5\ ns}$	0.035^{ns}	0.000^{ns}	0.84^{ns}	0.00^{ns}	1.05^{ns}
AD	0.000^{ns}	1.32 x $10^{-5\ ns}$	0.48^{ns}	0.21^{ns}	1.45^{ns}	0.32^{ns}	4.20^{ns}
BC	0.058^{ns}	7.57 x $10^{-4\ ns}$	2.92^{ns}	0.000^{ns}	2.09^{ns}	0.00^{ns}	1.05^{ns}
BD	6.23**	5.29**	0.070^{ns}	0.83^{ns}	0.84^{ns}	1.27^{ns}	2.36^{ns}
CD	0.79^{ns}	4.19 x $10^{-3\ ns}$	0.44^{ns}	0.21^{ns}	0.24^{ns}	0.00^{ns}	2.36^{ns}
A^2	0.15^{ns}	0.45^{ns}	0.12^{ns}	0.49^{ns}	2.23^{ns}	0.047^{ns}	0.97^{ns}
B^2	4.25^{ns}	4.10^{ns}	2.01^{ns}	3.08^{ns}	2.40^{ns}	7.37^{ns}	11.92*
C^2	0.47^{ns}	0.94^{ns}	0.46^{ns}	0.19^{ns}	6.73**	2.31^{ns}	2.49^{ns}
D^2	0.12^{ns}	0.10^{ns}	26.92*	2.78^{ns}	0.072^{ns}	0.58^{ns}	9.35*
Lack of fit	10.47^{ns}	1.44^{ns}	10.03^{ns}	17.10^{ns}	1.26^{ns}	2.62^{ns}	3.22^{ns}

*Indicates p value as significant at 1% level of significance, ** at 5 % level of significance
Where, A- Deltamethrin 2.8EC, B-Canola oil, C-Kinnow peel powder, D-Storage period

increase in overall acceptability of green gram grains which may be due to shinning look of the grains by application of canola oil on the surface of grains. Canola oil had positive, while storage period had negative effect on the overall acceptability of green gram grains. Thus, increases in storage period reduce the overall acceptability of green gram grains. The quadratic terms of B^2 and D^2 had significant effect on overall acceptability of green gram grains (Tables 2, 3).

Optimization of process parameters: The results of the analysis discussed above have been used to optimize various process parameters *i.e.* deltamethrin (A), canola oil (B), kinnow peel powder (C) and storage period (D) to protect green gram grains from *C. maculatus*. In optimizing process parameters, the results were aimed to have minimum grain damage, colour change and cooking time as well as maximum overall acceptability. The optimized conditions *viz.* deltamethrin 2.8 EC @ 0.027%, canola oil @ 1.43%, kinnow peel powder @ 0.85% with 6 month of storage period resulted in minimum grain damage (0.17 %), minimum colour change (3.96), optimum protein content (21.92%), minimum cooking time (62 min) with maximum overall acceptability (8 point) showing a desirability of 0.851 (Table 4).

End-use quality comparison of optimized parameters with hermetic zerofly, metallic drum with sand layer and untreated control stored green gram grains: The various physical and quality attributes of green gram grains stored with optimized parameters were compared with hermetic zerofly, metallic drum with sand layer and untreated control (Table 5). The results revealed that the grain damage to green gram in optimized parameters, hermetic zerofly bag, metallic drum and untreated control stored grains were 0.17, 1.8, 0.0 and 71.6%, respectively at 6 month of storage period. The less grain damage in optimized parameters showed the effect of insecticide and botanicals, while in hermetic zerofly bag, it was probably due to oxygen starvation which plays a role in killing or less multiplication of insects as compared to untreated control (Yewle et al 2022). There was no grain damage to metallic drum with 7cm layer of sand stored grains

Table 3. Regression models developed for prediction of responses

Regression equation	Best model	R^2
Grain damage $=0.27+0.092*A-0.68*B+0.13*C+0.47*D-0.42*AB+0.00*AC+0.00*AD +0.075*BC0.77*BD+0.27*CD+0.10*A^2+0.55*B^2-0.18*C^2+0.092*D^2$	Quadratic	0.75
Weight loss $=0.11+0.94*A-3.67*B+0.072*C+1.69*D-2.87*AB-7.5x10^{-3}*AC +7.5 x10^{-3}*AD + 0.057*BC-4.74*BD +0.13*CD +1.20*A^2 +3.62*B^2-1.73*C^2+0.57*D^2$	Quadratic	0.69
Colour change $=4.58+0.29*A-5.5 x10^{-3}*B +0.29*C+0.31*D-0.17*AB+0.0063*AC-0.23*AD-0.58*BC+0.089*BD +0.22*CD +0.100*A^2 +0.41*B^2+0.20*C^2-1.51*D^2$	Quadratic	0.82
Moisture content $=10.33-0.10*A+0.083*B +0.067*C+0.083*D+0.25*AB+0.000*AC +0.050*AD-0.000*BC+0.10*BD +0.050*CD-0.067*A^2 0.17*B^2+0.042*C^2+1.16*D^2$	Quadratic	0.66
Protein content $=25.82-0.45*A+0.26*B +0.41*C-1.20*D+1.17*AB-0.70*AC -0.92*AD+1.10*BC-0.70*BD +0.37*CD-0.99*A^2 -1.02*B^2+1.71*C^2-0.18*D^2$	Quadratic	0.68
Cooking time $=66.33-0.33*A-2.92*B+0.17*C-0.25*D+0.25*AB+0.00*AC +0.25*AD+0.00*BC-0.50*BD +0.00*CD+0.083*A^2 -1.04*B^2+0.58*C^2-0.29*D^2$	Quadratic	0.92
Overall acceptability $=5.33-0.42*A+0.83*B-0.42*C-1.17*D-0.25*AB-0.50*AC -1.00*AD-0.50*BC+0.75*BD +0.75*CD+0.42*A^2 -1.46*B^2+0.67*C^2-1.29*D^2$	Quadratic	0.87

Table 4. Optimum values of process parameters and responses for green gram grains

Process parameters	Target	Experimental range		Optimum values	Desirability
		Minimum	Maximum		
Deltamethrin (%)	Range	0.025	0.075	0.027	0.851
Canola oil (%)	Range	0.50	1.50	1.43	
Kinnow peel powder (%)	Range	0.50	1.50	0.85	
Storage period	Range	2.00	6.00	6.00	
Responses					
Grain damage (%)	Minimize	0.00	3.6	0.176	
Colour change	Minimize	2.246	6.095	3.96	
Cooking time (min)	Minimize	62.00	69.00	62.00	
Overall acceptability	Maximize	2.00	8.00	8.00	
Protein content (%)	Range	21.08	26.94	21.92	

which may be due to restriction in movement of beetles as inter-granular space was filled with sand, which leads to death of beetles even before mating. All the tested treatments were superior to untreated control to store green gram grains for a period of 6 month. The colour change of green gram grains under various treatments showed maximum change in untreated control (4.21) at 6 month of storage, which may be due to presence of eggs on grains or insect eaten grains, which leads to degradation of colour during storage (Kaur et al 2013). Minimum colour change of green gram grains were under optimized parameters and hermetic zerofly bags at 6 month of storage and supported by Yeole et al (2018) where green gram can be stored up to 6 month in hermetic bag without any fumigation maintained the food quality. Further, no change in colour was observed in metallic bin stored green gram grains (2.18) when compared with initial colour (2.17) of grains as observed by Saini et al (2022). The moisture content in green gram grains stored with optimized doses were 10.20%, while in hermetic zerofly bags, metallic bin and untreated control stored grains were 8.50, 9.80 and 10.50%, respectively at 6 month of storage Kadam et al (2013) also recorded the moisture content ranged from 8.34 to 8.66 per cent after 9 month of storage of chickpea and 10.1 to 10.8 % recorded in stored green gram seed for 6 month (Saini et al 2022). The protein is an important nutritional parameter for human being, 26.27% protein content was recorded initially in green gram grains used for storage. The protein content 21.92, 25.10, 26.26 and 25.51% were recorded under optimized parameters, hermetic zerofly bag, metallic bin and untreated control stored grains, respectively. The protein content in untreated control grains didn't fall much, which may be due to the presence of insects, eggs and their excreta on/in grains which contributed a major part of N_2 estimated in the damaged grains and then converted into crude proteins. Similar trend was observed by Hamdi et al (2017) and Mbah and Silas (2007) that protein content increased in infested cowpea seeds. There was very little difference in cooking time observed in various treatments *i.e.* 62 min required to cook green gram grains stored under optimized parameters, while 65 and 63 min required for hermetic zerofly and metallic bin stored green gram grains, respectively. Minimum time was recorded to cook untreated green gram grains (57 min), which may be due the presence of insect eaten grains. In overall acceptability of green gram grains, 8 point (liked very much) was scored by grains stored with optimized parameters and hermetic zerofly bag for 6 month, which may be due to coating of oil give shining appearance to grains and less insect incidence. Further, metallic drum stored green gram grains scored 9 point (liked extremely), which may be because the drum retain the actual appearance of grains even at 6 month of storage. Least score *i.e.* 2 (disliked very much) were recorded for green gram grains stored in untreated control bags, which may be due to heavy infestation, egg laid on grains and presence of insect

Table 5. End-use quality comparison of optimized parameters with hermetic zerofly, metallic drum with sand layer and untreated control stored green gram grains

Process parameters	Responses					
	Grain damage (%)	Colour Change	Moisture content (%)	Protein content (%)	Cooking time (min.)	Overall acceptability (score)
Optimized values of D:CO:KPP:SP (0.027:1.43:0.85:6.00)	0.17	3.96	10.20	21.92	62	8.0
Hermetic zerofly bag						
2 month	0.4	3.36	11.10	24.70	65	8.0
4 month	1.4	3.60	10.60	25.30	63	8.0
6 month	1.8	3.71	8.50	25.10	65	8.0
Metallic drum with sand layer						
2 month	0.0	2.17	10.40	26.21	66	9.0
4 month	0.0	2.17	10.20	26.25	65	9.0
6 month	0.0	2.18	9.80	26.26	63	9.0
Untreated control						
2 month	5.40	3.73	10.00	24.17	60	5.0
4 month	59.6	4.16	10.10	25.23	58	2.0
6 month	71.6	4.21	10.50	25.51	57	1.0

D= Deltamethrin, CO= Canola Oil, KPP= Kinnow Peel Powder, SP= Storage period
Fresh sample: Protein content- 26.27 %, Moisture content- 10.20%, Colour change- 2.17

eaten grains which gave bad appearance and renders them unfit for consumption.

CONCLUSIONS

Green gram was successfully stored for a period of six month with the use of optimized parameters of deltamethrin, canola oil and kinnow peel powder. The above-treated green gram samples under optimal conditions agreed with the hermetic zerofly and metallic drum containing the sand layer storing the green gram grains, indicating that all the practices were at par for the efficient control of pulse beetle without degrading the quality criteria. This indicate that treatment of green gram with optimized conditions can be used as a part of integrated pest management for safe storage of green gram grains.

ACKNOWLEDGEMENTS

The authors thank the ICAR- AICRP on Post-harvest Engineering and Technology, New Delhi for financial support.

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Received 29 March, 2024; Accepted 30 June, 2024

Indian Journal of Ecology (2024) 51(4): 867-871
DOI: https://doi.org/10.55362/IJE/2024/4322

Manuscript Number: 4322
NAAS Rating: 5.38

Biology of *Ephestia cautella* (Walker) on Dehulled Foxtail millet and Efficacy of Conventional Methods for its Control

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***Abstract*:** The biology of the warehouse moth, *Ephestia cautella* (Walker) was studied on dehulled foxtail millet at Post-harvest Technology Centre, Bapatla. Oval-shaped, sculptured, pearly white coloured eggs were laid singly. The neonate larva was semi-translucent, yellowish-white with a distinctly dark brown head and thoracic shield. Fully grown larva measured about 10 mm. Pupa is obtect, which measured 6.37 mm in length and 1.71 mm in width. Adult longevity was 6.46 days. The adult moth is small measuring 9.0 to 11.0 mm in length and 2-3 mm in width. The total life cycle of *E. cautella* varied from 24 to 40 days. Conventional methods namely; use of neem leaves, karanj leaves, bay leaves, sweet flag rhizomes, garlic, cloves, camphor, common salt, and Parad tablets were evaluated against warehouse moth based on the emergence of progeny adults. The insect could establish successfully in all the treatments. However, there was significant reduction over control in moth emergence in the treatments of Parad tablets, cloves, and camphor at single dose (91.57, 67.54, and 59.55%, respectively) and (95.30, 72.25, and 72.74%, respectively) at double dose.

Keywords: Biology, Conventional methods, Foxtail millet, Management, Warehouse moth

Millets are commonly referred to as "small seeded grasses" that belong to the family Poaceae. Though millet production was declined during the post-green revolution period, realizing their nutritional benefits, low input requirement and climate resilience, their cultivation and consumption have been increased. In the recent past, concerted efforts made by various organizations and stakeholders to create awareness among the farmers, entrepreneurs and consumers have resulted in enormously increased demand for millet foods. India is the world's leading producer. With 10.24 million tons of millet production, India shared 36.08% of the global production which was 28.37 million tons during 2019 (FAOSTAT 2019). Recognizing the importance of millets, 2018 was observed as the National Year of Millets by the Indian government and 2023 as the International Year of Millets by the United Nations. Millets are stored at various points before reaching the consumer during which they are susceptible to stored grain insect pests. No internally feeding insect was found in minor millets owing to their smaller grain space which is insufficient for the development of feeding stages (Rajendran and Chayakumari 2003). On the other hand, processed millet grains are more susceptible to externally feeding insects especially Tropical warehouse moth, *Ephestia cautella* (Walker) (Lepidoptera: Pyralidae) (Gueye and Delobel 1999). As many as nine insect species were recorded in processed millets retailed in the market while infestations by meal moth and red flour beetle were common (Swamy and Wesley 2021b). The warehouse moth feeds on a wide variety of materials including grain, flour, dried fruits, nuts, oilseeds, beans, and confectionery items. Food materials are contaminated with frass, cast skins, pupal cases, and dead insects. Copious amounts of silk produced by larvae result in deterioration of the quality and shelf life of the food. Since over-reliance on synthetic pesticides and fumigants for stored-product insect pest control is hazardous to the environment, alternatives that can ensure sustainable pest management are of great significance (Yüksel et al 2023). Several indigenous methods like the use of neem seed kernels, neem leaves, karanj leaves, camphor, ash, table salt, turmeric powder, matchboxes, sand, lime, *etc* have been documented as commonly adopted grain protection measures (Reddy 2006, Karthikeyan et al 2009, Dhaliwal and Singh 2010, Anju and Kanchan 2013 and Prakash et al 2016). Plant and natural products are known to show repellence, feeding deterrence, growth regulation and insecticidal activities against stored grain insects. Indigenous methods namely the use of dung powder, ash and camphor could effectively prevent pulse bruchid in blackgram (Swamy and Wesley 2021a). Hence, studies were conducted to understand the biology of warehouse moth and also to evaluate various low-cost control techniques.

MATERIAL AND METHODS

Biology of *E. cautella* on dehulled foxtail millet was studied during *rabi* season 2019-20 at ambient room temperature and relative humidity and efficacy of certain additives was assessed during 2020-21 at Post-harvest Technology Centre, Bapatla. Insect culture was established on sterilized dehulled foxtail millet using mother culture obtained from the local godowns. Freshly emerged male and female adults were captured using injection vials and introduced into a plastic funnel which was fastened with wire mesh on its wide mouth to contain the moths while the tubular end of the funnel was closed with a glass vial. A cotton swab dipped in 10 percent honey solution was hung through a thread into the oviposition containment to facilitate feeding by moths and fresh food was provided every day by changing the swab. This setup was placed in a plastic tray and white paper was kept below the inverted funnel to collect the eggs. Eggs were gently separated from the scales and collected into glass vials and observed for eclosion. The incubation period was recorded and the neonate larvae were transferred individually into glass insect vials having a small quantity of foxtail millet grains with the help of a soft camel's hairbrush. They were placed in cages at ambient conditions and each glass vial was examined daily to record larval, pupal, and adult durations. Morphometrics of the individual life stages of warehouse moth was also recorded.

Experiment was conducted to evaluate some eco-friendly methods namely the use of neem leaves, karanj leaves, bay leaves, sweet flag rhizomes, garlic, cloves, camphor, common salt, Parad tablets for the management of warehouse moth. Fresh leaves of neem and karanj were collected from healthy trees and shade dried, while the remaining treatment materials were obtained from the local market. Parad tablets (M/s Zandu Pharmaceutical Works Pvt Ltd) were purchased from an ayurvedic medical store. Freshly harvested produce of foxtail millet was dehulled in the Agro-processing centre of Post-harvest Technology Centre, Bapatla to use as a substrate for the insects. There were ten treatments including an untreated control in three replications. The dose of each treatment was fixed based on available reports and they were tested at single and double doses. After treating the millet grains, neonate larvae (30 no.s) were released into each container and closed with a lid. The treated samples were incubated at ambient laboratory conditions. Data on progeny emergence of moths were recorded twice at 60 days interval after insect release and total emergence was worked out for 120 days. The data obtained were suitably transformed and subjected to analysis of variance ANOVA by completely randomized design using web-based agricultural statistics software package WASP 2.0.

RESULTS AND DISCUSSION

Within a few hours of emergence, pairing of the moths had taken place, and oviposition by females was also observed by the next day. Oval-shaped, sculptured, pearly white coloured eggs were laid singly scattered among the food grains. The average incubation period was found to be 3 days with a range of 2.5 – 3.5 days (Table 1). The neonate larva is semi-translucent, yellowish-white with a distinctly dark brown head and thoracic shield (Plate 1). The larval colour showed a pink tinge, more so in later instars. Production of salivary threads for webbing the grains was observed from the neonate stage itself. As the larva grows, it gathers more grains for webbing and finally undergoes pupation inside the same cocoon. Fully grown larva measured about 10 mm. Larva moves freely amongst the food grains. The pre-pupal stage was marked with cessation of feeding and larva assumed spindle shape before pupation which occurred inside the white silken structure. The pupa is obtect, which measured 6.37 mm in length and 1.71 mm in width and weighed an average of 0.007 g. Mean larval development and pupal periods were 13.69 days and 8.45 days, respectively. Adult longevity was observed to be 6.46 days. The adult moth was small measuring 9.0 to 11.0 mm in length and 2 –3 mm in width. The fore wings were greyish brown with transverse black patterns while the hind wings were dull white and deeply fringed. The total life cycle of warehouse moth was found to vary from 24 to 40 days. Later stage of infestations was observed with thick mat formation due to dense white silken cocoons, damaged grains, and frass material coupled with mold growth (Plate 2). The observations on biology of *E. cautella* were similar to the earlier findings although on other substrates (Karuppaiah et al 2018, Oyedokun et al 2012, Aldawood et al 2013 and

Table 1. Longevity and morphometrics of different life stages of *E. cautella*

Insect stage	*Mean ± Std dev.	Range
Egg period (days)	3 ± 0.33	2.5 to 3.5
Neonate larval size (mm)	1.13 ± 0.09	1.0 to 1.3
Larval duration (days)	13.69 ± 2.22	10 to 18
Pupal duration (days)	8.45 ± 1.35	6 to 12
Pupal size		
Length (mm)	6.37 ± 0.51	5.73 to 7.67
Width (mm)	1.71 ± 0.09	1.49 to 1.86
Pupal Weight (g)	0.007 ± 0.00	0.006 to 0.009
Adult longevity (days)	6.46 ± 0.50	6 to7
Moth size		
Length (mm)	9.88 ± 0.72	9 to 11
Width (mm)	2.61 ± 0.37	2 to 3
Wingspan (mm)	16.42 ± 1.05	14 to 17

*Mean of 50 insects

Oyewo and Amo 2020). *Ephestia cautella* adults do not damage the product directly, yet the feeding of larval stage and its webbing nature causes enormous damage to the produce. With shorter larval and total developmental periods, initial population of a few adults of *E. cautella* has the potential to cause massive damage to the stored-products both quantitatively and qualitatively.

Despite the treatments, warehouse moth could establish successfully in foxtail millet grains and produce a good number of progeny adults. However, there were significant differences among the treatments in progeny production of warehouse moth (Table 2). At 120 days after release of insects (DAR), Parad @ 2 tablets/kg treatment was significantly superior to the remaining treatments with minimum emergence of moths and it was followed by the treatments; cloves @ 5 g/kg, bay leaves @ 5 g/kg, and camphor @ 1 g/kg. Thus, 91.57, 67.54, 59.03 and 59.55 percent reduction was obtained with the treatments of Parad, cloves, bay leaves and camphor, respectively over the control from which a total of 116.0 moths were emerged. More or less similar pattern was observed in moth emergence even at double doses of treatments. All the treatments were significantly superior to the untreated control which recorded a population of 135.0 moths at 120 DAR (Table 2). Parad @ 4 tablets/kg recorded the minimum moth emergence and resulted in 95.30% reduction over untreated control. It was followed by camphor @ 2 g/kg and cloves @ 10 g/kg treatments, which resulted in the reduction of 72.74 and 72.25%, respectively over untreated control.

Plate 1. Life stages of *E. cautella*; A) adult, B) Mating pair, C) Eggs, D) Neonate larvae, E) Grownup larva, F) Pupa, G) Pupa inside the webbing

Plate 2. Damage caused by *E. cautella*; A) Heavily infested millet grain, B) Copious silk produced by larvae, C) Grain contaminated by dead insects, D) Insect webbings

Although a dose-dependent bioactivity was observed, the indigenous methods tested were not sufficiently effective to suppress the progeny build-up of warehouse moth. It was observed that none of the treatments at both single and double doses were free from warehouse moth infestation. Contrary, effective control of pulse bruchid was obtained in blackgram treated with botanicals *viz*, neem seed powder, sweet flag rhizome bits, and vasaka plant powder (Swamy et al 2015 and Sarada et al 2017) and with camphor (Swamy and Wesley, 2021a). Neem seed kernel powder and neem leaf powder were effective against *E. cautella* in sunflower seeds only up to 45 days after treatment (Kumaranag et al 2010). It is surprising to note that *E. cautella* can also infest stored garlic (Karuppaiah et al 2018 and Bhardwaj and Thakur 1974), the extracts of which are widely used against various agricultural pests (Ho et al 1996 and Rueda et al 2017). Similarly, rhizome powder and ethanolic oil extracts of *Zingiber officinales* showed contact and fumigant activity on *E. cautella* in stored cocoa beans (Akinneye et al 2021). However, leaves and materials tested at various doses in this experiment could not exert a similar effect on the insect pest.

Further, the results confirmed the efficacy of Parad tablets against warehouse moth. Parad tablets were effective in extending the shelf life of brown rice without affecting nutrient quality (Avijit et al 2012 and Swamy et al 2020). Though Parad tablet is a mercury-based ayurvedic preparation used for treating some ailments, it is widely used for domestic grain preservation. However, accidental swallowing may turn poisonous. Hence, other alternatives such as hermetic storage or better packaging material that does not allow insect establishment (Popoola and Braimah 2011) and use of low (5°C) temperatures (Aldawood et al 2013) may be considered for the storage of processed foxtail millet grains. In a confectionary factory, Savoldelli and Suss, (2010) could achieve effective control of *E. cautella* through integrated use

Table 2. Effect of certain additives (at single dose & double dose) on progeny build-up of warehouse moth in dehulled foxtail millet

Treatment	Single dose/kg	Emergence of moths (No.) at 120 DAR	Reduction (%) over control	Double dose/kg	Emergence of moths (No.) at 120 DAR	Reduction (%) over control
Neem leaves	5 g	111.33 (10.53)[e]	3.79	10 g	80.67 (8.96)[d]	39.49
Karanj leaves	5 g	112.0 (10.57)[e]	3.54	10 g	110.0 (10.49)[e]	17.94
Bay leaves	5 g	47.67 (6.88)[b]	59.03	10 g	57.67 (7.60)[c]	56.73
Sweet flag rhizomes	5 g	114.0 (10.67)[e]	1.55	10 g	109.67 (10.46)[e]	17.73
Garlic	10 g	87.0 (9.33)[d]	24.75	20 g	83.67 (9.15)[d]	37.21
Cloves	5 g	37.33 (6.11)[b]	67.54	10 g	37.0 (6.07)[b]	72.25
Camphor	1 g	46.67 (6.83)[b]	59.55	2 g	36.0 (5.98)[b]	72.74
Common salt	100 g	60.0 (7.73)[c]	48.46	200 g	47.33 (6.88)[c]	64.57
Parad	2 tablets	9.67 (3.10)[a]	91.57	4 tablets	6.33 (2.52)[a]	95.30
Untreated control	-	116.0 (10.76)[e]	-	-	135.0 (11.61)[f]	-
CD (p=0.05)		0.80			0.74	

DAR: Days after release of insects. The values in parentheses are square root transformed values; In each column values with the same letters do not vary significantly at P=0.05

of pheromone traps for monitoring, water traps for mass trapping, pheromones for mating disruption and intensive sanitation. Nevertheless, integration of indigenous techniques of storage of food grains with modern scientific knowledge would be more economical and profitable (Swamy and Wesley 2020).

CONCLUSION

The total life cycle of *E. cautella* ranged from 24 to 40 days. Among the conventional methods tested for the management of warehouse moth in dehulled foxtail millet, the total emergence of moths at 120 DAR was negligible in the treatments of parad @ 4 tablets /kg followed by camphor@ 2 g/kg and cloves 10 g/kg with significant reduction (95.30, 72.25, and 72.74%, respectively) over control. Identification of cost-effective non-chemical methods that can be used for the prevention of insects in millets is highly useful.

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Received 30 March, 2024; Accepted 30 June, 2024

Indian Journal of Ecology (2024) 51(4): 872-876
DOI: https://doi.org/10.55362/IJE/2024/4323

Manuscript Number: 4323
NAAS Rating: 5.38

Seasonal Incidence of Asian Bee-Eater, *Merops orientalis* Lan. on *Apis mellifera* Linn. under *Terai* Agro-ecological Region of West Bengal

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Abstract: The present study was conducted to evaluate the seasonal incidence of Asian green bee-eater, *Merops orientalis* on Western honey bee, *Apis mellifera* under *Terai* agro-ecological region of West Bengal, India. Different trees, crops, shrubs, electric power lines, instructional boards, fencing, bamboo pegs, rice stubbles, as well as ground were the perching sites used by the birds. Their incidence on honey bees was maximum during December to February and completely absent near the apiary from last week of March to the first week of July. They were quite successful as a predator with a success ratio of 76.27%. Highest activity of the birds was recorded at 13:00-14:00 when the foraging activity of the honey bees was also high enough. The results obtained from the present study could be helpful to adopt appropriate vertebrate pest management strategies against *M. orientalis* that will allow the beekeepers to look after that particular time period when these birds are more abundant.

Keywords: *Apis mellifera*, *Merops orientalis*, Seasonal incidence

Beekeeping is always considered as a lucrative venture, specifically for the rural people, who heavily rely on agriculture and forest resources. The *Terai* agro-ecological region of West Bengal is home of many of such rural communities who are fully depend on agricultural and horticultural as well as forest resources to earn a livelihood. Moreover, this region is also blessed with a rich floral diversity that can be utilized by honey bees as a potential source of pollen and nectar (Saha et al 2023a). So, beekeeping could play an important role in the socio-economic upliftment of these rural communities. However, in the present framework of technological advancement, worldwide commercial beekeeping is facing a downward trend (Potts et al 2010a, Kohsaka et al 2017, Gajardo-Rojas et al 2022) due to various biotic and abiotic stressors (Potts et al 2010b, Hristov et al 2020, Saha et al 2023b). Among them, different pests and natural enemies of honey bees have a significant impact on beekeeping. In our previous works, we have already evaluated the incidence of some important pests and natural enemies on Western honey bee, *Apis mellifera* Linn. colonies under *Terai* agro-ecological region of West Bengal (Singha et al 2022, 2023a, 2023b, 2023c). However, a few pests and/or natural enemies still remain.

Bee-eater is a group of insectivorous bird (Coraciiformes: Meropidae), predominantly feeding on any flying insects. However, as their name suggests, they mostly prefer hymenopterans in their diet. There are a total of 26 bee-eater species distributed throughout the Palaeotropics and southern Eurasia (Glaiim 2014) of which six species are found in India (Vaidyanathan and Venkatraman 2022). Among the bee-eaters found in India, *Merops orientalis* is the most variable one in terms of their plumage colour. This birds frequently forage over agricultural fields and search for insects, as 95% of their prey consist of various group of insect (Asokan et al 2010). However, their role as pest is not well defined. As insects are their basic food, so some people, mostly farmers consider this bird beneficial due to their feeding on crop pests. Whereas, some people, like beekeepers consider them as pest, as they prey on honey bees and reduce the colony strength. This present work has been designed to evaluate the seasonal incidence of another important natural enemy of honey bees, i.e., Asian green bee-eater bird, *Merops orientalis* Lan. (Meropidae: Coraciiformes) in the agro-climatic region under consideration.

MATERIAL AND METHODS

Study area: The present investigation was carried out at the apiary of Uttar Banga Krishi Viswavidyalaya, Pundibari, West Bengal, India located at latitude of $26^{0}19'$ N and longitude of $89^{0}23'$ E, at an elevation of 43 meter above mean sea level (msl) during 2019 and 2020. In the apiary unit, a total of ten strong (similar in strength) *A. mellifera* colonies have been placed without adopting any vertebrate pest management strategies. During dearth period, the colonies were fed with only sugar-syrup solution to maintain their strength. This region is characterized by typical per humid climate with an annual average rainfall of >3000mm and relative humidity of 65–90%. Here, the southwest monsoon is responsible for 80% of the total rainfall during June–September. This region has an average maximum and minimum temperature of 24°C and 33.2°C, respectively, with the presence of warm weather except December-February months having a short spell of winter.

Seasonal incidence of *Merops orientalis*: To evaluate the seasonal incidence of *Merops orientalis* on *Apis mellifera*, their foraging activity near the apiary was carefully monitored using a 360°viewing CCTV Camera, installed in the apiary. Recorded movie was analysed/viewed to record data at a time gap of one hour, viz. 09:00-10:00, 11:00-12:00, 13:00-14:00, and 15:00-16:00. Direct observation was also recorded. Data was recorded based on continuous stay by birds near the apiary during study time, number of total, successful and unsuccessful attempts to catch the bees, number of raids by a bird, and number of individual birds participated in raid.

RESULTS AND DISCUSSION

Merops orientalis used to perch on different trees, crops, shrubs, electric power lines, instructional boards, fencing, bamboo pegs, rice stubbles, as well as on ground. Electric cables were the most utilized perching site by the birds, where they wait and capture the flying bees whenever noticed. Such high elevations allow them to capture the bees more efficiently (Fig. 1). Along with the visual observation, the sound of chewing bees by the birds also served as an indication of successful attempt. Usually, the activity of honey bee predators depends on the activity of foraging bees. Maximum incidence of *Merops orientalis* on *Apis mellifera* colonies was from December to February with the population reaching its peak in January (i.e., 68 individual birds attempting a total of 344 number of raids) (Table 1). Usually in

Fig. 1. Act of predation of *Merops orientalis* on honey bee

Table 1. Seasonal incidence of Asian green bee-eater bird, *Merops orientalis* during 2019-20 (Mean±SEm)

Months	Number of individual birds encountered in attack	Number of attacks observed	Raid/ individual bird	Raids by the birds in a day during study time	Number of successful attacks observed	Number of successful raids/day	% of successful raids	Number of unsuccessful attacks observed	Number of unsuccessful raids/day	% of unsuccessful raids
September	50	190	3.80	47.50±3.23	134	33.50±2.10	70.63±0.95	56	14.00±1.22	29.37±0.95
October	51	216	4.24	54.00±2.12	158	39.50±1.66	73.16±1.53	58	14.50±1.04	26.84±1.53
November	60	273	4.55	68.25±2.75	216	54.00±2.38	79.10±1.08	57	14.25±0.85	20.90±1.08
December	62	316	5.10	79.00±1.78	257	64.25±2.53	81.25±1.69	59	14.75±1.11	18.75±1.69
January	68	344	5.06	86.00±2.86	275	68.75±2.69	79.90±0.92	69	17.25±0.75	20.10±0.92
February	62	317	5.11	79.25±3.50	249	62.25±2.87	78.53±0.78	68	17.00±0.91	21.47±0.78
March	25	95	3.80	23.75±8.14	71	17.75±6.18	72.87±2.09	24	6.00±1.96	27.13±2.09
April-June	0	NA	NA	NA	0	NA	NA	0	NA	NA
July	19	65	3.42	16.25±4.46	49	12.25±3.42	73.76±3.72	16	4.00±1.22	26.24±3.72
August	36	140	3.89	35.00±2.12	108	27.00±1.47	77.25±1.41	32	8.00±0.82	22.75±1.41
Total	433	1956	—	—	1517	—	—	439	—	—
Mean±SEm	—	—	4.33±0.22	—	—	—	76.27±1.24	—	—	23.73±1.24

northern districts of West Bengal, this time period was considered as honey flow period with presence of ample amount of pollen and nectar providing plants (Saha et al 2023a), which might be responsible for higher foraging activity of honey bees in fields that ultimately increased the incidence of birds preying on them. Thereafter, from March onwards there was a steady decline in the incidence of *M. orientalis*. There was no presence of these birds from last week of March to the first week of July. This time period is characterized by high temperature and high rainfall which

Table 2. Time variation in the incidence of Asian green bee-eater bird, *Merops orientalis* during 2019-20 (Mean±SEm)

Months	Time duration	Duration of staying in apiary at an hour interval	No. of birds involved in attack	No. of raids carried out by the birds	No. of raids/min (during staying in the apiary)
September	09:00-10:00	8.75±3.15	1.00±0.41	3.00±1.08	0.34±0.03
	11:00-12:00	30.50±2.10	3.75±0.48	12.00±1.08	0.42±0.09
	13:00-14:00	60.00±0.00	4.50±0.29	21.75±1.49	0.37±0.03
	15:00-16:00	38.00±2.97	3.25±0.25	10.75±1.11	0.33±0.04
October	09:00-10:00	21.00±1.08	1.75±0.25	5.50±0.65	0.27±0.04
	11:00-12:00	38.00±2.86	3.75±0.48	16.75±1.38	0.45±0.06
	13:00-14:00	60.00±0.00	4.75±0.48	21.75±2.59	0.36±0.04
	15:00-16:00	34.5.±2.02	2.50±0.29	10.00±0.71	0.29±0.03
November	09:00-10:00	35.5.±1.66	2.50±0.29	8.00±0.82	0.23±0.03
	11:00-12:00	40.5.±2.10	4.75±0.25	22.50±1.85	0.55±0.02
	13:00-14:00	60.00±0.00	5.25±0.25	27.00±1.29	0.45±0.02
	15:00-16:00	37.75±2.21	2.50±0.29	10.75±0.85	0.29±0.04
December	09:00-10:00	25.50.±1.85	2.00±0.00	7.25±0.48	0.29±0.02
	11:00-12:00	56.00±1.68	5.75±0.48	29.00±1.80	0.52±0.05
	13:00-14:00	60.00±0.00	5.25±0.25	33.00±1.08	0.55±0.02
	15:00-16:00	46.75±2.84	2.50±0.29	9.75±0.85	0.21±0.02
January	09:00-10:00	16.25±1.75	2.00±0.41	7.00±0.82	0.43±0.02
	11:00-12:00	55.50±1.66	5.75±0.25	30.75±1.75	0.56±0.04
	13:00-14:00	60.00±0.00	7.00±0.41	39.75±1.80	0.66±0.03
	15:00-16:00	38.75±1.49	2.25±0.25	8.50±0.65	0.22±0.02
February	09:00-10:00	23.50±2.18	2.25±0.25	7.50±0.65	0.33±0.03
	11:00-12:00	48.75±2.29	4.75±0.25	27.00±1.78	0.56±0.03
	13:00-14:00	58.75±1.25	6.25±0.48	35.25±2.25	0.60±0.03
	15:00-16:00	33.25±1.38	2.25±0.25	9.50±0.65	0.29±0.02
March	09:00-10:00	3.00±3.00	0.25±0.25	0.75±0.75	0.25±00
	11:00-12:00	16.75±6.75	1.75±0.63	7.50±3.23	0.44±0.03
	13:00-14:00	23.75±9.44	2.25±0.75	9.25±3.25	0.41±0.05
	15:00-16:00	14.00±3.19	2.00±0.41	6.25±1.38	0.44±0.09
April–June	No incidence observed	NA	NA	NA	NA
July	09:00-10:00	12.50±5.20	0.75±0.25	1.75±0.63	0.16±0.04
	11:00-12:00	19.75±6.71	1.25±0.48	3.50±1.19	0.18±0.01
	13:00-14:00	30.00±7.36	2.00±0.41	8.50±1.94	0.30±0.04
	15:00-16:00	20.00±7.36	0.75±0.25	2.50±0.87	0.14±0.03
August	09:00-10:00	16.00±5.89	0.75±0.25	2.50±0.87	0.16±0.03
	11:00-12:00	26.75±1.93	2.25±0.25	8.25±0.48	0.32±0.04
	13:00-14:00	43.75±4.27	4.00±0.41	17.75±2.06	0.41±0.03
	15:00-16:00	34.75±3.54	2.00±0.41	6.50±0.87	0.20±0.04

may be attributed to the absence of *M. orientalis* in the apiaries. Moreover, these months also indicate the onset of dearth period (Saha et al 2023a) when the foraging activity of honey bees might be minimum due to the unavailability of proper foraging sources. In contrast, Ali (2012) reported that *M. orientalis* appeared from last week of March to first week of May during spring season with no presence during summer season and again appeared in last week of September to first week of November during autumn season with no presence during winter season in Saudi Arabia. The slight difference in finding may be due to the variation in prevailing weather condition and topography of the study location.

During the study period, 433 individual birds were encountered, attempting 1956 raids with a success ratio of 76.27%. This success ratio was much higher compared to that of black drongo, *Dicrurus macrocercus* (Vieillot) (56.27%), which was another important bird predator in this region (Singha et al 2023a). The average number of raids per bird during the study period was recorded 4.33 raids/bird. These birds caught the foraging bees from the field instead of visiting the front of beehives. The activity of *Merops orientalis* was minimum at early morning hours, *viz.* 09:00-10:00 and increased thereafter (Table 2). Highest incidence was noted at mid hours, *viz.*13:00-14:00 and birds also spent maximum time near the apiary during this time interval. Usually, *A. mellifera* was highly active during mid hours of the day in this region (Nath et al 2023a, 2023b), that may responsible for higher incidence of *M. orientalis* during this time period. Moreover, presence of low temperature at morning hours and ample temperature at midday hours may also responsible for variation in incidence of *M. orientalis*.

CONCLUSIONS

Merops orientalis is an important predator of honey bees in the region under consideration. Their presence near the apiary significantly reduce the honey bee colony strength as well as the honey production. The management of this bird, specifically near the apiary is necessary to safeguard the beekeepers from facing an economic loss. For that, monitoring is a prerequisite action to address the incidence of *M. orientalis* as soon as possible to protect the colonies from severe loss specifically in December-February. In this respect different vertebrate pest management strategies, such as use of mechanical sounding devices, fire crackers, hanging of plastic strips or red coloured cloths can be utilized to manage this bird from causing severe loss.

AUTHORS' CONTRIBUTION

Designed the work: Sibananda Singha, Nripendra Laskar. Performed the field observation: Sibananda Singha, Samrat Saha, Riju Nath. Wrote the paper: Samrat Saha, Pushpa Kalla, Nripendra Laskar. Photography: Adrish Dey.

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Received 22 February, 2024; Accepted 20 June, 2024

Indian Journal of Ecology (2024) 51(4): 877-882
DOI: https://doi.org/10.55362/IJE/2024/4324

Manuscript Number: 4324
NAAS Rating: 5.38

Survey of Insects Fauna of Al-Tar Caves in Karbala, Iraq

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Abstract: The Al-Tar caves are geologically important sites due to their location in a semi-desert area and proximity to Al-Razzaza Lake in Karbala, Iraq. Multiple surveys were conducted from September 1, 2020, to November 15, 2020, to collect and identify the insect species that occur inside and around these caves. During this investigation, a variety of species were collected from different orders and families. These include Blattodea (Termitidae), Orthoptera (Acrididae), Odonata (Libellulidae), Diptera (Muscidae and Calliphoridae), Coleoptera (Meloidae and Tenebrionidae), and Hymenoptera (Formicidae and Sphecidae). Beetle species showed a high degree of diversity compared to the insect species in other groups during the study period.

Keywords: Al-Razzaza, Al-Sayed, Caves, Fauna, *Halothamnus*

The Tar Al-Sayed area, also known as the Al-Tar caves, is one of the important geological areas in Iraq. It is situated approximately 100km southwest of Baghdad, in the western part of Karbala Governorate, and to the south of Al-Razzaza Lake. Covering an area of about one square kilometer, this location possesses unique geological and historical features that make it a potential candidate for a Geopark (Al-Shakeri et al 2017) The caves can be strongly affected by even modest human changes in their environment. Furthermore, due to the high environmental stability of caves, such environments become highly vulnerable to external impacts, since this stable condition can often be easily unbalanced. Therefore, any direct or indirect impacts on caves can cause serious damage to the fauna and the physical integrity of these environments (Souza-Silva et al 2015). Surveys to identify invertebrate species, including insects, in this region and adjacent areas are lacking, except for a few studies that have primarily focused on the biological diversity of vertebrates, such as the works by Mohammad et al (2010) and Mohammad and Al-Zubaidi (2017). There is a lack of study regarding the insect species found in this area. Therefore, this study was aimed to conduct a survey on insect diversity in Al Tar Caves and adjacent areas, with the aim of identifying different insect orders, families, genera and species that belonging to it.

MATERIAL AND METHODS

Study area: The Al Tar Caves (32°28'54.6"N 43°46'37.4"E, elevation: 65 m) investigated in this study are located on the right side of the road that leads to Ain Al-Tamur District (32°34'08.5"N 43°29'06.1"E); they are situated 45 km from the city center of Karbala Province, towards the southwest, and 15 km northeast of Al-Ukhaydhir Fort (Fig. 1, 2). The area adjacent to the caves is characterized by low density and of plants cover in both diversity and density. The most prominent plant species is *Salsola kali* L., 1753 (Caryophyllales, Amaranthaceae) (Fig. 3). Other species found in the area are *Tamarix* sp. (Caryophyllales, Tamaricaceae) and *Capparis spinosa* L. (Brassicales, Capparaceae).

Sampling: Specimens were collected by diverse tools such as aerial net, aspirator, pitfall trap and forceps during the period from 1st September to 15th November 2020. The specimens are identified by the authors and verified through comparison with the collection of the Iraq Natural History Research Center and Museum, University of Baghdad. Species synonyms are provided according to Borowiec (2014) and the GBIF Secretariat (2019).

RESULTS AND DISCUSSION

In this particular study, a total of 16 species from 14 genera, nine families, and six orders were identified. The beetles were found to be the most abundant, particularly the Tenebrionidae family, in comparison to the flies. The species are listed below.

(1) Order: Blattodea
Family: Termitidae
Genus: *Amitermes* Silvestri 1901
Synonyms: *Hamitermes* Silvestri 1903
Monodontermes Silvestri 1909
Amitermes desertorum (Desneux 1902)
Common name: Desert subterranean termite
Synonym: *Hamitermes santschi* Silvestri 1911
Materials examined: 6 soldiers and 14 workers collected at 23.ix.2020.

Global distribution: Algeria and Egypt (E-Sebay et al 2010).

(2) Order: Orthoptera

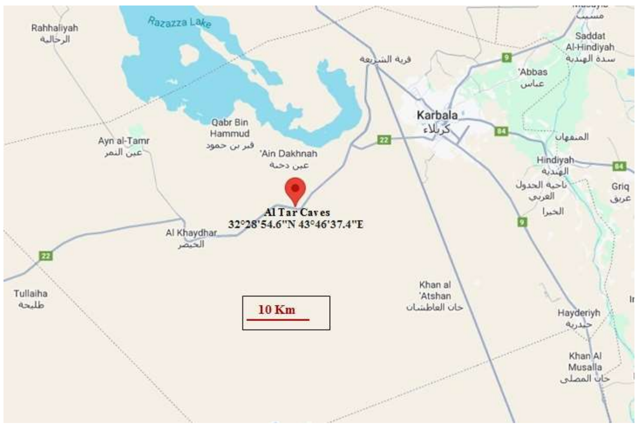
Family: Acrididae

Genus: *Calliptamus* Serville 1831

Calliptamus deserticola Vosseler 1902

Materials examined: one male collected at 23.ix.2020.

Global distribution: Morocco (Defaut and François 2018), Tunisia, Algeria, Turkey and Iran (Tlili et al 2020).



(Source: https://www.google.com/maps/place/AL-Tar+Caves/)

Fig. 1. The Al- Tar Caves site, Iraq

Fig. 2. Al Tar Caves (see the dominant plants around caves)

Fig. 3. *Salsola kali* L., 1753

(3) Order: Odonata

Family: Libellulidae

Genus: *Crocothemis* Brulle 1832

Crocothemis servilia Drury 1773

Synonyms: *Crocothemis ferruginata* Fabricius 1781

Crocothemis flavostigma Navás 1932

Crocothemis indica Sahni 1965

Crocothemis novaguineensis Foerster 1898

Crocothemis reticulate Kirby 1886

Crocothemis soror Rambur 1842

Materials examined: 6 specimens- 3♂♂, 3♀♀, collected at 5. xi. 2020.

Global distribution: It is one of Asia's most widespread dragonfly species, ranging from the Arabian Peninsula in central Asia to Japan and Australasia in the Far East. It has been introduced into Hawaii, Caribbean Islands, Cuba and parts of the USA (Joshi et al 2020) and Armenia (Ananain and Tailly 2013). Native to east and southeast Asia and introduced to Jamaica, Florida, and Hawaii (Subramanian et al 2018), Kuwait (Amr 2021).

(4) Order: Diptera

Family: Muscidae

Genus: *Musca* Linnaues 1758

Musca albina Wiedemann 1830

Synonyms: *Musca speculifera* Bezzi 1911

Plaxemyia beckeri Schnabl & Dziedzicki 1911

Materials examined: 10 specimens, Karbala Province, Al Tar Caves 4♂♂, 6♀♀, 8.xi.2020.

Global Distribution: Namibia (Couri et al 2012), Middle East (Marshall and Pont 2013), Saudi Arabia (El-Hawagry et al 2013, 2016), Iran (Zielke 2017).

Musca domestica Linnaeus 1758

Synonyms: *Ascaris conosoma* Jordens 1802

Degeeria dawsoni Rainbow 1897

Limnophora vicaria (Walker 1853)

Musca analis Macquart 1843

Musca antiquissima Walker 1849

Musca atrifrons Bigot 1888

Musca aurifacies Robineau-Desvoidy 1830

Musca australis Macquart 1843

Musca basilaris Macquart 1843

Musca campicola Robineau-Desvoidy 1863

Musca chilensis Macquart 1843

Musca consanguinea Rondani 1848

Musca contigua Walker 1853

Musca cuthbertsoni Patton 1936

Musca determinata Walker 1853

Musca divaricata Awati 1916

Musca divisa Meigen 1975

Musca flavifacies Bigot 1888

Musca flavinervis Thomson 1869
Musca frontalis Rondani 1868
Musca harpyia Harris 1869
Musca minor Macquart 1851
Musca multispina Awati 1916
Musca nancauriensis Schiner 1868
Musca oceanica Le Guillou 1842
Musca pampasiana Bigot 1888
Musca pellucens Meigen 1835
Musca rufifrons Macquart 1843
Musca rufiventris Macquart 1846
Musca sordidissima Walker 1864
Musca soror Robineau-Desvoidy 1830
Musca taitensis Macquart 1843
Musca tiberina Sacca 1947
Musca umbraculata Fabricius 1805
Musca vaccina Robineau-Desvoidy 1863
Musca vagatoria Robineau-Desvoidy 1830
Musca vicaria Walker 1853
Musca vicina Macquart 1851

Materials examined: 31 specimens. 7specimens (3♂♂, 4♀♀), 12.ix.2020; 15 specimens (9♂♂, 6♀♀,), 8.x.2020; 9 specimens (5♂♂, 4♀♀), 27.x.2020.

Distribution: Cosmopolitan (World-wide distribution), it is found on every continent, with the exception of Antarctica (Bertone et al 2016).

The house fly, *Musca domestica*, is a well-known cosmopolitan pest of both farm and home; this species is always found in association with humans or the activities of humans. As a result, it is abundant almost anywhere people live. This common fly has its origins on the steps of central Asia. However, now it occurs on all inhabited continents, thriving in all climates from tropical to temperate, and adapting to a wide range of environments, from rural to urban settings (Sanchez-Arroyo and Capinera, 2018).

Family: Calliphoridae

Genus: *Chrysomya* Ronieau-Desvoidy 1830

Chrysomya albiceps (Wiedemann 1819)

Synonyms: *Chrysomya nubiana* (Bigot 1877)
Chrysomyia indica Patton 1934
Compsomyia flaviceps Seguy 1927
Compsomyia mascarenhasi Seguy 1927
Lucilia arcuata Macquart 1851
Lucilia testaceifacies Macquart 1851
Musca albiceps Wiedemann 1819
Musca bibula Wiedemann 1830
Musca elara Walker 1849
Musca emoda Walker 1849
Musca felix Walker 1853
Musca himella Walker 1849

Materials examined: 8 specimens, 2♂♂, 15.x.2020; 3♂♂, 3♀♀, 15.xi.2020.

Distribution: Argentina, Bermuda, Bolivia, Brazil, Colombia, Ecuador, Costa Rica, Guatemala, India, Iran, Mexico, Pakistan, Paraguay, Peru, Poland, Portugal, Puerto Rico, Ukraine, Venezuela (Verves and Khrokalo 2010, Bharti 2011, Hassan et al 2018).

(5) Order: Coleoptera

Family: Meloidae

Genus: *Mylabris* Fabricius 1775

Mylabris sp.

Materials examined+ 2♂♂, 5♀♀, specimens collected at 25.ix.2020 on *Salsola kali* L., 1753 plant.

Global distribution: It is endemic to the Palearctic region and includes over 170 species (Salvia et al 2018).

Family: Tenebrionidae

Genus: *Adesmia* Fisher 1833

Adesmia dilatata (Klug 1830)

Synonym: *Pimelia dilatata* Klug 1830

Materials examined: 2♀♀ specimens, specimens collected at 5.xi.2020.

Global distribution: Egypt, Israel, and Jordan (Bunalski, 2018); Saudi Arabia (Seufi et al 2019).

Genus: *Blaps* Fabricius 1775

Blaps hispanica Solier 1848

Materials examined: 2 ♀♀,specimens collected at 23.ix.2020.

Distribution: Iraq (Ismail and Husain, 2018); Portugal and Spain (GBIF Secretariat 2023).

Mesostena Eschscholtz 1831

Synonyms: *Comphosida* Dejean 1834
Mesostenopa Kraatz 1865
Platystena Koch 1940
Saxistena Koch 1940

Mesostena arabica (Gestro 1881)

Material examined: 1♂, specimen collected at 3.xi.2020.

Global distribution: British Isles (Guff 2012), Korea, UAE, Egypt, Algeria, KSA (GBIF Secretariat, 2023).

Genus: *Pimelia* Fabricius, 1775

Synonyms: *Agelarches* Gistl 1848
Amblyptera Solier 1836
Aphanaspis Wollaston 1864
Camphonota Solier 1836
Chaetotoma Motschoulsky 1860
Doderoella Schuster 1926
Ecphoroma Solier 1836
Eurypimelia Reitter 1915
Homalopus Solier 1836
Pimella Brullé 1832
Pimidia Rafinesque 1815

Pseudamblyptera Pierre 1985

The genus *Pimelia* Fabricius, 1775 is the most species in the tribe Pimeliini and consists of approximately 320 species distributed mainly in xeric environments in the western Palaearctic region and northern deserts in the Afrotropical region (Mas-Peinado et al 2018). They present a diverse array of sizes, a large variability in elytral morphology, nocturnal or diurnal habits, and occupy very different habitats in arid or semiarid zones (Soldati 2009), and dry forests (Caro Pintos 2015).

Pimelia arabica (Klug 1830)

Materials examined: 2♂♂, 1♀, 2♂♂, 23.ix.2020; 1 ♀, 30.x.2020.

Global distribution: Oman, UAE, and Qatar (GBIF Secretariat, 2023).

Genus: *Prionotheca* Dejean 1834

Synonym: *Prionotheca* Solier 1836

Prionotheca coronata Olivier 1795

Materials examined: 2 specimens (1♂+1♀), collected at 15.ix.2020.

Common name: Radian Sun Beetle

Distribution: Saudi Arabia (Abdel-Dayem et al 2017). Algeria, Chad, Egypt, Iran, Jordan, Kuwait, KSA, UAE, Morocco, Mauritania, Oman, Qatar, Sri Lanka, and Tunisia (GBIF Secretariat, 2023).

(6) Order: Hymenoptera

Family: Formicidae

Genus: *Cataglyphis* Förster 1850

Among the most noticeable and distinctive ants found in the arid and semiarid regions of the Palearctic, which extend from Mauritania to the Gobi Desert (Amor and Ortega 2014). Due to their huge workers population and preference for open, they are relatively easy to find. Researchers are interested in a number of species because of their unique and varied reproductive strategies (Peeters and Aron 2017) and remarkable adaptations to hot conditions, such as the management of foraging activity and landmark navigation (Mangan and Webb 2012).

Cataglyphis bicolor (Fabricius 1793)

Synonym: *Formica bicolor* Fabricius, 1793

Materials examined: 32 workers, 9 specimens, 05.ix.2020; 14 specimens, 12.ix.2020; 7 specimens, 8.x.2020; 2 specimens, 27.x.2020.

Global distribution: Algeria, Egypt, Libya, Morocco, Israel, Syria, Spain, Canary Is. (Borowiec 2014).

Cataglyphis lividus (Andre 1881)

Synonym: *Myrmecocystus lividus* Andre 1881

Materials examined: 11 workers, 9 specimens, 8.x.2020; 2 specimens, 27.x.2020.

Global distribution: Armenia, Bulgaria, Egypt, Iran, Israel, Kuwait, Oman, Saudi Arabia, Turkey, United Arab Emirates and Yemen (Borowiec 2014).

Genus *Messor* Forel 1890

Messor arenarius (Fabricius 1787)

Synonyms: *Formica arenaria* Fabricius 1787

Myrmica amaurocyclia Förster 1850

Myrmica scalpturata Nylander 1856

Stenamma (*Messor*) *bugnioni* Forel 1904

Materials examined: 7 workers): 5 specimens, 8.x.2020; 2 specimens, 27.x.2020.

Global distribution: Algeria, Egypt, Iran, Israel, Kuwait, Libya, Morocco, Saudi Arabia, Syria, Tunisia (Borowiec 2014).

Family: Sphecidae

Genus: *Sceliphron* Klug 1801

Members of *Sceliphron* commonly referred to as mud daubers;they are solitary and build nests made of mud; this genus build aerial nests using mud collected from moist soil sources and transported to the appropriate location to build the nest (Chatenoud et al 2012). Salticidae are the most commonly collected prey among ground-hunting spiders, which are mostly preyed upon by specific species of the genus *Sceliphron*. This species takes its prey with a big body size. Furthermore, an unanticipated finding revealed that the enclosed mud nests offer a micro niche that is home to a diverse range of insects. We also talk about how these findings advance our understanding of the function of insects in urban ecosystems and their importance to research on ecology, biodiversity, and conservation (Yuan et al 2022).

Sceliphron arabs (Lepeletier de Saint Fargeau 1845)

Synonyms: *Pelopaeus arabs* Lepeletier de Saint Fargeau 1845

Pelopaeus caucasicus Ed. André 1888

Sceliphron caucasicum (Ed. André 1888)

Materials examined: 12 workers, 4 specimens, 05.ix.2020; 7 specimens, 23.ix.2020; 1 specimen, 8.x.2020.

Global distribution: Georgia, Azerbaijan, Turkey, Syria, and Iran (Maharramov et al 2020).

CONCLUSION

The current study provides some information on insect diversity. Inventory of 16 species belonging to 14 genera, nine families, and six orders; mostly represented by the house fly *Musca domestica* in this unique site. Our observation during the survey period stated that wild plants were very rare here significantly, which may be negatively affect insect diversity there. The order Coleoptera had a high level of the diversity at the species level compared with other insect groups, because it possesses a morphological characteristics that enable it to overcome unfavorable environmental conditions such as high temperatures and dry.

AUTHORS CONTRIBUTION

The first author, Razzaq Shalan Augul, conceptualized the idea, wrote the manuscript, reviewed and finalized the manuscript. All authors performed the sampling and tabulation of the data. The second author, Hanaa H Al–Saffar, and the third author Hayder Badri Ali, identified the specimens and analyzed the results.

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Received 22 February, 2024; Accepted 22 July, 2024

Indian Journal of Ecology (2024) 51(4): 883-890
DOI: https://doi.org/10.55362/IJE/2024/4325

Manuscript Number: 4325
NAAS Rating: 5.38

Host Plants of Invasive Whiteflies - Rugose Spiralling Whitefly, *Aleurodicus rugioperculatus* Martin and Bondar's Nesting Whitefly, *Paraleyrodes bondari* Peracchi

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***Abstract*:** Coconut tree is infested by various insect pests throughout the year. Among the array of coconut pests, the sucking pests, notably invasive whiteflies, present a significant threat to coconut yield. The Rugose spiralling whitefly (RSW), *Aleurodicus rugioperculatus* Martin and Bondar's nesting whitefly (BNW), *Paraleyrodes bondari* Peracchi, have inflicted significant damage across the major coconut-growing districts of Tamil Nadu since 2016 and 2018, respectively. These two are invasive pests that are polyphagous in nature. In its native habitat, it mostly attacks coconut trees and other broad-leaved hosts, but now its widening host range includes economic and horticultural crops as well as weed populations posing a significant threat to the farming community**.** Between December 2020 and October 2021, an extensive survey was conducted at fortnightly intervals in the southern districts of Tamil Nadu, namely Thoothukudi, Tenkasi, Tirunelveli, and Kanyakumari. The survey aimed to examine the expanding host range of RSW and BNW, revealed the presence of *A. rugioperculatus* in 46 host plants across 25 families and *P. bondari* in 25 host plants across 19 families, which included plantation crops, fruits, vegetables, spices, tubers, tree species, ornamental plants, and weed plants.

***Keywords*:** Survey, *Aleurodicus rugioperculatus, Paraleyrodes bondari,* Host plants

The rugose spiralling whitefly (RSW), *Aleurodicus rugioperculatus* (Hemiptera: Aleyrodidae) is a serious exotic pest that causes much damage to coconut growing tracts of India. It was originally identified by Martin (2004) from Belize, Central America, which later spread to Mexico, Guatemala and Florida in Central and North America (Evans 2008). *Aleurodicus rugioperculatus* was reported as a serious pest on gumbo limbo trees, olive tree leaves and the underside of coconut fronds in 2009 in the Florida region (Stocks and Hodges 2012). In India, it has been reported from Tamil Nadu, Karnataka, Kerala and Andhra Pradesh (Selvaraj et al 2017). In Tamil Nadu, first identified during July-August, 2016 at Pollachi taluk of Coimbatore district (Selvaraj et al 2017). Later, the pest was reported from coastal regions of Andhra Pradesh during October-November, 2016 (Rao et al 2018). Chakravarthy et al (2017) reported *A. rugioperculatus* in Karnataka, Kerala, Tamil Nadu, Maharashtra, Gujarat, Himachal Pradesh and Sikkim. Mondal et al (2020) observed significant infestation of *A. rugioperculatus* in the coconut plantations at Mandouri in June 2019, which was the first report on the occurrence of this deadly insect in the Nadia region of West Bengal. Recently also reported in the Saurashtra region of Gujarat in coconut (Jethva et al 2020). Selvaraj et al (2017, 2019) reported approximately 40 host plants including coconut, banana, mango, sapota, guava, cashew, ramphal, oil palm, maize, Indian almond, water apple, jack fruit and many other ornamental plants such as bottle palm, Indian shot, false bird of paradise and butterfly palm. Nandhini and Srinivasan (2022) documented 67 host plants, with ornamental plants leading (17), followed by fruit crops (14), medicinal plants (9), and vegetables (5). Additionally, identified host plants in categories like fibre crops, biofuels, flower crops, and more, each represented by varying numbers.

The bondar's nesting whitefly (BNW), *P. bondari* (Hemiptera: Aleyrodidae) was first reported in coconut plantations of Kayamkulam, Kerala in 2018. It feeds on more than 25 host plants '(Josephrajkumar et al 2019) which is also creating menace in the coconut gardens of Tamil Nadu recently. The nymphs and adults of *P. bondari* construct nesting chambers of woolly wax and the adults will be remaining on the nests for egg laying. The woolly wax nests will be seen on the under surface of the leaves. Omongo et al

(2018) reported the attack of *P. bondari* on cassava in Uganda. Raghuteja et al (2023) recorded host plants of bondar's nesting whitefly including Coconut, Oil palm, Banana, Cinnamon, False rubber, Mango, Jackfruit, Guava, Temple pod, and Hibiscus. Coconut and Oil palm exhibited the highest incidence and intensity, while *Hibiscus* showed the lowest incidence level recorded.

MATERIAL AND METHODS

Surveys were conducted on the host plants of invasive whiteflies regularly at fortnightly intervals in the southern districts of Tamil Nadu *viz.*, Thoothukudi, Tenkasi, Tirunelveli and Kanyakumari (5 locations/ district) (Table 1) from December 2020 to October 2021. These surveys focused on host plants situated near coconut plantations infested with invasive whiteflies. Twenty plants of each host underwent examination to confirm the presence of Rugose spiralling whitefly and Bondar's nesting whitefly. Host plants were documented meticulously using portable cameras. These included plants bearing all life stages of *Aleurodicus rugioperculatus* and *Paraleyrodes bondari*. They were categorized into three groups: those containing only egg stages without progressing to nymphal and adult stages, those supporting eggs and nymphal stages but with no adult emergence, and those facilitating the complete development of Rugose spiralling whitefly and Bondar's nesting whitefly life stages, displaying eggs, nymphs, and adult colonies of both pests. Plants was carried out by referencing plant botany and weed science manuals, along with consultations with experts from the Department of Horticulture and Agronomy at V.O.C. Agricultural College and Research Institute, TNAU, Killikulam, Tamil Nadu, India. The various host plants attacked by invasive whiteflies were recorded during the survey and documented.

RESULTS AND DISCUSSION

The 46 host plants belonging to 25 families including plantation crops, fruits, vegetables, tubers, tree crops, ornamentals and weed species were identified as the host plants for *A. rugioperculatus* (Table 1). The host plants include 3 plantation crops *viz*., coconut, oil palm, fan palm, 11 fruit crops like banana, guava, water apple, citrus, sapota, mango, custard apple, soursop, mulberry, fig, avocado, 4 vegetables such as brinjal, bhendi, chilli, cucumber, 1 spice crop (curry leaf), 2 tubers (tapioca, taro), 9 tree species, 4 ornamentals and 12 weeds. Among the 46 host plants, 34 plant species comprise of all life stages of rugose spiralling whitefly whereas, egg and adult stages are only seen in 7 and 5 host plants, respectively (Table 2) (Plate 1). The incidence of rugose spiralling whitefly was severe in coconut and banana ecosystem in the four districts of southern Tamil Nadu. The host plants of *A. rugioperculatus* was already reported by Alagar et al. (2020) who noticed 28 plant species under 21 families as host plants. Elango et al (2019) reported 20 host plants harbouring rugose spiralling whitefly from Coimbatore, Tiruppur, Erode, Theni, Pudukkottai and Kanyakumari districts. Srinivasan et al (2016) indicated 15 host plants of *A. rugioperculatus* belonging to 13 families in western zone of Tamil Nadu, Pollachi of Coimbatore district. Shanas et al (2016) reported 17 host plant species under 11 families comprising of *A. rugioperculatus* in Kerala. In Pollachi, Tamil Nadu *A. rugiperculatus* was observed from coconut, arecanut, guava, wild almond, pepper, cocoa, mango, teak, banana, *Bauhinia*, *Annona squamosa*, *Ficus* sp., fish tail palm, *etc* (Chakravarthy et al 2017). In total, the pest has been observed on 118 host species comprising of edible plants, ornamentals, palm species, fruit crops and weed plants in Florida (Stocks and Hodges 2012, Francis et al 2016).

The studies on the host plants of *P. bondari* in different locations of southern districts of Tamil Nadu *viz*., Thoothukudi, Tenkasi, Tirunelveli and Kanyakumari (Table 1) indicated that 25 host plants belonging to 19 families were observed, including Arecaceae (1), Musaceae (1), Myrtaceae (1), Moraceae (2), Sapotaceae (2), Rutaceae (2), Annonaceae (1), Sapindaceae (1), Euphorbiaceae (2), Combretaceae (1), Meliaceae (1), Lamiaceae (1), Fabaceae (2), Oleaceae (1), Zingiberaceae (1), Verbenaceae (2), Asparagaceae (1), Solanaceae (1) and Poaceae (1). In addition, 16 new hosts of *P. bondari viz*., mulberry, sapota, citrus, egg fruit, rambutan, curry leaf, tapioca, Indian almond, neem, cassia, gliricidia, jasmine, red ginger, lantana, snake plant, Indian acalypha were also identified in the present study which was not earlier reported by other researchers (Plate 2). Seventeen host plants harbour all the life stages of *P. bondari* and 2 and 6 hosts consist of bondar's nesting whitefly eggs and adults, respectively (Table 2). The host plants of *P. bondari* reported by earlier workers include coconut, banana, guava, bhendi, chilli, *Populus alba*, *Duranta erecta* at Coimbatore and coconut at Namakkal (Banumathi et al 2020), coconut, guava, banana, noni, ficus, portia tree and an unidentified plant in Lakshadweep Islands (Selvaraj et al 2020), *Annona* sp.*, Atrocarpus heterophyllus, Bridelia retusa*, *Capsicum annum*, *Cinnamomum verum*, *Cocos nucifera*, *Leucaena leucocephala*, *Macaranga peltata*, *Mangifera indica*, *Morinda citrifolia*, *Musa* sp., *Psidium guajava* and *Tectona grandis* in Kerala, Karnataka and Andaman and Nicobar Islands (Vidya et al 2019).

Table 1. Survey location, GPS coordinates and Host plants of Rugose spiralling whitefly and Bondar's nesting whitefly

District and location	GPS coordinates of the location	Host Plants	
Thoothukudi		Rugose spiralling whitefly	Bondar's nesting whitefly
Vellanputhukulam	8.4730° N, 77.8717° E	Coconut, Banana, Guava, Sapota, Tapioca, Taro, Neem, Indian Almond, Native goosberry, Creeping panic grass, Shoe flower, Prickly chaff flower, Thumbai, Black night shade, Chilli, Curry leaf, Indian acalypha, Fig.	Coconut, Banana, Sapota, Gliricidia, Neem, Indian acalypha.
Pandarapuram	8.4281° N, 77.8989° E	Coconut, Banana, Sapota, Mango, Teak, Tapioca, Brinjal, Chilli, Black night shade, Thumbai, Bhendi, Curry leaf, Indian Acalypha, Neem, Indian mulberry.	Coconut, Banana, Guava, Indian acalypha, Pipal tree, Teak, Neem.
Udangudi	8.4271° N, 78.0260° E	Coconut, Sapota, Mango, Tapioca, Chilli, Black night shade, Indian acalypha, Neem, Thumbai, Gliricidia.	Coconut, Indian acalypha, Creeping panic grass, Gliricidia, Teak, Banana, Tapioca.
Kayamozhi	8.5141° N, 78.0471° E	Coconut, Guava, Sapota, Chilli, Black night shade, Indian mallow, Croton, Teak, Pipal tree, Thumbai, Indian almond, Curry leaf, Bhendi, Brinjal.	Coconut, Banana, Indian acalypha, Pipal tree, Teak, Cassia tree.
Karunkulam	9.3723° N, 78.7551° E	Coconut, Sapota, Black night shade, Indian mallow, Teak, Croton, Thumbai, Indian almond, Curry leaf, Bhendi, Brinjal, Indian acalypha.	Coconut, Banana, Sapota, Pipal tree, Teak, Neem, Cassia tree, Curry leaf.
Tenkasi			
Vadagarai	9.0410° N, 77.2740° E	Coconut, Banana, Guava, Indian almond, Neem, Teak, Milk weed, Smooth crotalaria, Mango, Pipal tree, Thumbai, Black night shade, Brinjal, Bhendi, Chilli, Curry leaf.	Coconut, Guava, Banana, Sapota, Mulberry, Tapioca, Gliricidia, Indian acalypha, Jasmine, Pipal tree.
Pattakurichi	8.9660° N, 77.3576° E	Coconut, Banana, Guava, Citrus, Sapota, Brinjal, Bhendi, Pipal tree, Croton, Creeping panic grass, Thumbai, Indian almond, Indian mallow.	Coconut, Guava, Banana, Sapota, Pipal tree, Teak, Neem, Bird eye chilli, Indian acalypha, Curry leaf.
Melagaram	8.9511° N, 77.2965° E	Coconut, Banana, Citrus, Bhendi, Croton, Pipal tree, Native gooseberry, Thumbai, Teak.	Coconut, Guava, Banana, Bird eye chilli, Jasmine, Curry leaf, Indian acalypha, Tapioca.
Mathalamparai	8.9068° N, 77.3782° E	Coconut, Banana, Guava, Sapota, Chilli, Bhendi, Mango, Shoe flower, Neem, Brinjal, Teak, Milk weed, Curry leaf, Indian almond.	Coconut, Guava, Banana, Curry leaf, Cassia tree, Jasmine, Tapioca, Indian acalypha.
Ilanji	8.9613° N, 77.2793° E	Coconut, Banana, Guava, Citrus, Mango, Sapota, Black night shade, Brinjal, Bhendi, Curry leaf, Neem, Teak, Pipal tree, Shoe flower, Gliricidia, Thumbai, Indian almond.	Coconut, Guava, Banana, Sapota, Cassia tree, Jasmine, Common lantana, Indian acalypha, Creeping panic grass, Neem.
Tirunelveli			
Panagudi	8.3199° N, 77.5767° E	Coconut, Guava, Banana, Citrus, Sapota, Mango, Custard apple, Brinjal, Chilli, Curry leaf, Neem, Pipal tree, Cassia tree, Croton, Black night shade, Milk weed, Indian mallow, Smooth crotalaria, Thumbai, Gliricidia, Mulberry.	Coconut, Banana, Guava, Sapota, Citrus, Custard apple, Bird eye chilli, Common lantana, Indian acalypha, Creeping panic grass, Jasmine, Neem.
Nanguneri	8.4961° N, 77.6465° E	Coconut, Guava, Banana, Citrus, Sapota, Mango, Custard apple, Brinjal, Bhendi, Chilli, Neem, Pipal tree, Croton, Milk weed, Indian mallow, Smooth crotalaria, Indian acalypha, Thumbai, Gliricidia.	Coconut, Banana, Sapota, Guava, Custard apple, Tapioca, Curry leaf, Indian acalypha.
Thisayanvilai	8.3343° N, 77.8635° E	Coconut, Banana, Guava, Indian almond, Teak, Neem, Milk weed, Indian mallow, Smooth crotalaria, Mulberry, Indian acalypha, Thumbai, Chilli, Neem, Native gooseberry, Indian mulberry, Gliricidia, Mango.	Coconut, Banana, Sapota, Guava, Neem, Indian acalypha, Gliricidia, Bird eye chilli, Jasmine, Pipal tree.

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Table 1. Survey location, GPS coordinates and Host plants of Rugose spiralling whitefly and Bondar's nesting whitefly

District and location	GPS coordinates of the location	Host Plants	
		Rugose spiralling whitefly	Bondar's nesting whitefly
Valliyur	8.4014° N, 77.6174° E	Coconut, Banana, Guava, Indian almond, Neem, Teak, Milk weed, Smooth crotalaria, Croton, Gliricidia, Native gooseberry, Mango, Pipal tree, Thumbai, Mulberry, Creeping panic grass, Brinjal, Bhendi, Chilli, Curry leaf.	Coconut, Banana, Sapota, Guava, Tapioca, Curry leaf, Cassia tree, Jasmine, Teak, Gliricidia, Pipal tree.
Rosmiapuram	8.3514° N, 77.5652° E	Coconut, Banana, Smooth crotalaria, Brinjal, Chilli, Thumbai, Mulberry, Curry leaf, Citrus, Teak, Milk weed, Croton, Prickly chaff flower.	Coconut, Banana, Guava, Indian acalypha, Creeping panic grass, Pipal tree.
Kanyakumari			
Seethapal	8.2529° N, 77.4526° E	Coconut, Palmyra, Fan palm, Banana, Guava, Soursop, Wild jute, Neem, Avocado, Pipal tree, Cassia tree, Giant lily, Croton, Milk weed, Indian mallow, Indian acalypha, Creeping panic grass, Smooth crotalaria, Thumbai, Gliricidia, Wild indigo	Coconut, Banana, Guava, Sapota, Cassia tree, Gliricidia, Indian acalypha, Creeping panic grass, Neem, Rambutan.
Derisanamcope	8.2875° N, 77.4421° E	Coconut, Palmyra, Fan palm, Banana, Guava, Water apple, Sapota, Custard apple, Sapota, Mulberry, Fig, Bhendi, Chilli, Brinjal, Curry leaf, Taro, Indian almond, Teak, Neem, Malay gooseberry, Wild indigo, Native gooseberry, Wild cinnamon, Crape myrtle, Croton, Lobster claw, Shoe flower, Giant lily, Indian baywatch, Thumbai, Gliricidia, Indian mallow.	Coconut, Banana, Guava, Custard apple, Indian almond, Rambutan, Common lantana, Golden dew drop, Teak.
Erumpukadu	8.1491° N, 77.3916° E	Coconut, Palmyra, Fan palm, Banana, Guava, Water apple, Fig, Bhendi, Chilli, Brinjal, Curry leaf, Taro, Teak, Neem, Wild cinnamon, €crape myrtle, Croton, Shoe flower, Indian acalypha, Thumbai, Indian almond, Smooth crotalaria.	Coconut, Banana, Guava, Mulberry, Sapota, Citrus, Egg fruit, Rambutan, Indian acalypha, Pipal tree.
Villukuri	8.2225° N, 77.3535° E	Coconut, Palmyra, Banana, Guava, Fig, Bhendi, Chilli, Brinjal, Neem, Crape myrtle, Croton, Curry leaf, Citrus, Indian almond, Mango, Wild indigo, Milk weed, Cassia tree.	Coconut, Banana, Guava, Egg fruit, Bird eye chilli, Snake plant, Gliricidia, Red ginger.
NGO colony	8.1426° N, 77.4336° E	Coconut, Guava, Fig, Bhendi, Chilli, Brinjal, Neem, Croton, Shoe flower, Curry leaf, Citrus, Indian almond, Wild indigo, Milk weed, Thumbai, Smooth crotalaria, Croton.	Coconut, Banana, Guava, Sapota, Egg fruit, Custard apple, Curry leaf, Tapioca, Indian almond, Rambutan.

Table 2. Host plants and Life stages of rugose spiralling whitefly, *A. rugioperculatus* and Bondar's Nesting whitefly, *P. bondari*

Common name	Botanical name	Family	Life stage		
			Egg	Nymph	Adult
i) Complete life stages					
Coconut	*Cocos nucifera* L.	Arecaceae	+	+	+
Palmyra	*Borassus flabellifer*	Arecaceae	+	+	+
Banana	*Musa* spp.	Musaceae	+	+	+
Guava	*Psidium guajava* L.	Myrtaceae	+	+	+
Water apple/ Rose apple	*Syzygium samarangense* (Blume) Merr. & L.M. Perry	Myrtaceae	+	+	+
Citrus	*Citrus* spp.	Rutaceae	+	+	+
Sapota	*Manilkara zapota* L.	Sapotaceae	+	+	+
Mango	*Mangifera indica* L.	Anacardiaceae	+	+	+
Custard apple	*Annona squamosa* L.	Annonaceae	+	+	+
Soursop	*Annona muricata*	Annonaceae	+	+	+

Cont...

Table 2. Host plants and Life stages of rugose spiralling whitefly, *A. rugioperculatus* and Bondar's Nesting whitefly, *P. bondari*

Common name	Botanical name	Family	Life stage		
			Egg	Nymph	Adult
Mulberry	*Morus* spp.	Moraceae	+	+	+
Fig	*Ficus* spp.	Moraceae	+	+	+
Avocado	*Persea americana* Mill.	Lauraceae	+	+	+
Brinjal	*Solanum melongena* L.	Solanaceae	+	+	+
Bhendi	*Abelmoschus esculentus* (L.) Moench	Malvaceae	+	+	+
Chilli	*Capsicum annuum* L.	Solanaceae	+	+	+
Curry leaf	*Murraya koenigii* (L.) Spreng	Rutaceae	+	+	+
Tapioca	*Manihot esculenta* Crantz.	Euphorbiaceae	+	+	+
Indian Almond	*Terminalia catappa* L.	Combretaceae	+	+	+
Teak	*Tectona grandis* L.	Lamiaceae	+	+	+
Neem	*Azadirachta indica* A. Juss.	Meliaceae	+	+	+
Pipal tree	*Ficus religiosa* L.	Moraceae	+	+	+
Native goosberry	*Physalis minima* L.	Solanaceae	+	+	+
Cassia tree	*Senna siamea* (Lam.) H. S. Irwin & Barneby	Fabaceae	+	+	+
Wild cinnamon	*Cinnamomum malabatrum* (Burm.f.) Blume	Lauraceae	+	+	+
Lobster claw	*Heliconia rostrata* Ruiz & Pav	Heliconiaceae	+	+	+
Croton	*Croton sparsiflorus* Morong	Euphorbiaceae	+	+	+
Wild indigo/ Fish poison	*Tephrosia purpurea* (L.) Pers	Fabaceae	+	+	+
Milk weed	*Euphorbia* spp.	Euphorbiaceae	+	+	+
Prickly chaff flower	*Achyranthes aspera* L.	Amaranthaceae	+	+	+
Creeping panic grass	*Brachiaria reptans* (L.) C.A. Gardner & C.E. Hubb.	Poaceae	+	+	+
Smooth crotalaria	*Crotalaria pallida* Aiton	Fabaceae	+	+	+
Gliricidia	*Gliricidia sepium* (Jacq.)	Fabaceae	+	+	+
Fan palm	*Chamaerops humilis* L.	Arecaceae	+	+	+
ii) Incomplete life stages					
Wild jute	*Corchorus* spp.	Malvaceae	+	-	-
Black nightshade	*Solanum nigrum* L.	Solanaceae	+	-	-
Crape myrtle	*Lagerstroemia indica* L.	Lythraceae	+	-	-
Indian baywatch	*Syzygium polyanthum* (Wight) Walp.	Myrtaceae	+	-	-
Giant lily	*Crinum asiaticum* L.	Amaryllidaceae	+	-	-
Malay gooseberry	*Phyllanthus acidus Skeels*	Phyllanthaceae	+	-	-
Taro	*Colocasia esculenta* (L.) Schott.	Araceae	+	-	-
Thumbai	*Leucas aspera* (Wild.) Link	Lamiaceae	-	-	+
Indian Acalypha	*Acalypha indica* L.	Euphorbiaceae	-	-	+
Indian mallow	*Abutilon indicum* L.	Malvaceae	-	-	+
Shoe flower	*Hibiscus rosa-sinensis* L.	Malvaceae	-	-	+
Indian mulberry	*Morinda coreia* Buch. -Ham.	Rubiaceae	-	-	+
Host plants of Bondar's Nesting whitefly, *P. bondari*					
i) Complete life stages					
Coconut	*Cocos nucifera* L.	Arecaceae	+	+	+
Banana	*Musa* spp.	Musaceae	+	+	+
Guava	*Psidium guajava* L.	Myrtaceae	+	+	+

Cont...

Plate 1. Host plants of rugose spiralling whitefly, *Aleurodicus rugioperculatus* Martin

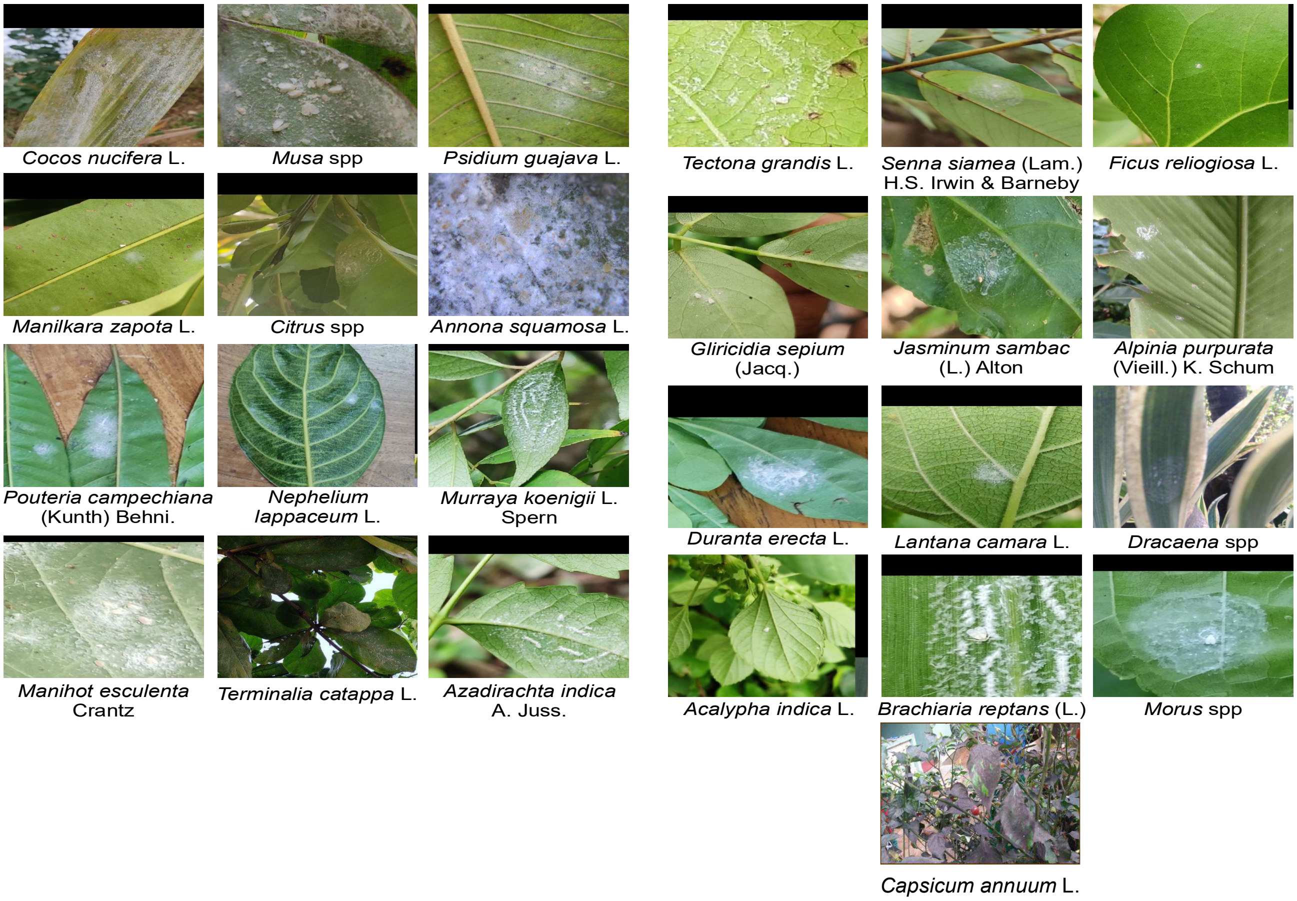

Plate 2. Hosts plants of Bondar's nesting whitefly, *Paraleyrodes bondari* Peracchi

Table 2. Host plants and Life stages of rugose spiralling whitefly, *A. rugioperculatus* and Bondar's Nesting whitefly, *P. bondari*

Common name	Botanical name	Family	Life stage		
			Egg	Nymph	Adult
Mulberry	*Morus* spp.	Moraceae	+	+	+
Sapota	*Manilkara zapota* L.	Sapotaceae	+	+	+
Citrus	*Citrus* spp	Rutaceae	+	+	+
Custard apple	*Annona squamosa* L.	Annonaceae	+	+	+
Egg fruit	*Pouteria campechiana* (Kunth) Baehni.	Sapotaceae	+	+	+
Rambutan	*Nephelium lappaceum* L.	Sapindaceae	+	+	+
Bird eye chilli	*Capsicum annuum* L.	Solanaceae	+	+	+
Curry leaf	*Murraya koenigii* L. Spren	Rutaceae	+	+	+
Tapioca	*Manihot esculenta* Crantz.	Euphorbiaceae	+	+	+
Indian almond	*Terminalia catappa* L.	Combretaceae	+	+	+
Jasmine	*Jasminum sambac* (L.) *Aiton*	Oleaceae	+	+	+
Cassia tree	*Senna siamea* (Lam.) H. S. Irwin & Barneby	Fabaceae	+	+	+
Golden dew drop	*Duranta erecta* L.	Verbanaceae	+	+	+
Common lantana	*Lantana camara* L.	Verbenaceae	+	+	+
ii) Incomplete life stages					
Red ginger	*Alpinia purpurata* (Vieill.) K. Schum.	Zingiberaceae	+	-	-
Snake plant	*Dracaena* spp.	Asparagaceae	+	-	-
Neem	*Azadirachta indica* A. Juss.	Meliaceae	-	-	+
Teak	*Tectona grandis* L.	Lamiaceae	-	-	+
Pipal tree	*Ficus religiosa* L.	Moraceae	-	-	+
Gliricidia	*Gliricidia sepium* (Jacq.)	Fabaceae	-	-	+
Indian acalypha	*Acalypha indica* L.	Euphorbiaceae	-	-	+
Creeping panic grass	*Brachiaria reptans* (L.) C.A. Gardner & C.E. Hubb.	Poaceae	-	-	+

*(+ Present, - absent)

CONCLUSION

This study sheds light on whitefly host plants, notably *Aleurodicus rugioperculatus* and *Paraleyrodes bondari* in southern districts of Tamil Nadu. Surveys spanning 2020-2021 revealed whitefly infestations across diverse crops and plant species were documented. The invasive pests *A. rugiopercultus* and *P. bondari* have already been reported in coconuts, causing significant damage in Tamil Nadu. However, recent observations reveal that these pests have invaded 46 host plants across 25 families and 25 host plants across 19 families, respectively. This highlights the alarming situation for crop growers, as these pests could potentially spread to other cultivation areas as well. Categorizing host plants by life stages enhances our grasp of whitefly ecology and its impact, aiding in population monitoring and management strategies.

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Received 21 February, 2024; Accepted 21 June, 2024

Indian Journal of Ecology (2024) 51(4): 891-894
DOI: https://doi.org/10.55362/IJE/2024/4326

Manuscript Number: 4326
NAAS Rating: 5.38

Impact of Inoculative Releases of *Trichogramma chilonis* for *Helicoverpa armigera and Hippodamia variegata* for *Myzus persicae* in Ecologically Engineered Tomato Ecosystem of Kashmir

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***Abstract*:** Field experiments were conducted to determine the impact of inoculative releases of two natural enemies, *Trichogramma chilonis and Hippodamia variegata* for the suppression of *Helicoverpa armigera* and *Myzus persicae*, respectively in ecological engineering practiced tomato field of Kashmir. The application of *T. chilonis* @150, 000 per ha significantly reduced *H. armigera* population (90.0 %) as compared to the only ecological engineering practiced field (62.46%). *H. variegata* @ 25,000/ha significantly suppressed *M. persicae* population with a reduction of 90.38% as compared to the only ecological engineering practiced field (60.64%). The study indicate that *T. chilonis* @150, 000/ha and *H. variegata* @ 25,000/ha significantly managed the population of *H. armigera* and *M. persicae*, respectively in ecological engineering practiced tomato field helps in avoidance of pesticidal applications.

Keywords: *Helicoverpa armigera, Myzus persicae, Trichogramma chilonis*, *Hippodamia variegata*, Biological control, Ecological engineering, Tomato

Tomato (*Solanum lycopersicum*) is one of the most common and important vegetable crops in terms of production and consumption all over the world. Among various insect pest of tomato, *Helicoverpa armigera* and *Myzus persica a*re most destructive pest that causes significant losses about 50-60% and 19.43%, respectively (Rawat 2020 , Sharma et al 2022). Since their habitats are in constant flux and the area under cultivation is often small, and only biological control strategies cannot be effectively used in short-term annual vegetables, ornamentals and field crops (Rusch et al 2010, Khan et al 2020). This strongly suggests that new approaches to solving the problem are needed. The active biological control system i.e., inundative release or inoculative release of biological control agents, overcomes a large number of pest problems that come with short-lived crops (Tang et al 2009). Potential biological agents should therefore be targeted during this period to effectively destroy the pest(s) before causing significant economic loss. In comparison to insecticides, there is no variety of biological control agents (Khan and Riyaz 2017a). Since tomato is a short-duration crop, the combination of habitat manipulation and inoculative releases of natural enemies (*Trichogramma chilonis* and *Hippodamia variegata*) might prove effective in the biological control of tomato pests (Kumar et al 2014, Baber and Khan 2022). The most commonly used biological control agent in the Indian subcontinent, *Trichogramma chilonis* Ishii is responsible for suppression of *Helicoverpa armigera* (Hubner) in several crops (Tscharntke et al 2016). The parasitoids occurs naturally in tomato ecosystem, but the population of tomato fruit borers in the tomato ecosystem cannot be reduced below the ET level significantly. The inoculative release of egg parasitoids can manage the *Helicoverpa armigera* (Hubner) populations. In many crops, ladybeetles are play an important role in pest control. Aphids and other soft-bodied insects are favorites of adults and larvae of ladybeetles and their efficacy is documented in controlling pests. The research has also been performed on the feeding patterns of various coccinellids on various aphids (Khan et al 2017). One of such species, *Hippodamia variegata* (Coleoptera: Coccinellidae), a polyphagous predator of medium size, is a potential biological agent for *Myzus persicae*. The inclusion of *Hippodamia variegata* in a biocontrol program necessitates comprehensive information on its critical functions, including numerical and functional responses, with predation effectiveness being a key component of functional response (Shah and Khan 2014).

Ecological engineering, also known as habitat manipulation, might be of great help in the conservation and enhancement of the natural enemy population by plant diversity enhancement and providing agro-ecosystem with sufficient refugee (Khan et al 2020). Hence for the purpose of coupling the benefits of ecological engineering and inoculative bio-agent releases for pest management, study aimed at the biological control of these pests using tomato crops maintained in ecologically engineered field conditions at Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar, Srinagar, was conducted during 2019.

MATERIAL AND METHODS

Tomato crop was maintained under ecologically engineered, a form of conservation biological control, is an ecologically based approach aimed at favoring natural enemies and enhancing biological control in agricultural systems and its provide resources such as food for adult natural enemies, alternative prey or hosts, and shelter for survival in adverse conditions)field conditions at Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar, Srinagar, India, during 2019. In order to count the insect pests and natural enemies population, a hybrid tomato variety (Shalimar Hybrid 1) was raised in plots of size 3.00 x 3.30 m. In order to maintain healthy crop growth, all the recommended agronomic practices were carried out except pesticide application. The design of experiments under ecologically engineered tomato were buckwheat (*Fagopyrum esculentum* Moench) was grown as cover crop on boarder three line a row (width of row of 30cm) for pollen, nectars and shelter of natural enemies; after that a line row of marigold (*Tagetes* spp.) was grown as trap crop (width of row of 30cm) and expected to avoiding egg laying of tomato fruit borer damage of main tomato crop, after each plot of tomato crops one row of maize (*Zea mays* L.) crop in between two plots of tomato, grown as barrier crop expected to check the movement of aphid and flying insect such as tomato fruit borer. Similarly, one row of cowpea (*Vigna unguiculata* L.) grown as trap crop opposite direction of maize crop expected to prefer as host for aphid and avoid egg laying of tomato fruit borer damage of tomato crop and results were compared with the control plot which was grown away from ecological engineering plots to avoid effect of their follow the General Management Practices.

To evaluate the impact of inoculative releases of natural enemies in ecologically engineered tomato field, experiments were laid out in a randomized block design with five treatments and four replications. Comprising of *T. chilonis* with 3 dosages (1, 00, 000, 1, 50, 000 and 2, 00, 000/ha) against *Helicoverpa armigera* and *Hippodamia variegata* with 3 dosages (20,000, 25,000 and 30,000/ha) against *M. persicae.* Each experiment also consisted of a standard check (ecologically engineered field plot) and a control away from the ecologically engineered field plot (following the general management practices). *T. chilonis* were released in the field in the form of tricho-cards by tying them to the tomato plants at the flowering stage (35 days after transplanting of tomato) . The randomly selected plants were observed at weekly intervals to observe the effects of *T. chilonis* releases on larval population of *H. armigera*. The efficacy of *H. variegata* was worked out by computing the number of aphids (per plant) before release and after release from the 3 randomly selected plants in each replication. Percent reduction was worked out by computing the difference between the pre and post-treatment populations of *M. persicae* (Abbott, 1925). The observation regarding the recovery of natural enemies was taken one day before release and 30 days after release.

To record the fruit damage by *H. armigera* number of healthy and damaged fruits was recorded from each of the 3 randomly selected plants in each replication. The yield of tomatoes was recorded from and worked out on hectare basis. The effect of *T. chilonis* releases on fruit damage by *H. armigera* was also estimated by comparing the percent damage with the control. Total number of damaged fruits and healthy fruits from each replication at each picking . Analysis of data was done by using R software (R Development Core Team, 2016).

RESULTS AND DISCUSSION

Impact of Releases of *Trichogramma chilonis* on *Helicoverpa armigera*

Larval population: There was a decrease in the population of *Helicoverpa armigera* after installing tricho-cards of *Trichogramma chilonis* in the tomato field (Table 1). There was a significant difference in the larval population in different treatments on all the dates of observation. The mean larval population in the control was significantly higher (2.96 larvae/plant) than all the treatments. The lowest 0.24 larvae per plant population were recorded when *T. chilonis* was released @ 2, 00, 000/ha and was significantly lower than dosage of *T. chilonis* @ 1, 00, 000/ha. *T. chilonis* released @ 1, 50, 000/ha and *T. chilonis* @ 2, 00, 000/ha were at par with each other having no significant difference. The population decrease due to inoculative releases in the ecologically engineered field proved effective as compared to the standard check where no inoculation was done. Similar results were observed by Khan (2011) and Ballal and Singh (2003).

Fruit damage and yield: The mean fruit damage in all the treatments was significantly lower than control. Lowest fruit damage was when *T. chilonis* was released @ 2, 00, 000/ha (5.05%) and highest in the control (17.19%) followed by ecologically engineered field (7.59%) where no inoculative release was done. Mean fruit damage in *T. chilonis* @ 1, 50, 000/ha was significantly lower than *T. chilonis* @ 1, 00, 000/ha but mean fruit damage in *T. chilonis* @ 1, 50, 000/ha and *T. chilonis* @ 2, 00, 000/ha was at par. Similarly, the marketable yield when *T. chilonis* was released @ 2, 00, 000/ha was statistically not significant different from *T. chilonis* @ 1, 50, 000/ha but was significantly high than the other dose and standard check as well as control. Liang *et al*. (2013) also observed that fruit damage in all the treatments containing different dosages of trichogrammatids was significantly lower than that of control.

Impact of Releases of *Hippodamia variegata* on *Myzus persicae*

Population of *M. persicae*: *M. persicae* population was reduced during the course of time which was less than the pre-treatment count ecologically engineered check also showed decreasing trend (Table 2). *H. variegata* released at different doses showed decreasing trend in the population of *M. persicae* on increasing the dosage as compared to ecologically engineered check and control. However, *H. variegata* @ 25,000/ha showed a significant reduction in aphid population (3.07 aphids/plant) as compared to *H. variegata* @ 20,000/ha but was at pat with @ 30,000/ha. Earlier study also reported that *H. variegata* is a potential predator and significantly reduces aphid population after release which are in support with this study (Franzmann 2002, Kontodimas and Stathas 2005, Khan and Riyaz 2017b). The recovery of *H. variegata* was also recorded after 30 days of release and highest recovery of 43.06 % was when *H. variegata* was released @ 30,000/ha followed by *H.*

Table 1. Impact of inoculative releases of *T. chilonis* on the population of *H. armigera*, fruit damage and yield in ecologically engineered tomato ecosystem of Kashmir (2019)

Treatment	Dosage/ha	Population of *H. armigera* larvae (per plant)					Mean fruit damage# (%)	Yield (Q/ha)**
		July 22	July 29	August 5	August 12	Mean*		
Trichogramma chilonis	100000	0.87[a]	0.73[a]	0.47[a]	0.32[a]	0.59[a] (80.05)	6.97[a] (2.82)	642.58[a]
	150000	0.46[a]	0.31[a]	0.22[a]	0.23[a]	0.30[b] (89.68)	5.61[b] (2.57)	764.52[b]
	200000	0.3[a]	0.21[a]	0.23[a]	0.21[a]	0.24[b] (91.96)	5.05[b] (2.46)	777.32[b]
Ecologically engineered field	Standard check	1.31[b]	1.23[b]	1.03[b]	0.87[b]	1.11[c] (62.46)	7.59[c] (2.93)	571.75[c]
Control	_	4.03[c]	3.15[c]	2.49[c]	2.16[c]	2.96[d]	17.19[d] (4.26)	431.87[d]
CD (p = 0.05)	-	0.76	0.47	0.39	0.64	0.27	(0.13)	100.84

*Figures in the parenthesis are the per cent mean reduction over control, #Date of release = July 18, 2019
**(Q/ha) = Yield of tomato quintals per hectare, #Figures in the parenthesis of are the square root transformed values

Table 2. Impact of inoculative releases of *H. variegata* on the populations of *M. persicae* in ecologically engineered tomato ecosystem of Kashmir

Treatment	Dosage/ ha	Number of aphids (Per plant) before treatment	Number of aphids (Per plant) after treatment					Per cent reduction*	Yield (q/ha)	Recovery of natural enemies	
			July 22	July 29	August 5	August 12	Mean			Before treatment	After treatment (30 days after release)
Hippodamia variegata	20,000	16.35[a]	9.34[a]	7.07[a]	6.43[a]	6.07[a]	7.23	55.77 (77.34)	687.46[a]	2.21	3.19 (30.72)
	25,000	16.46[a]	4.64[b]	3.66[b]	2.01[b]	1.96[b]	3.07	81.34 (90.38)	775.27[b]	1.95	3.38 (42.38)
	30,000	14.23[b]	3.49[c]	3.12[b]	1.08[c]	1.51[b]	2.3	83.83 (92.78)	787.09[b]	2.3	4.04 (43.07)
Ecologically engineered field	Standard check	16.34[a]	15.4[d]	14.25[c]	9.55[d]	11.01[c]	12.55	23.19 (60.64)	638.58[c]	2.43	3.12 (22.11)
Control	_	36.88[c]	34.2[e]	30.23[d]	31.05[e]	32.11[d]	31.89	13.53	457.87[d]	0.95	1.03 (7.77)
CD (p=0.05)	-	1.46	0.87	0.77	0.28	0.54	3.70	-	75.34	-	-

* Figures in parenthesis represent per cent reduction over control, #Date of release = July 15, 2019, # Figures in the parenthesis shows % recovery of natural enemies

variegata @ 25,000/ha (42.30%) and both were statistically similar to each other than other treatments including ecologically engineered standard check and control (Table 2). Khan et al (2017) also mentioned that on increasing the dosage percent recovery also.

Yield: Highest yield (787.09 Q/ha) was observed when the *H. variegata* released @30,000/ha which was at par with @ 25,000/ha (775.27 Q/ha) but was significantly higher than the other dose and standard check (638.58Q/ha) as well as control.

CONCLUSION

This study showed that the inoculative releases of two natural enemies, *T. chilonis*@1,50,0,00 and *H. variegata* @ 25,000/ha were significantly reduced the population of *H. armigera* and *M. persicae*, respectively and helps in avoidance of pesticidal applications by maintaining the pest defender ratio in ecological engineering tomato practiced fields.

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Received 27 December, 2023; Accepted 10 June, 2024

Indian Journal of Ecology (2024) 51(4): 895-899
DOI: https://doi.org/10.55362/IJE/2024/4327

Manuscript Number: 4327
NAAS Rating: 5.38

Effect of Imidacloprid on Foraging Behaviour of Wild Bee Species on Coriander

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Abstract: The experiment was carried out at Beekeeping Unit, TCA, Dholi (Muzaffarpur) during '*rabi* 2021-22' on c.v. of coriander 'Rajendra Dhania-2'. Foraging behaviour of rock bee and little bee such as duration of foraging, foraging speed and rate was studied under two conditions *i.e.* with and without insecticide application. In untreated area duration of foraging was maximum in *Apis dorsata* (7.16 second) and minimum in *Apis florae* (3.51 second). Foraging rate was highest in *A. florea* (11.66 flowers) followed by *A. dorsata* (6.64 flowers). Application of insecticide imidacloprid @ 25 gm a.i/ha completely ceased the activity of honey bee species on flowers of coriander for three days. Effect of insecticide on foraging behaviour was observed for a period of 4 to 5 days in wild bee species. Insecticide application caused 20 to 25 % reduction in foraging activity of both wild species during complete flowering period.

Keywords: *Apis dorsata*, *Apis florea*, Foraging activity, Imidacloprid 17.8 % SL, Deviation

India is considered as the home of spices due to largest production, consumption and export of seed spices. Coriander (*Coriandrum sativum* L.) is an important tropical spice crop of family Apiaceae (Umbelliferae). Although it is a native to eastern Mediterranean region, India has the production share of more than 70 per cent to the total world output (Coskuner and Karababa 2007). Spices are highly cross pollinated and around 75 per cent are dependent on the animals for pollination while the only 28 crop spices crops depend on wind or self-pollination (Klein et al 2007). The flowering phenology of coriander *i.e.,* protandrous condition is responsible for cross pollination in it. Around 11 to 14 insect pollinators were documented as the important agents responsible for pollinating coriander (Devi et al 2015, Thakur et al 2022). Genus *Apis* is the most studied because of their fascinating and complex lifestyle, communication systems, role as keystone and the valuable hive products that they produce (Giri et al 2018). Bees, in particular, excel as pollinators due to their pollen-collecting behavior driven by nutritional needs. Over 80 percent of a honey bee body is adorned with pollen-attracting hairs that utilize electrostatic forces to draw in pollen grains. Their remarkable loyalty to a single plant until it ceases flowering enhances pollination efficiency, making them highly favored for effective pollination. *Apis dorsata* (Fabricius) and *A. florea* (Fabricius), as wild species, cannot be kept in bee boxes, yet their role as primary pollinators becomes indispensable in the absence of domesticated species. Despite their lower honey yields compared to domesticated counterparts, they play a pivotal role in the pollination process.

Given coriander's reliance on honey bees for cross-pollination, the impact of insecticide on these vital pollinators becomes a pressing concern. The perils associated with insecticidal application encompass not only direct mortality but also indirect consequences such as fumigative effects, repellency, and the toxicity of residues found in nectar and on various floral parts (Desneux et al 2007). Consequently, investigating the effect of imidacloprid on the foraging behavior of wild bees holds paramount significance in preserving the pollination dynamics of coriander and other cross-pollinated crops. This research aims to investigate the impact of imidacloprid on the foraging behavior of wild bee species, *A. dorsata* and *A. florea* within the context of coriander pollination.

MATERIAL AND METHODS

The foraging pattern of the wild species of honey bee on coriander was observed at Beekeeping Unit, TCA, Dholi (Muzaffarpur) during *rabi* 2021-22. The observations were recorded on duration of foraging, foraging speed and foraging rate. This objective was studied under two different conditions *i.e.* with insecticidal application and without insecticidal application. Imidacloprid spraying was carried out on March 6, 2022 in 3 plots with imidacloprid 17.8% SL @ 25gm a.i/ha. Initiation time of foraging for bee pollinators was recorded in morning and cessation time in the evening .The duration of foraging (minute) was calculated. The time spent in seconds by honey bee species on individual flower is foraging speed. The number of flowers visited by honey bee species per minute is called foraging rate and was calculated by visual observations. Observations were recorded from 07:00 at 2 hour interval till 17:00 hours from 3 different spots from each plot on alternate day from March 3 to March 17, 2022

RESULTS AND DISCUSSION:

Foraging duration: In the untreated area duration of foraging was maximum in *A. dorsata* (10:37 hours) than A. *florea* (09:42 hours) under normal condition (Fig. 1). Earliest foraging activity was started by *A. dorsata i.e.* 06:46 AM and stopped at 17:25 PM. *A. florea* started foraging activity very late *i.e.* 07:15 AM and ceased at 16:56 PM. Maximum foraging period was observed on March 17,2022 *i.e.*11:12 hours in *A. dorsata*, whereas in *A. florea* it was observed on March 13, 2022 *i.e.* 10:09 hours. Chandel et al (2002) observed that maximum foraging period by *A. dorsata i.e.* 6.30 AM-6.50 PM. Negi et al (2020) observed that foraging period of *A. dorsata* was 6.30 AM to 6.55 PM, which was maximum among all other species. Kumar and Giri (2020) also observed that duration of foraging was maximum in *A. dorsata.* Duration of foraging was low during initial days of flowering when day length was shorter but increased with increase in day length. Duration of foraging increased with increase in pollen-nectar availability, temperature and day length. Requirement of floral resources was higher in *A. dorsata* due to bigger body size which resulted in maximum foraging duration.

In insecticide treated area before the date of insecticide application, the foraging activity was same as in the untreated plot for both bee species. After insecticide treatment the foraging activity was ceased completely for 3 days in all species (Table 1). Though foraging activity was restarted after 4 days in both bee species, foraging duration was lesser than the normal. Effect of insecticide on foraging behaviour was observed for 4 to 5 days in wild bee species. Giri et al (2022) also observed that neonicotinoid causes

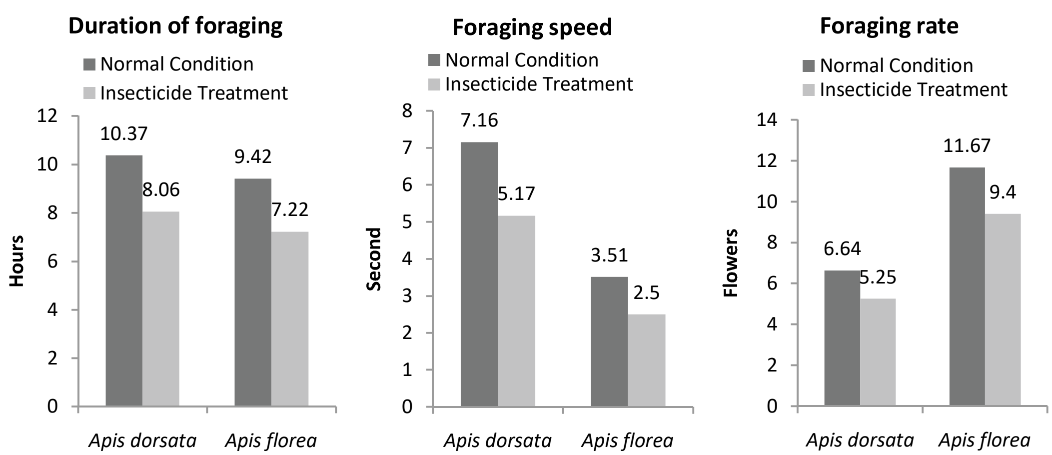

Fig. 1. Deviation in mean foraging activity due to imidacloprid treatment

Table 1. Foraging activity period of honey bee species on coriander bloom in untreated and imidacloprid treated area

Dates of observation (2022)	Untreated						Imidacloprid treated					
	A. dorsata			*A. florea*			*A. dorsata*			*A. florea*		
	I	C	D	I	C	D	I	C	D	I	C	D
March 3	07:02	17.10	10:08	07:50	17:00	09:10	07:02	17:09	10:07	07:52	17:01	09:09
March 5	06:54	17:22	10:28	07:35	17:03	09:28	06:55	17:23	10:28	07:35	17:04	09:29
March 9	06:50	17:25	10:35	07:00	17:04	10:04	00:00	00:00	00:00	00:00	00:00	00:00
March 13	06:40	17:29	10:49	06:57	17:06	10:09	06:40	17:28	10:48	06:55	17:08	10:13
March 17	06:28	17:40	11:12	06:53	16:30	09:37	06:27	17:42	11:15	06:50	04:32	09:42
Mean	06:46	17:25	10:38	07:15	16:56	09:41	06:46	17:25	08:31	07:18	13:56	07:42

I - Initiation time (AM), C - Cessation time (PM), D - Duration of foraging (Hrs) mortality of bee species under semi-field conditions which caused reduction in foraging duration. Honey bees avoided to visit the field due to toxic and strong smell of insecticide.

Foraging speed: In untreated area mean foraging speed (time spent on individual flower) was highest in *A. dorsata* (7.16 sec.) followed by *A. florea* (3.51 sec.) (Fig. 1). Foraging speed of *A. florea* was highest during early flowering, whereas at peak flowering stage *A. dorsata* showed highest foraging speed. *A. dorsata* showed high foraging speed during late afternoon hours *i.e.* 8.21 sec. *A. florea* (5.01 sec) spent more time during early morning hours (Table 2, 3). Devi (2011) also reported similar trend. *A. dorsata* spent more time on umbel followed by *A. florea.* Das et al (2019) observed that foraging speed of *A. florea* was maximum during morning hours (9:00 to 11:00 AM) and decreased as temperature started to increase. Mishra and Kumar (2018) reported that time spent on individual flower was maximum in *A. dorsata* and least observed in *A. florea*. Foraging speed of *A. florea* was maximum in morning while minimum in evening. *A. dorsata* spent more time on individual flower due to high floral resource requirement. Only small sized bee (*A. florea*) can enter the partially opened flowers in morning hours, which was the main reason behind high foraging speed of little bee during early morning.

In insecticide treated area after insecticide spraying, foraging activity ceased for 3 days. Effect of insecticide was prominent up to 5 to 6 days on foraging speed of *A. florea* and *A. dorsata* (Table 2, 3). Foraging activity restarted on 4th day, still the foraging speed was lower than the normal. Mean foraging speed in insecticidal treatment was highest in *A. dorsata* (5.17 sec) followed by *A. florea* (2.50 sec) (Fig. 1). Giri *et al* (2018) also reported that thiamethoxam had negative impact on foraging speed of honey bee.

Foraging rate: In untreated area mean foraging rate was highest in *A. florea* (11.67 flowers) followed by *A. dorsata* (6.64 flowers) (Fig. 1). *A. dorsata* (7.20 flowers) showed (maximum foraging rate during early morning period (Table 4, 5). *A. florea* visited maximum flowers (14.58 flowers) during late afternoon period and minimum foraging rate was of *A. dorsata* (5.56 flowers) during late flowering period. *A. florea* (8.22 flowers) showed less foraging rate at initial stage of flowering. *A. dorsata* visited fewer flowers when pollen-nectar availability of flower got increased *i.e.* up to peak period of flowering and again increased near to seed maturity. Chaudhary and Singh (2007) reported that lowest foraging rate in *A. dorsata* (6.61 flowers/minute). Devi (2011) reported that *A. dorsata* spent more time on onion umbel followed by *A. florea*. Foraging rate of *A. dorsata* was low

Table 2. Foraging speed of *A. dorsata* visiting coriander flowers in untreated and imidacloprid treated area

Dates of observation (2022)	Time spent on flowers (in sec.)							
	09:00		11:00		13:00		15:00	
	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated
March 3	6.12	6.10	6.75	6.70	6.90	6.95	6.45	6.40
March 5	6.88	6.92	7.89	7.80	7.12	7.20	8.88	8.90
March 9	7.86	0.00	7.77	0.00	8.05	0.00	8.56	0.00
March 13	7.35	7.3	8.24	8.20	8.89	8.88	9.04	9.06
March 17	6.89	6.88	6.88	6.90	7.34	7.30	8.12	8.14
Mean ± SD	7.02±0.64	5.44±3.07	7.51±0.66	5.92±3.37	7.66±0.81	6.07±3.48	8.21±1.04	6.50±3.78

Table 3. Foraging speed of *A. florea* visiting coriander flowers in untreated and imidacloprid treated plot

Dates of observation (2022)	Time spent on flowers (in sec.)							
	09:00		11:00		13:00		15:00	
	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated
March 3	5.75	5.76	5.04	5.08	4.12	4.11	3.77	3.78
March 5	6.12	6.15	5.78	5.70	4.52	4.45	4.25	4.18
March 9	4.78	0.00	4.89	0.00	3.78	0.00	3.25	0.00
March 13	4.69	4.66	3.84	3.85	3.50	3.56	3.10	3.12
March 17	3.72	3.75	3.45	3.46	3.02	3.05	3.03	3.02
Mean ± SD	5.01±0.95	4.06±2.46	4.60±0.94	3.62±2.22	3.79±0.57	3.03±1.78	3.48±0.52	2.82±1.65

Table 4. Foraging rate of *A. dorsata* visiting coriander flowers in untreated and imidacloprid treated plot

Dates of observation (2022)	Number of flowers visited in one minute							
	09:00		11:00		13:00		15:00	
	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated
March 3	8.22	8.22	7.44	7.45	7.22	7.11	7.67	7.67
March 5	7.56	7.45	6.44	6.45	7.11	7.00	5.67	5.67
March 9	6.33	0.00	6.44	0.00	6.33	0.00	6.00	0.00
March 13	6.67	7.00	6.11	6.22	5.67	5.67	5.56	5.67
March 17	7.22	7.33	7.33	7.33	6.67	7.00	6.22	6.22
Mean ± SD	7.20±0.74	6.00±3.38	6.75±0.59	5.49±3.12	6.60±0.63	5.36±3.05	6.22±0.85	5.05±2.94

Table 5. Foraging rate of *A. florea* visiting coriander flowers in untreated and imidacloprid treated plot

Dates of observation (2022)	Number of flowers visited in one minute							
	09:00		11:00		13:00		15:00	
	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated
March 3	8.67	8.67	10.00	9.67	12.11	12.22	13.22	13.11
March 5	8.22	8.10	8.67	8.67	11.00	11.11	11.67	11.56
March 9	10.45	0.00	10.22	0.00	13.22	0.00	15.33	0.00
March 13	10.67	10.67	13.00	13.00	14.33	14.22	16.11	16.00
March 17	13.44	13.33	14.56	14.45	16.56	16.45	16.56	16.56
Mean ± SD	10.29±2.06	8.15±5.00	11.29±2.41	9.16±5.64	13.44±2.14	10.80±6.37	14.58±2.07	11.45±6.72

Table 6. Per cent deviation in insecticide treated plots from normal condition

Parameters	*A. dorsata*	*A. florea*
Foraging duration	- 22.28	- 23.35
Foraging speed	- 27.79	- 28.77
Foraging rate	- 20.93	- 19.45

'-' indicates reduction in percentage

during peak flowering period as the more floral resource was available on individual flower. Due to partially opened flowers *A. dorsata* visited more flowers to collect the floral resources. In insecticide treated area after insecticide spraying, foraging activity ceased for 3 days. Effect of insecticide was prominent up to 5 to 6 days on foraging rate of *A. dorsata* and *A. florea*. Foraging activity restarted on 4th day and foraging rate suddenly increased to higher range. Mean foraging rate in insecticidal treatment was highest in *A. florea* (9.40 flowers) followed by *A. dorsata* (5.25 flowers).

Deviation in foraging activity: Foraging duration of *A. dorsata* and *A. florea* reduced by 22.28 and 23.35 %, respectively due to insecticide application during flowering period (Table 6). Foraging speed of *A. dorsata* (27.79 %) and *A. florea* (28.77 %) was also reduced due to insecticide treatment. Decrease in foraging rate due to insecticidal application was observed in *A. dorsata* (20.93 %) and *A. florea* (19.45 %).

CONCLUSION

Under untreated environmental conditions, *A. dorsata* forages extensively due to larger size and higher nutritional needs, resulting in prolonged foraging sessions. Foraging duration is linked to daylight hours, not the flowering period. *A. dorsata*, despite its slower pace, efficiently collects floral resources from individual blossoms. *A. florea*, faster but less resource-efficient, displays the highest foraging rate but fails to fully exploit available resources, indicating reduced efficiency. Food scarcity increases foraging rates but decreases speed. Insecticide use halts honey bee activity on coriander flowers for three days and affects *A. florea* and *A. dorsata* for five to six days, harming pollination. Wild bee species are more resilient than domestic ones but still suffer reduced pollination for up to a week. Insecticides disrupt foraging behavior, potentially harming coriander crop yields. Economic assessments are crucial before pesticide use in cross-pollinated crops like coriander.

AUTHOR CONTRIBUTION

The author MVT and NK conceptualized the idea. MVT and GSG designed the work. MVT and RDV collected data from field. RDV performed tabulation of the data, while NK and GSG analysed the data. MVT and SSM interpreted the result. SSM wrote the manuscript. MVT, NK and GSG reviewed and finalized the manuscript.

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Indian Journal of Ecology (2024) 51(4): 900-904
DOI: https://doi.org/10.55362/IJE/2024/4328

Manuscript Number: 4328
NAAS Rating: 5.38

Cultural and Physiological Variability in *Colletotrichum musae*-Causal Agent of Banana Post-Harvest Fruit Rot under Hill and Plain Agro-Ecosystems of Meghalaya

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Abstract: The study investigated the fungal pathogens contributing to the banana fruit rot complex, identifying *Colletotrichum musae* as significant causative agent. Ten *C. musae* isolates obtained from different market localities were subjected to cultural and physiological variability analyses. The isolates exhibited characteristics such as hyaline, aseptate, cylindrical conidia with dimensions ranging from 7.03-10.77 µm (length) and 3.02-3.77 µm (width), while acervuli sizes varied from 53.6 to 78.99 µm in diameter. Among tested media, Oat meal agar proved most suitable for *C. musae* growth, followed by potato dextrose agar , with Richard's agar showing sparse mycelial density. Martin's rose bengal agar demonstrated the lowest average radial growth and, thus, was deemed unsuitable. Colony colours were predominantly salmon white, greyish white, or completely white across the five media. Temperature studies revealed optimal radial growth for *C. musae* at temperatures between 15 and 27°C, with 27°C recording maximum growth. No growth occurred at 4 and 40°C. The pH of 6, 7, and 8 supported optimal growth, while extremes below 6 or above 8 were unfavourable. The slightly acidic pH of 6 was identified as the most suitable for *C. musae* growth when using PDA as a basal medium.

Keywords: *Musa* spp., *Colletotrichum musae*, Variability, Temperature, pH

Currently, India contributes 0.3% to the total global banana exports, holding the 21st position among exporters. India is responsible for 19.37% of the global banana production, cultivating 33.06 million tons across an area of 0.924 million hectares (Anonymous 2020). Bananas are cultivated in the elevated terrain of Meghalaya, located in the north-eastern region of India, particularly in mid-hill areas, primarily in the Ri-Bhoi district and to a lesser extent in the East Khasi Hills district. In Meghalaya, bananas are cultivated over 7,264 hectares, with specific regions like Ri-Bhoi covering 949 hectares and East Khasi Hills spanning 795 hectares. The overall state production amounts to 94,603 metric tons, with Ri-Bhoi contributing 17,614 metric tons and East Khasi Hills contributing 9,074 metric tons (Anonymous 2019). Significant losses occur during the transportation of bananas to markets, primarily due to the ripening process, leading to post-harvest and storage diseases such as anthracnose, crown rot, and cigar end rot, among others.. These diseases pose significant challenges to the marketability and export value of bananas. Anthracnose and crown rot, in particular, emerge as substantial post-harvest concerns for bananas intended for export. The overall quality of the produce is influenced by a combination of environmental factors and both pre- and post-harvest conditions. Banana fruit rot disease results from a combination of fungal genera, comprising *Colletotrichum musae, Musicillium theobromae,, Lasiodiplodia theobromae Nigrospora sphaerica, Cladosporium* sp., *Acremonium* sp., *Ceratocystis paradoxa*, *Penicillium* sp., *Aspergillus* sp., and numerous *Fusarium* spp. (Snehalatharani et al 2021)

The post-harvest fruit rot of bananas is prevalent in Meghalaya and no investigations were conducted on the morphological, cultural and physiological variability of different isolates of *C. musae* collected from diverse agro-ecosystems in the state. The current research was undertaken to evaluate the morphological, cultural, and physiological variations among *C. musae* isolates gathered from both hilly and lowland banana varieties in Meghalaya.

MATERIAL AND METHODS

The ten isolates were acquired from ten diverse market locations in the two districts of Meghalaya, specifically, Ri-Bhoi (Khanapara, Bymihot, Nongpoh, Bhoirymbong, and Umsning) and East Khasi Hills (Bara bazaar, Jalupara, Laitumukrah, Polo bazar, and Sohra) during the year 2019-20. Each of these ten isolates was sourced from distinct banana varieties namely 'Saeel', 'Sahsniang', 'Kait Syiem', 'Kait Khar', 'Kait Mon', 'Borton', 'Kait Kaji', 'Jahaji', 'Malbhog' and 'Chini Champa' (Table 1) and were designated with isolate codes Cm-1 to Cm-10 respectively (Table 2). The banana cultivars 'Saeel,' 'Sahsniang,' 'Kait Syiem,' 'Kait Khar,' 'Kait Mon,' 'Borton,' and 'Kait Kaji' are categorized as hill varieties, whereas 'Jahaji,' 'Malbhog,' and 'Chini Champa' are predominantly found in the lowland regions of Meghalaya, particularly in areas contiguous with Assam. *Colletotrichum musae* isolates were purified on PDA slants and subsequently stored in a refrigerator at 4ºC. Spores of *C. musae* isolates were placed on a clean glass slide. These spores were thoroughly mixed with lactophenol to achieve a uniform spread and then covered with a cover slip. Fifty conidia and acervuli from each of the ten isolates were measured under a high-power objective using an ocular and stage microscope.

The growth characteristics of *Colletotrichum musae* were examined on five solid media, namely, PDA, Czapek's Dox agar (CDA), Oat meal agar (OMA), Richards's agar (RA), and Martin's rose bengal agar (MRBA). The composition of these various media was sourced from "Dictionary of the Fungi" by Ainsworth and Bisby (1961) and "Plant Pathological Methods, Fungi and Bacteria" by Tuite (1969). All the media were sterilized at 121°C for 15 minutes. Then, 20 ml of each medium was poured into individual Petri plates. These plates were inoculated aseptically with a 5 mm disc taken from the outer edge of an actively growing culture. Subsequently, the plates were incubated in the dark at a temperature of 27±2°C for seven days. Every treatment was duplicated three times. Observations were made regarding colony size seven days after inoculation. Details such as colony colour, appearance, shape, zonation, and acervuli production were documented at the same seven-day mark. The data regarding radial growth were then subjected to statistical analysis using SPSS 16.0 software.

The pathogen's growth was assessed at various temperatures, including 4, 15, 27, and 40°C. 20 ml of sterilized PDA medium was dispensed into Petri plates with a diameter of 90 mm. These plates were then aseptically inoculated with a 5 mm disc from a seven-day-old culture of the pathogen. The Petri plates were placed in incubators set at different temperatures, and each treatment was repeated three times. After a seven-day incubation period, observations were made to record the colony diameter. PDA served as the base medium, with its pH adjusted using 0.1N NaOH (alkali) or 0.1N HCl (acid). The pH levels tested ranged from 4.0 to 9.0. The culture was introduced into Petri plates with a diameter of 90 mm, each containing 20 ml of the base medium. These plates were then kept in an incubator at a temperature of 27±2°C for period of 7 days. Three replicates were maintained for each pH level of the medium. Following the 7-day incubation period, observations regarding the colony diameter were documented.

Table 1. GPS coordinates of the surveyed locations

Place of collection	Coordinates
Sohra	25.2702° N, 91.7323° E
Laitumkhrah	25.5707° N, 91.8977° E
Jhalupara	25.5739° N, 91.8701° E
Barabazar	25.5724° N, 91.8745° E
Polo Bazar	25.5812° N, 91.8882° E
Bhoirymbong	25.7095° N, 92.0219° E
Umsning	25.7478° N, 91.8889° E
Nongpoh	25.8699° N, 91.8337° E
Byrnihut	26.0515° N, 91.8696° E
Khanapara	26.1213° N, 91.8208° E

RESULTS AND DISCUSSION

The characteristic symptoms caused by *C. musae* on banana fruits involve sunken lesions that are adorned with acervuli displaying a salmon colour. As the fruits ripen, these sunken areas progress into brown spots with acervuli taking on an orange hue. The average size of the conidia and

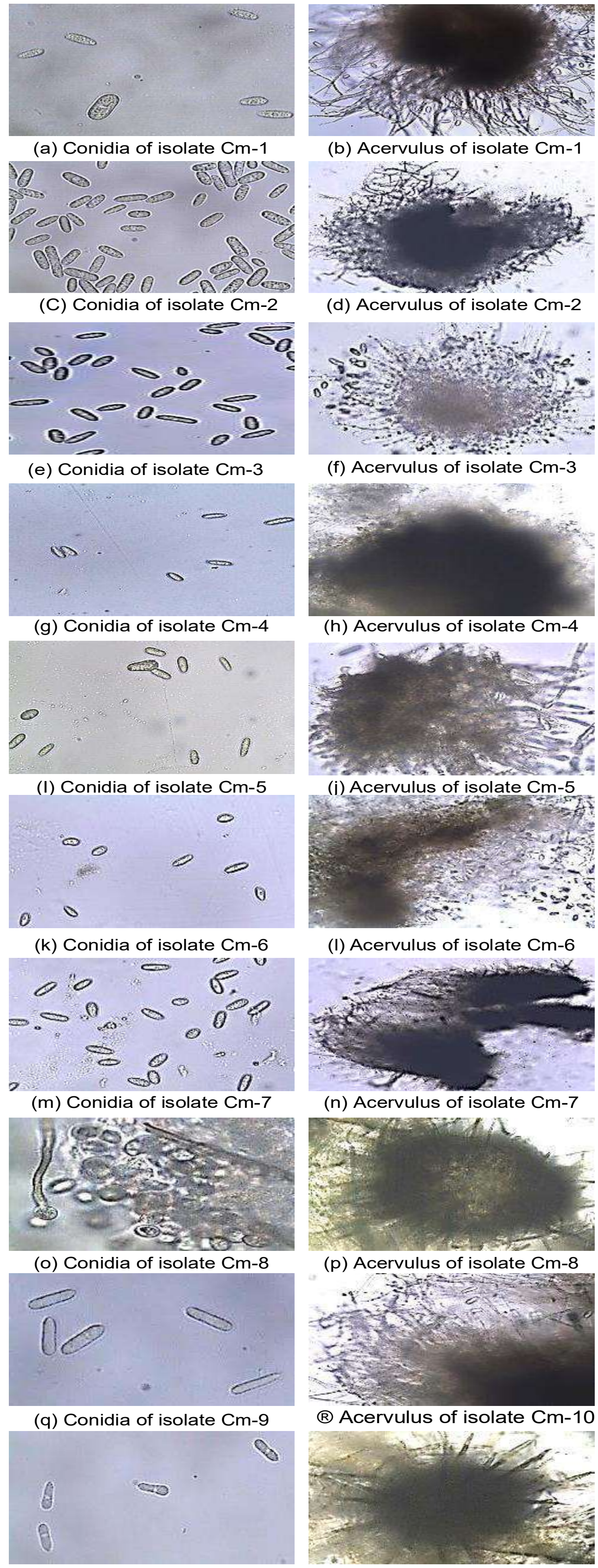
Table 2. Morphological variability among isolates of *C. musae*

Isolate	Place of collection	Variety	Length of conidia (μm)	Breadth of conidia (μm)	Diameter of acervuli (μm)
Cm-1	Sohra	Saeel	7.76	3.59	66.23
Cm-2	Laitumkhrah	Sahsniang	10.77	3.65	67.90
Cm-3	Jhalupara	Kait Syiem	8.83	3.02	66.30
Cm-4	Barabazar	Kait khar	8.07	3.24	68.56
Cm-5	Polo Bazar	Kait mon	9.69	3.36	70.60
Cm-6	Bhoirymbong	Borton	7.25	3.16	53.60
Cm-7	Umsning	Kait Kaji	9.29	3.77	78.99
Cm-8	Nongpoh	Jahaji	7.03	3.61	61.36
Cm-9	Byrnihut	Malbhog	8.74	3.49	60.23
Cm-10	Khanapara	Chini Champa	9.36	3.21	62.35

acervuli of the ten isolates were computed, and photomicrographs were captured to illustrate the typical morphology of the fungus (Fig. 1a-t). The conidia shapes in all *C. musae* isolates were transparent and cylindrical. The size of these conidia ranged from 7.03×3.61 to 10.77×3.65 µm (Table 2). Every *C. musae* isolate generated transparent cylindrical conidia. The acervuli diameter (excluding setae) varied between 53.6 and 78.99 µm (Table 2). Saurabh et al (2023) documented that the conidia were oblong to cylindrical in shape and measured 6 to 18 µm in length and 3 to 6 µm in width. Lim et al (2002) documented aseptate, hyaline, predominantly ellipsoid conidia of *C. musae*. Jagana et al (2017) stated that the conidia size ranged from 11.43 to 16.27 x 3.86-5.47 µm. Saurabh et al (2023) indicated that the acervuli (including setae) measured between 111 to 450 µm in length and 42 to 180 µm in width, with setae dimensions of 82-125 µm in length and 3-5 µm in width. Consequently, the actual acervuli size can be calculated as ranging from 29 to 325 µm, which aligns with the findings of our study. The morphological variations observed in the current study validate the findings of these earlier research studies.

Radial growth, colony colour, appearance, shape, zonation, acervuli production, and consistency of the culture were recorded in the five different media viz., Potato dextrose agar (PDA), Martin's rose bengal agar (MRBA), Oat meal agar (OMA), Richard's agar (RA), Czapek's Dox agar (CDA) following a seven day incubation period. Nearly all the colonies from the isolates displayed a white or salmon-white coloration on OMA, Martin's rose bengal MRBA, CDA and Richard's agar RA. In PDA few isolates exhibited a slightly greyish-white mycelium, while the majority of isolates appeared white even on PDA medium. The average radial diameter was highest in OMA medium, 8.9 cm for the Cm-1 isolate, followed closely by isolates Cm-3 and Cm-5 in PDA medium, with a growth of 8.83 cm (Table 3). Thangamani et al (2011) observed the greatest average colony diameter on PDA medium, followed by OMA medium. Across PDA, OMA, RA, CDA, and MRBA media, the colonies exhibited colours ranging from white to pink for different isolates. The present observations align with the results reported by Thangamani et al (2011).

The growth and development of any pathogen are primarily influenced by temperature and pH of medium. The examination of the growth of the *C. musae* pathogen at varying temperatures indicated a preference for a temperature range between 15 and 27°C across all isolates (Table 4). The majority of isolates exhibited the highest average radial growth at a temperature of 27°C. The fungus displayed no mycelial growth at temperatures of 4°C and 40°C. Unnithan et al (2017) observed peak growth of *C. musae* was at 30°C (9 cm).



(a) Conidia of isolate Cm-1; (b) Acervulus of isolate Cm-1; (C) Conidia of isolate Cm-2; (d) Acervulus of isolate Cm-2; (e) Conidia of isolate Cm-3; (f) Acervulus of isolate Cm-3; (g) Conidia of isolate Cm-4; (h) Acervulus of isolate Cm-4; (I) Conidia of isolate Cm-5; (j) Acervulus of isolate Cm-5; (k) Conidia of isolate Cm-6; (l) Acervulus of isolate Cm-6; (m) Conidia of isolate Cm-7; (n) Acervulus of isolate Cm-7; (o) Conidia of isolate Cm-8; (p) Acervulus of isolate Cm-8; (q) Conidia of isolate Cm-9; ® Acervulus of isolate Cm-10; (s) Conidia of isolate Cm-10; (t) Acervulus of isolate Cm-10

Fig. 1. Conidia and acervuli of *C. musae* isolates

Table 3. Radial Growth (cm) of *C. musae* in different media

Isolate	PDA	RBA	OMA	RA	CDA
Cm-1	8.70^{ab}	6.00^{c}	8.90^{a}	8.23^{bc}	7.8^{b}
Cm-2	8.80^{a}	7.23^{b}	7.77^{de}	8.50^{ab}	7.93^{b}
Cm-3	8.83^{a}	7.40^{b}	7.97^{d}	8.50^{ab}	7.23^{c}
Cm-4	8.07^{c}	8.26^{a}	7.67^{e}	8.80^{a}	8.17^{ab}
Cm-5	8.83^{a}	4.47^{e}	7.70^{e}	7.87^{cd}	7.00^{cd}
Cm-6	7.10^{f}	5.03^{d}	8.60^{b}	8.43^{ab}	6.83^{d}
Cm-7	7.40^{e}	$5.70\pm^{c}$	8.33^{c}	8.80^{a}	8.53^{a}
Cm-8	7.77^{d}	7.13^{b}	7.03^{f}	7.70^{de}	7.00^{cd}
Cm-9	7.00^{f}	4.23^{e}	8.80^{ab}	8.47^{ab}	7.23^{c}
Cm-10	8.50^{b}	4.20^{e}	7.73^{de}	7.40^{e}	6.67^{d}

Table 4. Radial growth (cm) of *C. musae* at different temperatures (*NG= No growth)

Isolate	4°C	15°C	27°C	40°C
Cm-1	NG	4.67^{d}	8.70^{ab}	NG
Cm-2	NG	2.67^{f}	8.80^{a}	NG
Cm-3	NG	4.20^{e}	8.83^{a}	NG
Cm-4	NG	2.90^{f}	8.07^{c}	NG
Cm-5	NG	4.20^{e}	8.83^{a}	NG
Cm-6	NG	5.50^{b}	7.10^{f}	NG
Cm-7	NG	6.60^{a}	7.40^{e}	NG
Cm-8	NG	4.10^{e}	7.77^{d}	NG
Cm-9	NG	5.10^{c}	7.00^{f}	NG
Cm-10	NG	4.07^{e}	8.50^{b}	NG

Table 5. Radial growth (cm) of *C. musae* at different pH levels

Isolate	pH4	pH5	pH6	pH7	pH8	pH9
Cm-1	4.80^{c}	7.53^{bc}	8.93^{a}	8.70^{ab}	8.70^{ab}	5.80^{bc}
Cm-2	4.87^{bc}	8.63^{a}	8.70^{bc}	8.80^{a}	6.50^{d}	6.00^{ab}
Cm-3	2.70^{f}	7.70^{b}	7.97^{d}	8.83^{a}	8.70^{ab}	4.90^{d}
Cm-4	$4.83\pm^{bc}$	5.13^{f}	7.73^{e}	8.07^{c}	4.17^{bc}	5.73^{c}
Cm-5	5.20^{b}	5.60^{e}	8.67^{bc}	8.83^{a}	8.77^{a}	4.70^{d}
Cm-6	3.23^{e}	3.80^{g}	5.63^{g}	7.10^{f}	4.17^{f}	3.60^{f}
Cm-7	4.83^{bc}	5.00^{f}	6.30^{f}	7.40^{e}	4.27^{f}	4.13^{e}
Cm-8	2.87^{f}	3.63^{g}	5.40^{h}	7.77^{d}	8.37^{c}	6.10^{a}
Cm-9	3.60^{d}	6.87^{d}	8.60^{c}	7.00^{f}	4.83^{e}	2.20^{g}
Cm-10	6.10^{a}	7.33^{c}	8.83^{ab}	8.50^{b}	4.67^{e}	1.90^{h}

The isolate Cm-1 exhibited the highest growth at pH 6 (8.93 cm) followed by isolates Cm-3 and Cm-5 at pH 7 (8.83 cm). Consequently, pH levels 6 and 7 were identified as the optimum range for the favourable growth of *C. musae.* Isolate Cm-10 displayed the minimal radial growth (1.9 cm) at pH 9, while Cm-3 exhibited the least growth (2.7 cm) at pH 4. pH levels below 6 and above 8 were unsuitable for the optimal growth of the fungus (Table 4). Jagana et al (2017) documented the highest dry mycelial weight of *C. musae* at pH 6.0 (398 mg), which was comparable to pH 7.0 (383 mg), followed by 8.0 (377.33 mg). Similarly, Yang et al (2000) observed that the peak growth and spore germination of *C. musae* occurred at pH 6 and 7, respectively.

CONCLUSION

Oat meal agar and potato dextrose agar were the optimal substrates for the proliferation of *Colletotrichum musae*. Additionally, the research identifies the optimal thermal range for the growth and development of the fungus to be between 15 and 27°C, while temperatures of 4 and 40°C inhibit its growth. The fungus exhibits optimal survival at a neutral pH range of 6-7, with growth cessation occurring at pH levels outside this range. Future research could explore the genetic and biochemical responses of the fungus to varying temperatures and pH levels which could provide insights into its adaptability and resilience at various climatic conditions. Additionally, developing more effective control strategies for managing *Colletotrichum musae* in agricultural settings could benefit from these findings, particularly by manipulating environmental conditions for storage and transportation of the fruits from fields to the markets to inhibit fungal growth.

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Indian Journal of Ecology (2024) 51(4): 905-911
DOI: https://doi.org/10.55362/IJE/2024/4329

Manuscript Number: 4329
NAAS Rating: 5.38

Impact of Weather Variables on Severity and Progression of Powdery Mildew on Rapeseed-mustard in Haryana

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Abstract: Powdery mildew is a major devastating disease rapeseed-mustard causing significant reduction in yield as well as quality. Present investigation was under taken to study the impact of weather variables on disease severity and progression of powdery mildew. The maximum disease intensity was in variety Varuna (51.3%) followed by RH-30 (46.0%). The minimum disease intensity was in varieties HC-9002 and YSPb-24 (17.3%). Powdery mildew intensity on pods was also maximum on Varuna (36.7%) and minimum was on GSH-1. The minimum speck size was in the variety GSH-I (2.87mm) whereas maximum in RH-9304 (5.20mm) whereas in all other varieties, speck size ranged between 3.40 to 4.67 mm. The progression was maximum up to the mid of March and there after progression was slowed down. At the end of Marchm progression was static in all the varieties. Temperature (maximum) and relative humidity (morning) played pivotal role on the severity and progression of powdery mildew disease on leaves. The R^2 values were observed in the range of 0.70 to 0.92 indicating that most of the weather variables contributed significantly in powdery mildew progression.

Keywords: Powdery mildew, Weather variables, Severity, Rapeseed-mustard, Progression

Oilseeds cultivation is undertaken across the country in about 29.17 million ha, largely under rainfed areas covering 72 percent and producing around 37.70 million tonnes of oilseeds. In India, area, production and yield of rapeseed and mustard was 29.17 million ha, 37.70 million tonnes and 1292 kg/ha in *rabi* 2022-23, respectively (Anonymous 2023).The average productivity of Indian mustard in India is very low as compared to the developed countries. There is wide gap between the potential and the realized yield at the farmers' field, which is affected by number of biotic and abiotic stresses. The fungal foliar diseases are one of the major factors. Among them, white rust [*Albugo candida* (Pers.) Kuntze], alternaria blight [*Alternaria brassicae*(Berk.) Sacc.], downy mildew [*Peronospora parasitica*[Pers. ex. Fr.) Fr.], powdery mildew (*Erysiphe cruciferarum* Opiz. ex. Junell) and sclerotinia rot [*Sclerotinia sclerotiorum* (Lib.) de Bary)] are the most important diseases. Powdery mildew of rapeseed-mustard, caused by *Erysiphe cruciferarum* result in significant yield losses, sporadically, depending on the prevailing weather conditions (Meena et al 2014, Singh et al 2024). This disease was minor importance, but in the recent years, became widespread throughout the mustard growing regions of India. The meagre information is available on severity of six genera of *Brassica* (*Brassica juncea*, *B. campestris* var. yellow sarson, *B. campestris* var. brown sarson, *B.carinata*, *B. Napus* and *B. alba*) in India. The main objectives of the present investigations were to study the effect of environmental factors on severity and progression of these foliar diseases.

MATERIAL AND METHODS

The field experiments were conducted CCS Haryana Agricultural University, Hisar, India, which is situated in the subtropics at latitude 29°10'N and longitude 75°46'E with elevation of 215.2 meters above the mean sea level. These experiments were laid out in a randomized block design with three replications and plot size 1.8x2 m^2. The crop was raised in field keeping row to row distance 30 cm and plant to plant of 15 cm. Ten varieties (RH-9801, RH-30, RH-9304, RH-781, Varuna, YSPb-24, BSH-1, HC-9002, GSH-1and *B. alba*) belonging to six genera *viz*., *Brassica juncea, B. compestris* var. yellow sarson, *B. compestris* var. brown sarson, *B. napus, B. Carinata* and *B. Alba* were grown. Recommended agronomic practices were adopted (Anonymous 2021). Weather data were obtained for periods from the observatory of Department of Agriculture Meteorology, CCS, Haryana Agricultural University, Hisar, Haryana (India). Daily maximum temperature (X_1), minimum temperature (X_2), evaporation morning (X_3), evaporation evening (X_4), relative humidity morning (X_5), relative humidity evening (X_6), wind speed (X_7), sunshine (X_8) and rainfall (X_9) and the average data were used for analysis. Data were analysed statistically using SAS 9.3 software (SAS Institute Inc., Cary, USA).Data on severity of powdery mildew was recorded by recommended rating scale (0-9) of AICRP-RM on ten randomly selected leaves from each plot/replication at regular intervals till the maturity of the crop. The percent disease intensity was calculated McKinney (1923). Disease progression in terms of pustule size, spot size and speck size (mm) were measured with the help of scale on each cultivar after appearance of the disease on ten randomly selected tagged leaves at four days intervals till the maturity of the leaves.

$$DI\,(\%) = \frac{\text{Sum of all numerical rating}}{\text{Total number of leaves assessed x Maximum disase grade}} \times 100$$

RESULTS AND DISCUSSION

Symptomatological studies of powdery mildew: Powdery mildew appeared in the form of dirty white floury patches on both sides of leaves as well as on the pods. With the increase in time, the floury patches increased in size and coalesced to cover the entire leaves, pods, and stem (Fig. 5A-F). The green pods showed white patches in the initial stage of infection. Later, such pods were completely covered with white mass of mycelium and conidia (Fig. 5 C-D). Pods heavily covered with powdery mass remained empty or produce few seeds at base with twisted sterile tips. In the end of season, cleistothecia appeared on the both sides of infected leaves, stem, and pod. Powdery mildew symptoms were seen at different stages of the plant growth. Symptoms occurred in the initial stages in the case of rapeseed-mustard, jasmine, little gourd and ber. Based on the morphological studies of the pathogen mycelium of the fungus is amphigenous, white, septate spreading and persistent. Conidia are hyaline, borne singly or in short chain measuring 48.90x24.90µm in size and cylindrical in shape (Nayak et al 2023 and Saharan et al 2019). Conidia germinate only from one end the germ tube. Conidiophore length is 116.25µm. Perithecia scattered, globose at first yellowish orange, becoming brown to dark brown and black with maturity, 90-130µm in diameter (Table 1). Kumar et al (2015) also reported that conidia are hyaline, borne singly or in short chain measuring 25-45x12-16µm in size and cylindrical in shape. Conidia germinate only from one end the germ tube. Nanjundan et al (2020) reported that disease was recorded on all the plant parts leaves, stem, branches, and siliquae were covered with larger colonies *of E. cruciferarum*. A total of 996 accessions were found 'moderately susceptible' exhibiting heavy infection on leaves, stem, and branches and 11 entries were found as 'highly susceptible.

Role of weather variables on the severity of powdery mildew: Disease intensity of powdery mildew on leaves were maximum in Varuna (51.3%) followed by RH-30 (46.0%). The minimum disease intensity was in HC-9002 and YSPb-24 (17.3%) but there were no significant differences between varieties RH-9801 and RH-9304 in relation to powdery mildew intensity. However, the disease did not appear on *B. Alba* (Table 3). Similarly, the maximum disease intensity on pods was on Varuna (36.7%) (Table 2). Mir et al (2023) revealed that powdery layer of white spores is a common appearance of most powdery mildews and some notable examples are powdery mildew of *Brassica* (*E. cruciferarum*), powdery mildew of grasses and cereals (*Erysiphe graminis*) and gooseberry (*Sphaerotheca morsuvae*). Crucifer powdery mildew disease is caused by *E. cruciferarum*. *Erysiphe* spp. which infects all leaves, stems, and siliques, significantly reduces *Brassica* crop yields by lowering plant growth and seed development. There are number of weather variables which are very crucial to influence the powdery mildew development in to epidemic form with host pathogen

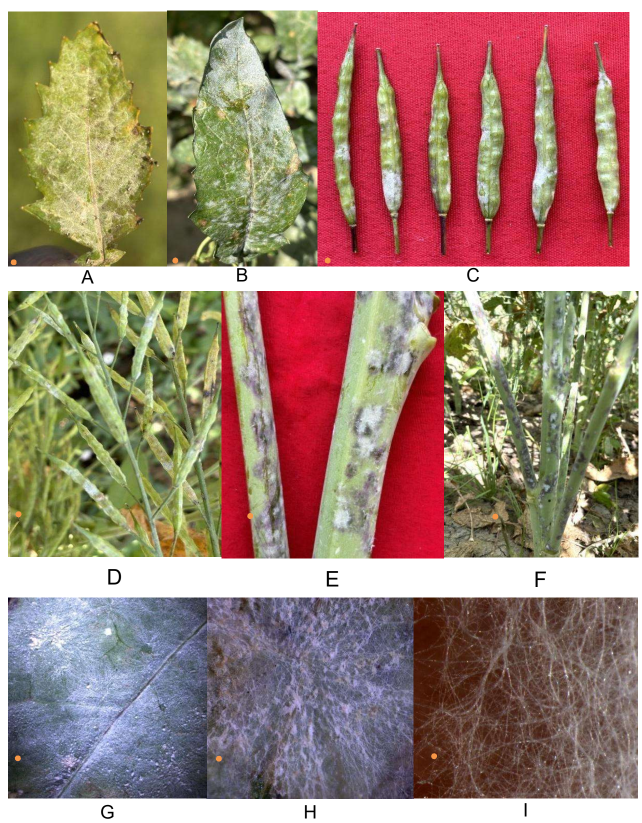

Fig. 1. A-B) Symptoms of powdery mildew on leaves; C-D) on siliqua; E&F) on stem and branches; G-I) Magnification showing hyphal network of powdery mildew on *Brassica juncea*

interaction. Maximum temperature in the range of 27.9-32.1°C was most favourable for disease development. Minimum temperature in the range of 8.7-12.8°C during March favoured severity of disease. Morning and evening relative humidity in the range of 90.6-91.3 percent and 32.4-37.3 percent was most appropriate for disease development after with increase in morning and evening relative humidity disease showed decreasing trend (Table 2). Nayak *et al* (2023) reported that percent disease index (PDI) of powdery mildew was positively correlated with the maximum and minimum temperature whereas, it was negatively correlated with maximum RH, minimum RH and rainfall in Indian mustard varieties Ganga, Varuna, Giriraj and RH-0749. Mehta (2019) reported that epidemic development of powdery mildew under field conditions, moderate temperature, low humidity, minimum rainfall, or dry season during February and March are more favourable in Haryana. Mean temperature between 16-28^{o}C, mean RH below 60 percent and low or no rainfall are the most congenial weather factors for the development of the disease under field conditions.

Role of different weather variables on the progression of powdery mildew: Disease appeared in all varieties in the first week of March except *B. alba* (disease did not appear). The minimum speck size was in GSH-I (2.87mm) whereas maximum in RH-9304 (5.20mm) whereas in all other varieties, speck size ranged between 3.40 to 4.67 mm. The progression was maximum up to the mid of March and there after progression was slowed down. At the end of March progression was static in all the varieties, but, disease progressed well in the staggering dates of observations and reached maximum in the end of crop season (Table 3). Manmohan and Mehta (2016) reported that progression of powdery mildew on both varieties (Varuna and RH-9801) with four dates of sowing and both pacing (30 × 15 cm and 45 × 20 cm) showed that the maximum speck size 5.39 mm In variety RH-9801, also the speck size increased with delay in date of sowing in both the spacing. The minimum progression of spot size 1.00 mm was observed in pacing 30 × 15 cm in the beginning of disease appearance which reached to maximum speck size 5.39 mm in pacing 30 × 15 cm at the end of observations.

Regression analysis between disease progression and weather variables: The most of weather variables were the major determinants in the disease progression and showed the variability in disease progression due to different weather

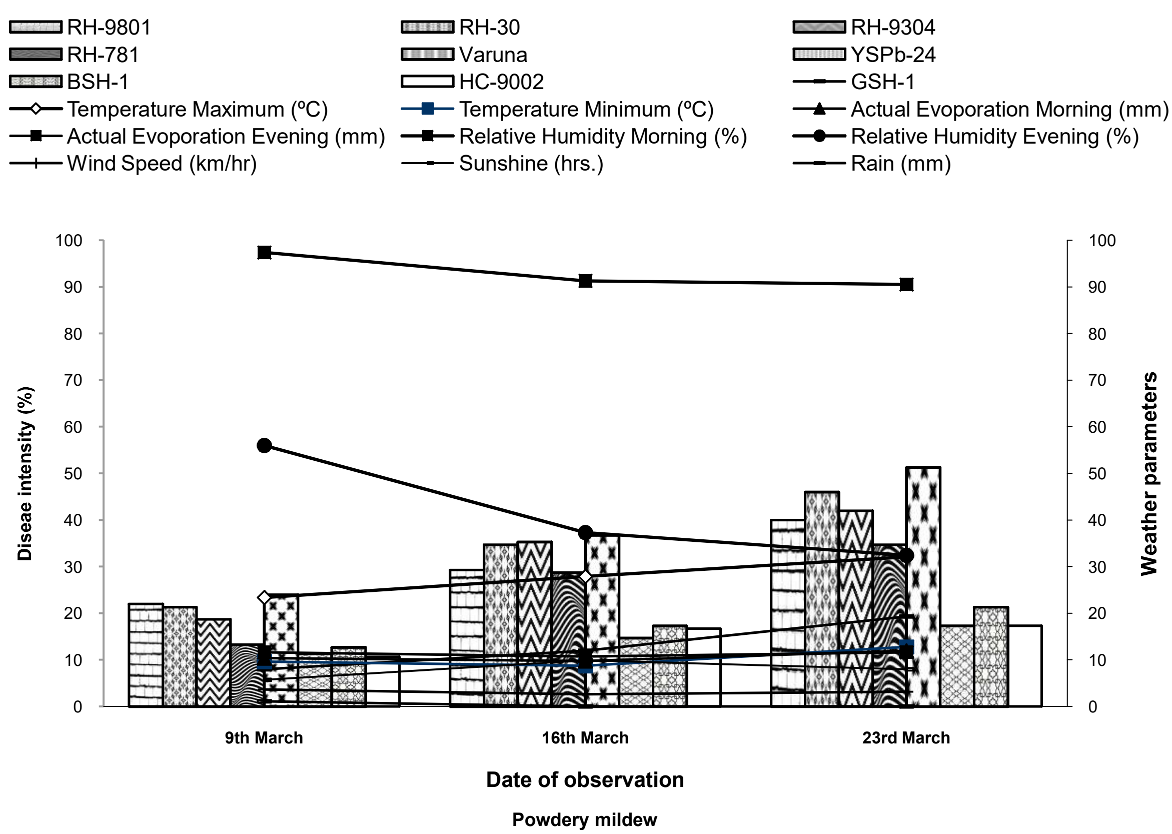

Fig. 2. Disease intensity (%) of powdery mildew on different cultivars of Indian mustard in relation to weather variables

parameters. The maximum R^2 *i.e.* 0.92 was on RH-30 followed by Varuna, YSPb-24 and minimum was on BSH-1 which indicated that in addition to weather variables included here other factors such as varietal resistance and some unknown factors have significant role in the disease development. The BSH-1 and *B. alba* appeared as resistant to powdery mildew with the expression of slow mildewing components whereas other varieties belonging to *B. junecea* group appeared as susceptible to the disease showing faster powdery mildew development under field conditions (Table 4). Razdan et al (2012) found maximum temperature, morning relative humidity and rainfall influence the disease incidence which is in corroboration with the present findings. Talukdar et al (2017) concluded that decrease of evening relative humidity and bright sunshine hours during the growing period aggravated the disease in late sown crops.

Correlation matrix between disease progression and weather variables: The temperature (maximum) had significant positive role in the progression of powdery mildew on all the varieties/cultivars except BSH-1, where it was positive but non-significant. Similarly, relative humidity (morning) also had significant and positive role in the disease progression on all the varieties/cultivars except *B. alba* (disease did not appear). Sunshine has negative and significant correlation in all the varieties. Other weather variables such as temperature minimum, relative humidity (evening), and average evaporation (evening) had positive but non-significant correlation in disease progression on all

Table 1. Description of symptoms and morphological characters of powdery mildew on *Brassica* sp

Symptoms on plant and stage	:	Circular to irregular patches on the upper surface leaves, flowering and siliqua
Genera	:	*Erysiphe cruciferarum*
Host	:	*Brassica* spp.
Mycelia	:	Amphigenous white
Conidia and conidiophores morphology	:	Oblong to cylindrical or oval borne conidia singly or in short chains. cylindrical composed of 3-4 cells
Germ tube and appressorium	:	Simple (non-forked) emerging apically or basally
Fibrosin bodies	:	-
Conidial size(µm)	:	Length: 48.90µm,Width: 24.90µm
Conidiophore length (µm)	:	116.25
Foot cell length	:	41.20

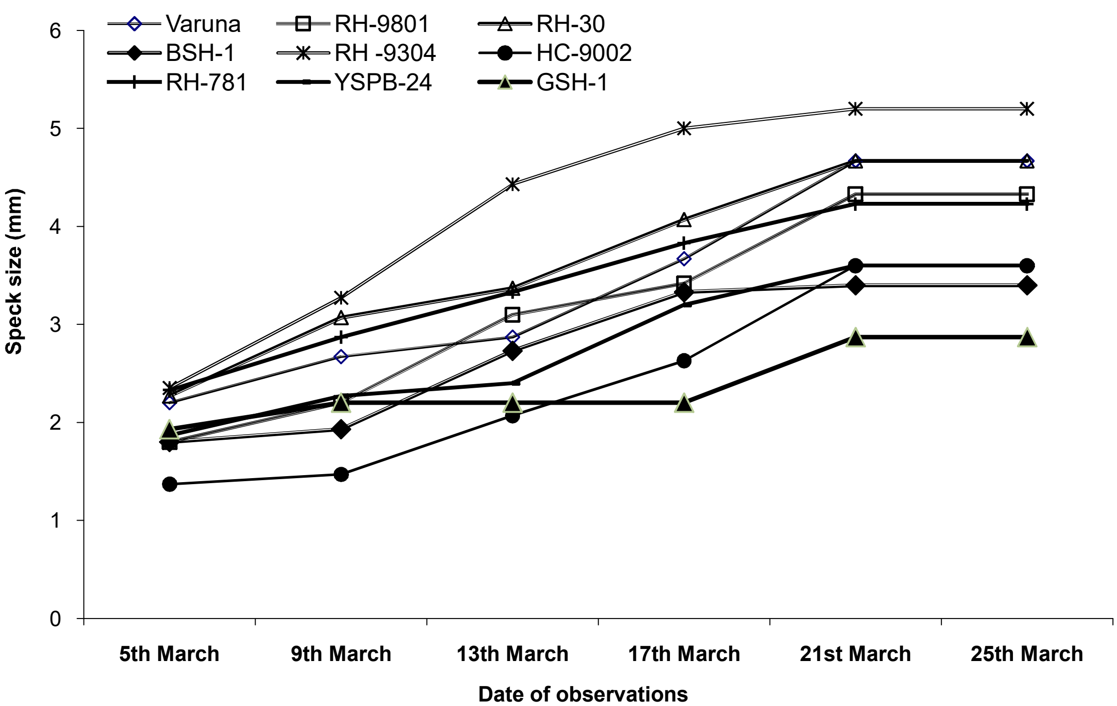

Fig. 3. Progression of powdery mildew on nine cultivars of rapeseed-mustard

Table 2. Effect of weather parameters on the severity (%) of powdery mildew on different varieties of rapeseed-mustard

Disease	Date of observations	Weather variables							Disease severity (%)									
		Temp. ºC max.	Temp. ºC min.	RHM%	RHE%	WS (km/hr)	SS (hrs.)	Rain (mm)	RH-9801	RH-30	RH-9304	RH-781	Varuna	YSPb-24	BSH-1	HC-9002	GSH-1	CD at 5%
Powdery mildew on leaves	09th March	23.4	9.6	97.4	56.0	3.7	5.7	1.1	22.0	21.3	18.7	13.3	24.0	11.3	12.7	10.7	8.0	4.7
	16th March	27.9	8.7	91.3	37.3	2.6	9.9	0.0	29.3	34.7	35.3	28.7	36.7	14.7	17.3	16.7	12.0	3.4
	23rd March	32.1	12.8	90.6	32.4	3.2	8.0	0.0	40.0	46.0	42.0	34.7	51.3	17.3	21.3	17.3	19.3	1.9
	Mean	27.8	10.4	93.1	41.9	3.1	7.9	0.4	30.4	34.0	32.0	25.6	37.3	14.4	17.1	14.9	13.1	3.3
Powdery mildew on pods	20th March	31.90	12.10	89.00	34.00	3.70	8.20	4.60	22.00	21.30	18.70	13.30	24.00	11.30	12.70	10.70	8.00	4.70
	29th March	32.00	13.30	84.00	35.00	5.20	8.90	10.30	29.30	34.70	35.30	28.70	36.70	14.70	17.30	16.70	12.00	3.40
	Mean	31.95	12.70	86.50	34.50	4.45	8.55	7.45	25.65	28.00	27.00	21.00	30.35	13.00	15.00	13.70	10.00	4.05

Table 3. Effect of weather variables on cumulative and periodical progression of powdery mildew specks size (mm) on cultivars of rapeseed-mustard

Date of observations	Weather variables							Periodical Progression of powdery mildew								
	Temp. max. (ºC)	Temp. min. (ºC)	RH M. (%)	RH E. (%)	WS (km/hr)	SS (hrs.)	Rain (mm)	RH-9801	RH-30	RH-9304	RH-781	Varuna	YSPb-24	BSH-1	HC-9002	GSH-1
5th March	20.03	10.63	100.00	80.00	3.40	1.13	1.65	1.8	2.27	2.35	2.33	2.2	1.87	1.8	1.37	1.93
9th March	25.10	8.88	95.50	42.50	3.83	8.90	0.33	2.20 (0.40)*	3.07 (0.80)	3.27 (0.92)	2.87 (0.54)	2.67 (0.47)	2.27 (0.40)	1.93 (0.13)	1.47 (0.10)	2.20 (0.27)
13th March	26.13	7.85	89.50	37.25	2.95	9.83	0.00	3.10 (0.90)	3.37 (0.30)	4.43 (1.16)	3.33 (0.46)	2.87 (0.20)	2.40 (0.13)	2.73 (0.80)	2.07 (0.60)	2.20 (0.00)
17th March	30.50	10.70	94.75	37.75	2.08	9.88	0.00	3.42 (0.32)	4.07 (0.70)	5.00 (0.57)	3.83 (0.50)	3.67 (0.80)	3.20 (0.80)	3.33 (0.60)	2.63 (0.56)	2.20 (0.00)
21th March	33.05	14.20	87.00	33.25	3.38	6.93	0.00	4.33 (0.91)	4.67 (0.60)	5.20 (0.20)	4.23 (0.40)	4.67 (0.10)	3.60 (0.40)	3.40 (0.07)	3.60 (0.97)	2.87 (0.67)
25th March	30.98	11.28	88.50	36.50	4.13	9.15	1.15	4.33 (0.00)	4.67 (0.00)	5.20 (0.00)	4.23 (0.00)	4.67 (0.00)	3.60 (0.00)	3.40 (0.00)	3.60 (0.00)	2.87 (0.00)

*Periodical progression

the varieties/cultivars (Table 6). Mehta (2019) reported that number of environmental factors which are very crucial to influence the powdery mildew development of crucifers in to epidemic form after host-pathogen interaction. To cause the infection in susceptible host after landing of pathogen conidia on host surface their germination and formation of appressoria is maximum between 15-20°C temperatures.

CONCLUSIONS

The maximum disease intensity was recorded in variety Varuna followed by RH-30. The minimum disease intensity was in varieties HC-9002 and YSPb-24 .The, temperature (maximum) and relative humidity (morning) played pivotal role in development powdery mildew disease. The coefficient of determinants (R^2) indicated that weather variable splay significant role in powdery mildew development and progression. The meteorological parameters can be used to develop weather-based disease prediction model which can be very helpful for issuing disease forewarning so that necessary precautions can be taken to manage disease incidence.

Table 4. Regression equation for the progression of powdery mildew on various mustard varieties in relation to weather parameters

Varieties	Regression equation	R^2
RH-9801	$Y= -14.50+0.52X_1-0.11X_7$	0.80
RH-30	$Y= -20.30+0.76X_1-0.12 X_7$	0.92
RH-9304	$Y=-16.10+0.52X_1-0.10 X_7$	0.80
RH-781	$Y= - 11.30+0.45X_1-0.10 X_7$	0.81
Varuna	$Y= -17.11+0.65X_1-0.11 X_7$	0.87
YSPb-24	$Y= - 10.60+0.45X_1-0.06 X_7$	0.85
BSH-1	$Y= - 8.90+0.40X_1-0.05 X_7$	0.70
HC-9002	$Y= - 10.10+0.39X_1-0.05 X_7$	0.80
GSH-1	$Y= - 0.80+0.80X_1-0.01 X_7$	0.74
B. alba	Disease did not appear	

X_1 = Temperature (Maximum); X_5 = Average Evaporation (Morning)
X_2 = Temperature (Minimum); X_6 = Average Evaporation (Evening)
X_3 = Relative Humidity (Morning); X_7 = Wind Speed
X_4 = Relative Humidity (Evening); X_8 = Sunshine

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Table 5. Correlation matrix between powdery mildew (speck size, mm) and weather parameters in mustard varieties

Weather variables	RH-9801	RH-30	RH-9304	RH-781	Varuna	YSPb-24	BSH-1	HC-9002	GSH-1	*B. alba*
T. maximum (X_1)	0.90*	0.92*	0.92*	0.90*	0.95*	0.68	0.88*	0.91*	0.65	-
T. minimum (X_2)	0.42	0.41	0.42	0.45	0.42	0.63	0.45	0.43	0.60	-
Av. Evap. morning (X_3)	0.61	0.55	0.59	0.61	0.58	0.54	0.65	0.63	0.50	-
Av.Evap. evening (X_4)	-0.83*	-0.85*	-0.84*	-0.82*	-0.85*	-0.68	-0.82*	-0.84*	-0.68	-
RH morning (X_5)	0.82*	0.82*	-0.82*	0.83*	0.82*	0.88*	0.82*	0.83*	0.85*	-
RH evening (X_6)	0.25	0.28	0.26	0.25	0.28	0.20	0.25	0.27	0.20	-
Wind speed (X_7)	-0.64	-0.63	-0.26	-0.63	-0.63	-0.48	-0.64	-0.64	-0.48	-
Sunshine (X_8)	-0.79*	-0.70	-0.78*	-0.81*	-0.72	-0.80*	-0.81*	-0.75*	-0.82*	-

-Disease did not appear

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Received 22 April, 2024; Accepted 15 July, 2024

Indian Journal of Ecology (2024) 51(4): 912-920
DOI: https://doi.org/10.55362/IJE/2024/4330

Manuscript Number: 4330
NAAS Rating: 5.38

Status of Temporary Wetland of Paddy Field Associated Molluscs of Coastal Karnataka: A Case study

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Abstract: Freshwater molluscs contribute to the ecosystem by increasing soil fertility and nutrient cycling. The study was designed to estimate the diversity and abundance of molluscs from the coastal paddy fields of Karnataka state of India. Six paddy fields of Karnataka state were selected for the study from June-November 2017 and 2018 whereas the paddy field of Marlimar was surveyed from June 2017-April 2018, June 2018-March 2019 as the paddy cultivation occurs up to two cropping cycles. Presence of *Idiopoma dissimilis, Indoplanorbis exustus, Physella acuta, Pila virens* and *Racesina luteola* was observed from paddy fields. *P. virens* and *I. exustus* were in most of the paddy fields of coastal Karnataka. Abundance of snails increased in the initial months of cropping and declined towards the harvest of the paddy. Snail diversity was highest in the paddy field of Marlimar and least in Mattu. pH of water ranged between 3.54 and 8.53, Electrical conductivity 3.89-1136µS/m, soil pH 3.07-7.08, and soil organic carbon 0.06-3.51%. Significant difference in salinity, the electrical conductivity of water and soil organic carbon was observed between the paddy fields. Precipitation, pH of soil and water correlated significantly with diversity of snails. Paddy fields, due to their unique ecological conditions and water holding capacity are suitable habitats for the snails. They are heterogeneous habitats providing space, shelter, and food for the survival of snails. Sustainable management of paddy fields is required to conserve the snail species associated with them.

Keywords: Snails, Karnataka, Abundance, Species richness, Management

Paddy fields are temporary man-managed wetlands, constitute 18% of the global wetlands. They are the unique agroecosystems and provide shelter for different aquatic organisms (Lawler 2001). Ecosystem services provided by paddy fields include production of non-rice foods, climate-change mitigation, groundwater recharge, flood control, soil erosion and landslide prevention, water purification, support other ecosystems and biodiversity (Natuhara 2013). In India, two cropping seasons of rice are followed based on monsoon. The *kharif* cropping season is from June-October during the south west monsoon and the *rabi* crop is from November-March (winter). Paddy fields are the only ecosystems that come across aquatic, semi-aquatic and terrestrial phases during a single cultivation cycle. They experience wet phase during the cropping and dry phase at the end of cropping period. Paddy fields remain interconnected with each other through the ditches, water ways favours the growth of variety of fauna. Molluscs are the primary consumers in the food chain, help in nutrient cycling, and decomposition of organic matter thus enhancing the soil fertility (Stripari and Henry 2002, Jong Song et al 2018).

The studies that document the diversity of snails paddy fields of India and Karnataka state are limited (Gopalan et al 2014, Narasimhaiah et al 2014, Vineetha et al 2015, Vineetha 2016). Environmental factors affecting the snail diversity of freshwater habitat areas are documented from different parts of the world (Nakanishi et al 2014, Bay and Park 2020). There are no adequate number of studies addressing the paddy field snail diversity of coastal Karnataka and factors governing the diversity of snails in paddy fields are not known. Although paddy fields are artificial wetlands the lack of knowledge on the patterns of species richness brings the urgent need for studies to provide scientific support to biodiversity management and conservation programs. Considering these points the study was designed to document the snail diversity in the paddy fields of coastal Karnataka.

MATERIAL AND METHODS

Coastal Karnataka is the stretch of land along the Arabian Sea in the Karnataka state of India. It has an average width of 50-80 km and is surrounded by the Western Ghats and is known for the production of rice. To compare snail diversity between the paddy fields of coastal Karnataka six sampling sites were chosen (Table 1). Site selection was based on the number of crops, soil type (Sandy, muddy and clayey) and irrigated/non-irrigated paddy fields. Paddy fields at a distance of at least 20 km from each other were selected.

Marlimar: It is 3 km away from the city of Panemangaluru in the Malnad district of Dakshina Kannada. This site is 27 km away from the seashore and surrounded by arecanut plantations. Clayey type of soil is present. Aquatic plants such as *Eichornia, Hydrilla,* and *Chara* can be seen in this paddy field. This paddy field undergoes two cropping cycles *kharif* and *rabi*. *kharif* crops are cultivated at the onset of rainfall whereas *rabi* crop depends on irrigated water.

Pavanje: It lies on the border of Dakshina Kannada and Udupi districts. This paddy field is situated 1km away from the seashore and is composed of muddy and sandy soil. Aquatic weeds and grasses were observed during the study.

Santoor: This is present in the southern part of the Udupi district and a coal-based thermal power plant (Udupi Power Corporation Limited) is situated in this region. The paddy field selected for the study is 1.5 km away from the thermal power plant. The paddy field consists of clayey soil with fine particles. The cultivation of rice is entirely dependent on rainwater. Aquatic weeds, grasses, algae, and plants like *Pistia, Vallisneria* are found in the paddy fields.

Mattu: It lies towards the north of Santoor at a distance of 17 kms from Santoor and paddy fields are 250 m away from the seashore. These paddy fields are situated adjacent to the path of the Pangala river which joins the Arabian Sea. Soil is blackishly intermixed with sand particles. *Chara, Vallisneria,* and grasses were seen in this paddy field. Concretised earthen ditches were present in these paddy fields which help in the regulation of water flow to other paddy fields.

Sastan: It is situated in the northern region of the Udupi district. The selected paddy fields of Sastan are 2 km away from the seashore. The fields contain sandy and muddy soil and are surrounded by coconut plantations. A passage in the form of earthen ditches was found in this paddy field.

Trasi: It lies in the northern end of Udupi district and is 200 m away from the seashore. The paddy fields are composed of muddy soil combined with many sand particles. Paddy fields are situated nearer to national highway 66. Paddy cultivation in this site is entirely dependent on rainfall.

Experimental details: 10 kg of fertilizers will be used twice during the cropping in the paddy fields. Water inundation in the paddy fields is the phase of inundating paddy fields with water before planting the crop till the end of the growth phase of paddy. It is generally started 15 days before the planting paddy and continued up to three months. The paddy field of Marlimar gets inundated with water for 6 months including both the cropping cycles whereas in other paddy fields water inundation takes place for 3 months.

Table 1. Location of sampling sites in coastal Karnataka

Sampling sites	GPS location
Marlimar	12°51'58.51"N, 75° 3'35.27"E
Pavanje	13° 2'14.02"N, 74°47'32.82"E
Santoor	13º 09' 42"N, 74º 49' 27.3"E
Mattu	13°15'43.90"N, 74°43'52.56"E
Sastan	13°28'8.77"N, 74°42'46.18"E
Trasi	13°41'32.44"N, 74°38'48.17"E

Sampling procedure: The paddy fields were visited on monthly basis and the sampling was carried out in a *kharif* cropping season from June to October 2017, 2018. To check the presence or absence of snails after the first crop was documented by sampling in November 2017, 2018. The paddy field of Marlimar was visited during from June 2017-April 2018, June 2018-March 2019 for two cropping cycles whereas other paddy fields were visited during the first cropping cycle as only a single crop was in practice. During every sampling, 21 quadrates of 50cm×50cm were scattered in each paddy field randomly the so that entire area of the paddy field at each site has an equal probability of sampling (Schoenly et al 2003). Snails were collected from each of the paddy fields and brought to the laboratory. Snails were preserved in 70% ethanol and identified using standard identification keys of Ramakrishna and Dey (2007). The abundance of snails is represented in the form of a percentage. Species richness is the number of species per quadrate.

Precipitation data of the study period was obtained from the Giovanni data system of NASA GES DISC. The paddy fields were visited between the interval of 8 A.M-11 A.M (IST) and 4 P.M-6 P.M (IST). The air temperature was measured in the field by holding the digital thermometer (SKU: TP-101 model, Ravi scientific industries) to air. Water temperature was measured by placing the digital thermometer inside the water samples. About 500 ml of water samples were collected from each paddy field and brought to the laboratory. Physico-chemical parameters of water such as electrical conductivity, pH and salinity have been analyzed in the laboratory (for 20 ml of water in each trial) using Systronics water analyzer 371 (Sripathy and Naveen Chandra 2014). About 0.5 kg of soil samples were collected from the paddy field, air-dried, powdered in the laboratory. Electrical conductivity, pH, and organic carbon of the soil were analyzed by standard protocols (Smith and Doran 1996).

Statistical analysis: Species diversity was calculated by the Shannon-Weiner index, species richness by Margalef's index, species evenness by Pielou's evenness index using PAST software version 2.17c. Shannon–Wiener diversity index (1949). Shannon–Wiener diversity index takes into account species richness and their evenness in an area.

Shannon – Wiener diversity index $H = -\Sigma\, pi \ln (pi)$ where $pi = S / N$

S = number of individuals of one species
N = the total number of all individuals in the sample
ln = logarithm to base e.
Margalef's index = (S – 1) / ln N
S = total number of species, N = total number of individuals in the sample, ln = natural logarithm

The value ranges from 0-1, 0=least number of species, 1=highest number of species in a community. For calculating the evenness of species, the Pielou's Evenness Index (e) was calculated as.

e = H / ln S

H = Shannon – Wiener diversity index, S = total number of species in the sample

Evenness refers to uniformity in species distribution. The evenness index ranges between 0-1, with 0 being no evenness and 1 being complete evenness.

Bray Kurtis similarity analysis was carried out using PAST software. As the data showed non normal distribution Kruskal-Wallis Test and Spearman correlation test were carried out. To find the significant differences if any, in species diversity and physicochemical parameters of soil and water between the sites, Kruskal-Wallis Test was performed. The influence of physicochemical parameters on snail abundance and species richness was studied using multivariate generalised linear model analysis. Relationship between species diversity and physicochemical parameters was determined by the Spearman correlation test. The data were analyzed statistically using SPSS version 21.

RESULTS AND DISCUSSION

Diversity and distribution of snails in paddy fields: Five species of snails belonging to 5 families and 5 genera were observed from paddy fields of Udupi and Dakshina Kannada districts (Fig. 1). They are *Idiopoma dissimilis, Indoplanorbis exustus*, *Physella acuta, Pila virens and Racesina luteola*. *P. virens* is the pest of paddy, showed ubiquitous distribution (Table 2). *I. exustus* was more in number in most of the study sites. *P. acuta* (80%) was abundant in the paddy field of Marlimar and *P. virens* (45%) dominated in the paddy field of Pavanje.

Among the total number of individuals of snails collected from the rice field of Marlimar during the first cropping cycle, the abundance of snails increased from June and was at a peak in August in the years 2017 and 2018 (Table 3). Snail abundance was more in the rice field of Pavanje in July. On the contrary, the number of snails subsided in the fields of Santoor and Trasi from June to September. The number of snails declined in all the paddy fields during the reproductive phase of the paddy. The number of species increased from June to September and lessened towards the harvest (Fig. 2). Species richness was highest in the paddy field of Marlimar (Table 1). Species like *P. virens* and *I. exustus* were abundant in earthen ditches and found feeding on aquatic plants in paddy fields of Mattu, Trasi and Marlimar.

The changes occurred in snail diversity in paddy fields in November. Among the total number of snails collected in November 2017, abundance of snails was d in the paddy

Table 2. Distribution of snails in paddy fields of coastal Karnataka

Species	Family	Marlimar	Pavanje	Santoor	Sastan	Mattu	Trasi
Idiopoma dissimilis	Viviparidae	+	+	-	+	+	-
Indoplanorbis exustus	Planorbidae	+	+	+	+	+	+
Physella acuta	Physidae	+	-	-	-	-	-
Pila virens	Ampullaridae	+	+	+	+	+	+
Racesina luteola	Lymneidae	+	+	-	+	-	-

+ : Present, - : Absent

Table 3. Abundance of snails in the paddy fields during the first cropping period (%)

Location	2017					2018				
	June	July	August	September	October	June	July	August	September	October
Marlimar	4	15	40	35	2	2	4	60	35	1
Pavanje	10	75	8	3	0	38	10	20	20	15
Santoor	30	5	20	7	4	100	0	0	0	0
Mattu	35	5	3	0	0	1	5	80	10	0
Sastan	3	2	7	0	0	10	1	1	85	0
Trasi	8	0	5	5	5	60	2	3	1	5

fields of Sastan (72.22%) and Mattu (27.78%) as the paddy fields were filled with water. However, no snails were found in Pavanje, Santoor and Trasi. In November 2018, snails were not observed as the paddy fields remained dry. Among the total number of snails during the second cropping cycle abundance was higher in mid cropping cycle (January) and no snails were found during the end of cropping (April). Species richness of snails increased gradually from November, highest in of January and declined thereafter during the study (Fig. 3). *P. virens, P. acuta, R. luteola* and *I. dissimilis* were present. *P. acuta* was abundant in this paddy field during both the cropping cycles.

Species diversity: Highest Shannon diversity in Marlimar (1.47) and least for paddy fields of Mattu (0.53) during the first cropping cycle in 2017 (Table 4). Shannon diversity index was more in the paddy field of Pavanje, least in the paddy field of Trasi in 2018. Species diversity was higher in the paddy field of Marlimar during the first cropping cycle and declined during second cropping cycle. Diversity indices were minimum in January as single species were abundant. Margalef's index was maximum in Marlimar (1.276) and Pavanje (0.983) in 2017 and 2018, respectively. The distribution of the snails was uneven in most of the paddy fields.

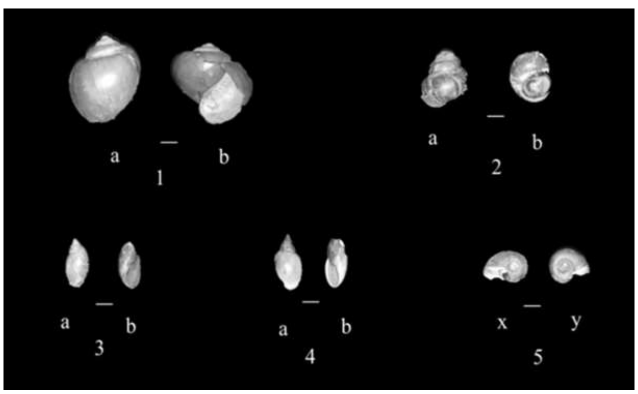

Fig. 1. Snails found in paddy fields of coastal Karnataka. 1. *P. virens* 2. *I. dissimilis* 3. *R. luteola* 4. *P. acuta* 5. *I. exustus* a: Abapertural views b: Apertural views x: Apical view. y: Basal view; Scale bar: 8 mm

Species composition of snails in the paddy fields: The highest number of molluscan species were in the paddy field of Marlimar (5) followed by Sastan (4) and Pavanje (4). *P. virens* was abundant in the rice fields of Pavanje, Santoor, and Trasi. *I. exustus* was dominant in the rice fields of Mattu (75%) and Sastan (55%) whereas *P. acuta* dominated (80%) the rice field of Marlimar (Fig. 4).

Bray Kurtis similarity index of 1 means that the two communities used for the comparison share all their species, while a value of 0 means they share none. Paddy fields of Santoor and Trasi formed a cluster indicating that they are ecologically similar in terms of the number of species. Paddy fields of Pavanje and Sastan formed a cluster with a Bray-Curtis similarity index of 0.5, which joined with the paddy field of Mattu to form a supercluster (Fig. 5). The paddy field of Marlimar with different species composition was dissimilar to other paddy fields thus forming a separate cluster. The clusters joined with a widely separated cluster of Marlimar denoting the least similarity.

Climatic conditions and physicochemical parameters of soil and water in the rice: Precipitation was the variable selected to understand the climatic conditions of the paddy fields. Precipitation ranged between 0.48mm-774.2mm. The highest and least values of precipitation were in July 2018 and January 2018 respectively. There was an increase in species richness with the increase in precipitation during the study. Water temperature and air temperature varied between 25.5^{0}c-36.1^{0}c and 25^{0}c-35.4^{0}c respectively. The temperature of air and water declined at the onset of the monsoon and increased towards the end. The abundance of

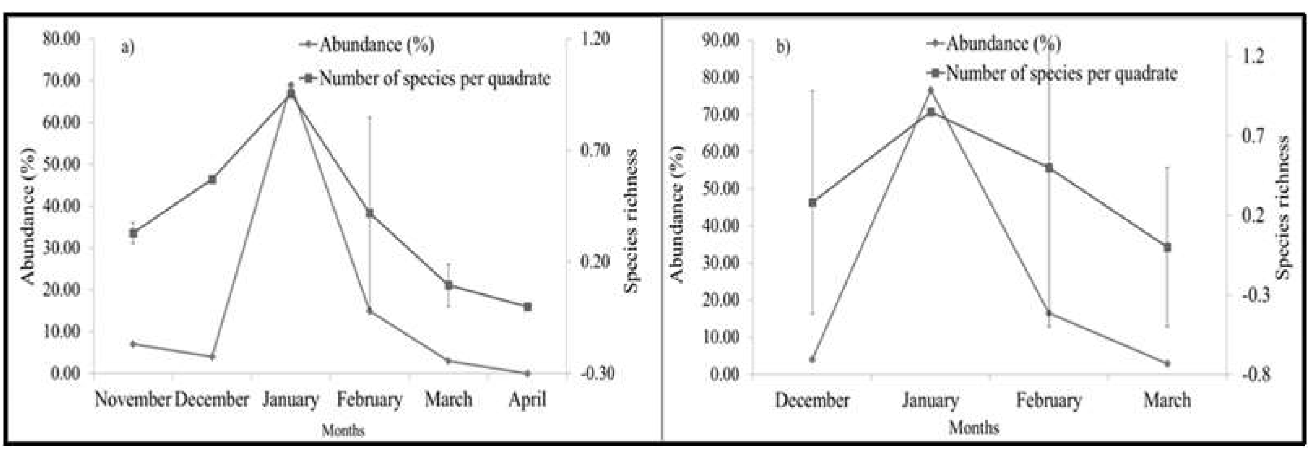

Fig. 2. Abundance and species richness (Mean ± Standard deviation) of snails in paddy field of Marlimar during second cropping cycle for the period (a) 2017-2018 and (b) 2018-2019

snails lessened when the water temperature was above 32^{0}c. The electrical conductivity of water ranged from 3.89-1136 µS/m during the study. Maximum values of electrical conductivity were recorded from the paddy field of Marlimar during the second cropping cycle.

The pH of water varied from 3.4-8.53 in the paddy fields. The highest pH was in Marlimar during the second cropping cycle. The abundance of *P. acuta* in the rice field of Marlimar was observed when the pH of the water was between 6-7. The salinity of water ranged between 0-0.9 ppt. Maximum salinity was observed in paddy field of Pavanje. The values increased towards the end of the cropping period with the reduced rainfall. Soil pH was in the range of 3.07-7.08. Soil pH was maximum in the paddy field of Pavanje (7.08) and minimum in Santoor (3.07). The electrical conductivity of the soil varied from 0.01-0.85µS/m. The highest and least were from Mattu in November 2017 and September 2018. Organic carbon of the soil ranged between 0.06-3.51%. Maximum values of organic carbon were recorded from the paddy field of Marlimar (3.510) during the second cropping cycle.

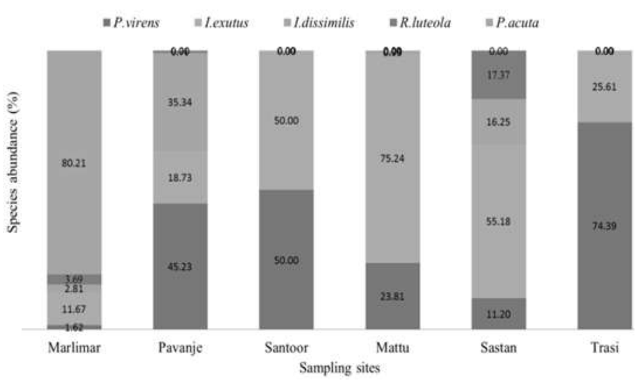

Fig. 4. Distribution of snails in paddy fields of coastal Karnataka

Kruskal-Wallis test revealed that there is a significant difference in salinity (*P*=0.002), the electrical conductivity of water (*P*=0.019), and organic carbon of the soil (*P*= 0.001) However, the abundance and species richness of snails did not vary significantly between the sites (Table 5). When species richness was considered as the dependent variable and the data was analysed using multivariate generalised linear model analysis the independent variable soil pH differed significantly suggesting that the soil pH significantly predicted richness (Table 6). Other independent variables are not statistically significant.

Multivariate generalised linear model analysis showed that the independent variable pH of water differs significantly when abundance was the dependent variable (Table 7).

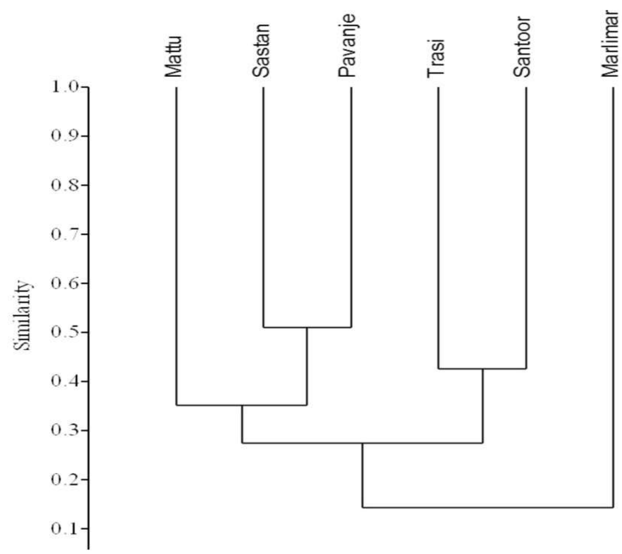

Fig. 5. Bray-Curtis similarity analysis for the paddy fields studied

Table 4. Diversity indices in the paddy fields during the first cropping cycle

Diversity indices	Marlimar		Pavanje		Santoor		Mattu		Sastan		Trasi	
Year	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
H´	1.470	0.616	0.827	1.076	0.674	0.495	0.532	0.685	0.983	0.723	0.679	0.000
R	1.276	0.620	0.589	0.983	0.703	0.500	0.510	0.497	0.678	0.602	0.750	0.000
J´	0.870	0.463	0.762	0.733	0.981	0.820	0.567	0.992	0.891	0.686	0.986	1.000

H´=Shannon Weiner Index, R=Margalef's Index; J´=Evenness Index

Table 5. Kruskal-Wallis test to check the variations in species diversity and physicochemical parameters of the paddy fields

	Abundance	SR	AT	WT	Salinity	EC of water	pH of water	Soil pH	Soil EC	SOC
Chi-Square	9.854	10.744	6.183	4.235	18.658	13.563	7.892	0.703	7.804	26.176
Significance	0.079	0.057	0.289	0.516	0.002	0.019	0.162	0.084	0.167	0.001

* SR= Species richness, AT = Air temperature, WT = Water temperature, SOC=Soil Organic Carbon, EC=Electrical conductivity

Other independent variables are not statistically significant. It is evident that pH of water significantly predicted abundance. When Spearman correlation was carried out, significant positive correlation was observed between abundance and pH of water, species richness and pH of water, soil pH and abundance, soil pH and species richness, salinity and electrical conductivity, salinity and pH of water, air temperature and water. Precipitation correlated significantly with species richness of snails. However, air temperature, water temperature, salinity, the electrical conductivity of water, soil conductivity, and soil organic carbon did not correlate significantly with the abundance and species richness of snails (Table 8).

The diversity of snails in paddy fields of coastal Karnataka was studied and 5 species of snails were documented. Of these*, P. virens* and *I. exustus* were in most of the paddy fields. These species have been reported by Narasimhaih et al (2014) from the paddy fields of Mangalore of coastal Karnataka and suggested that the climatic conditions including water and soil influence the survival of the snails. The population of *I. exustus* was more in the paddy fields of Marlimar, Pavanje and Mattu than the other paddy fields. This could be attributed to the availability of aquatic macrophytes. Molozzi et al. (2007) showed that the vegetative parts of aquatic macrophytes supply oxygen for the survival of snails. Aquatic macrophytes are food for snails and help in deposition of egg masses (Galan et al 2015). The spawning capacity of *I. exustus* and the ability to colonize varied habitats are the key factors that determine its presence in the paddy fields (Chantima et al 2018).

During the study, the number of species was highest in the paddy field of Marlimar which may be due to the water inundation and availability of habitable areas for the snails. In the present study, during the wet period (Beginning of cropping cycle) the number of snails started to increase and highest during the middle of the cropping when rainfall was

Table 6. Multivariate generalised linear model analysis for physicochemical parameters influencing species richness of snails between the sites

Parameter	Regression coefficient (B)	Std. error	95% Wald confidence interval		Hypothesis Test	
			Lower	Upper	Wald Chi-Square	P
Air temperature (^{0}c)	-0.034	0.035	-0.103	0.035	0.916	0.339
Water temperature (^{0}c)	0.029	0.030	-0.031	0.089	0.927	0.336
Salinity (ppt)	-0.027	0.019	-0.064	0.011	1.956	0.162
Electrical conductivity (µS/m)	0.000	0.000	-0.001	0.000	0.481	0.488
pH of water	0.062	0.048	-0.032	0.157	1.668	0.197
Soil pH	0.119	0.047	0.026	0.211	6.351	0.012
Soil conductivity (µS/m)	-0.230	0.230	-0.681	0.221	0.996	0.318
Organic carbon (%)	-28.763	202.58	-425.83	368.30	0.020	0.887

Dependent Variable: Species richness
Model (Intercept) Air temperature, Water temperature, Salinity, Conductivity, pH of water, Soil pH, Soil conductivity, Organic carbon

Table 7. Multivariate generalised linear model analysis to know the physicochemical parameters influencing species abundance of snails between the sites

Parameter	Regression coefficient (B)	Std. error	95% Wald confidence interval		Hypothesis Test	
			Lower	Upper	Wald Chi-Square	P
Air temperature (^{0}c)	-0.319	0.250	-0.810	0.173	1.617	0.204
Water temperature (^{0}c)	0.034	0.217	-0.392	0.461	0.025	0.874
Salinity (ppt)	-0.086	0.135	-0.351	0.179	0.405	0.525
Electrical conductivity (µS/m)	-0.001	0.001	-0.004	0.003	0.092	0.762
pH of water	0.862	0.344	0.188	1.536	6.278	0.012
Soil pH	0.333	0.335	-0.325	0.991	0.982	0.322
Soil conductivity(µS/m)	-2.062	1.638	-5.273	1.148	1.585	0.208
Organic carbon (%)	-1054.42	1441.035	-3878.79	1769.95	0.535	0.464

Dependent Variable: Abundance
Model: (Intercept), Air temperature, Water temperature, Salinity, Electrical conductivity, pH of water, Soil pH, Soil conductivity, Organic carbon

Table 8. Spearman correlation of abundance and species richness of snails with physicochemical parameters of soil and water (N=81)

	Abundance	SR	P	AT	WT	Salinity	EC of water	pH of water	Soil pH	Soil EC	SOC
Abundance	1.000										
SR	0.935**	1.000									
P	0.333	0.516**	1.000								
AT	-0.132	-0.128	NA	1.000							
WT	-0.082	-0.036	NA	0.585**	1.000						
Salinity	0.137	0.003	NA	0.239*	-0.119	1.000					
EC of water	-0.007	-0.078	NA	0.079	-0.131	0.681**	1.000				
pH of water	0.257*	0.243*	NA	0.056	0.203	0.292*	0.203	1.000			
Soil pH	0.422**	0.434**	NA	-0.216	0.047	0.050	-0.052	0.047	1.000		
Soil EC	-0.680	-0.071	NA	-0.208	-0.051	-0.145	-.0.073	0.142	-0.013	1.000	
SOC	0.021	0.003	NA	0.129	0.037	0.191	0.416**	0.050	-0.052	0.015	1.000

#AT=Air temperature, WT= Water temperature, P=Precipitation, SR=Species richness, EC=Electrical conductivity, SOC=Soil Organic Carbon, NA=Not applicable.
*, **. Correlation is significant at the0.05 and 0.01 level (2-tailed).

maximum and paddy fields were filled to the maximum extent. During the dry period (Harvest) the snails burrow in the soil due to inadequate soil moisture. The paddy field of Marlimar undergoes two cropping cycles and gets inundated with water for about 6 months. This inundation period may be a reason for the species richness of snails in the paddy field. Moreover, paddy field of Marlimar has a different species composition than the other paddy fields may be due to the clayey soil which can hold more water whereas rice fields such as Sastan and Trasi comprising of sandy soil have poor water holding capacity. In addition, the paddy field of Marlimar differs from other paddy fields as it is located 27 km away from the sea, which contributes to more species diversity. The abundance of *P. acuta* in the paddy field of Marlimar was observed which may be attributed to a higher rate of fecundity (Saha et al. 2016). The environmental conditions of the paddy fields form the unique habitats for molluscs (Vineetha 2016). The ecological conditions of the paddy field of Marlimar may have helped in the growth and reproduction of *P. acuta*. Since irrigation provides moisture for the snails to thrive in the paddy fields may be one of the reasons for species richness in the irrigated paddy fields. Irrigation cannot be the only reason for more species diversity in the study sites. The ecological conditions of the paddy field of Marlimar are unique from the other paddy fields and provide good habitats.

Species abundance and richness were similar in the paddy fields of Sastan and Pavanje, but dissimilar to other paddy fields. Similar ecological conditions and soil types in the paddy fields of Sastan and Pavanje may be the reason for this. Less diversity of molluscs in the paddy fields of Santoor, Mattu, and Trasi could be because of the unfavourable environmental conditions existing in this site such as an increase in air temperature and water temperature, variations in pH sandy, and muddy soil, and lesser period of water. Lawler (2001) opined that the paddy fields inundated with water for a longer period will have more species.

The increase in the number of snails from June to August was observed, which is ascribed to a higher rate of decomposition in the rice fields in the initial stages of cultivation that favoured the growth of snails (Vineetha et al. 2015). The abundance of the snails was observed in the middle of the second cropping cycle. The paddy field of Marlimar will be subjected to two cropping cycles and the fertilizers applications in November (first cropping) and in January (second cropping) will be used twice during the cropping period in these sites and water is supplied through irrigation. The decrease in the number of snails in the paddy fields during the reproductive phase of paddy may be because of the decrease in rainfall and less decomposition in the paddy fields. The shades of larger plants reduce the rate of decomposition and prevent sunlight penetration into the fields (Bambaradeniya and Amerasinghe 2004). Eventually, the snail population lessens due to the unavailability of decomposed matter. Besides, the paddy fields get occupied by the roots of the paddy, reducing the area for the growth of molluscs (Ojha et al. 2010). Previous studies from the Kerala state of India have shown the abundance of snails in paddy fields and suggested that the presence of aquatic plants is conducive to the abundance of snails and other invertebrates (Gopalan et al. 2014). The snail species survive in the paddy fields by resource partitioning i.e. by hiding under paddy straw, under the roots, within the soil and feeding the debris on the water, thus paddy fields act as suitable habitats for snails (Ojha et al 2010).

When water temperature was above 32^{0}c number of snails declined. Mortality of Ampullarids above this temperature has been reported Cowie (2001). The electrical conductivity of water varied during the study which could be due to inflow of water, nutrient cycling and fertilizer application (Stevens et al 2006). Organic carbon of the soil increased with the progress of monsoon, could be due to the decay of aquatic macrophytes. Maximum organic carbon was recorded in the growth phase of paddy during the second cropping cycle that could be attributed to increased carbon input to the soil due to fertilizer applications (WeiGong et al 2012). Organic carbon enhances water retaining capacity of the paddy soil (Rawls et al 2003) thus helping in survival of snails.

The present study suggests that diversity of snails in the rice fields is mainly dependent on monsoon and presence of water in post-monsoon. Besides, ecological conditions of paddy fields favour the abundance of snail species. Inundating rice fields with water after monsoon would help the many snail species to thrive in these manmade wetlands thus productivity can be enhanced.

CONCLUSIONS

The present study focused on the ecology of the paddy fields of coastal Karnataka and the number of snails found in these wetlands during the cropping period. Paddy fields of coastal Karnataka incorporate a variety of snail species are the unique ecological niches for their survival. Snail diversity increases with the onset of monsoon and during irrigation but declines as the water evaporates during summer. The water holding capacity of paddy fields and presence of earthen ditches determine the number of snails. Rainfall, pH of water and soil influences the species richness of the snails in the paddy fields. Snail species meeting the optimum pH conditions of the paddy fields survive in such habitats, however, the physicochemical parameters of water and soil along with the environmental variables have a cumulative effect on the diversity of snails. Paddy fields of coastal Karnataka are being lost because of rapid urbanization. Perhaps the loss of habitat for snails in the paddies is offset by the presence of space, microhabitats, connectivity between the paddy fields and earthen ditches. As the paddy fields of coastal Karnataka, are disappearing due to land use for developmental activities, paddy cultivation throughout the year with an improved water supply and conversion of barren lands into paddy fields would help to sustain and nourish the snail diversity of these wetlands.

ACKNOWLEDGEMENTS

The first author is thankful to Dr. Venkitesan, Scientist, Zoological Survey of India, Chennai, and Dr. Aravind N.A, Scientist, ATREE, Bangalore for the species identification, UGC-Maulana Azad National Fellowship for the financial assistance, Department of Applied Zoology, Mangalore University and UGC-SAP for the support.

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Received 11 April, 2024; Accepted 15 July, 2024

Indian Journal of Ecology (2024) 51(4): 921-925
DOI: https://doi.org/10.55362/IJE/2024/4331

Manuscript Number: 4331
NAAS Rating: 5.38

Catch Composition, Trade Practices and Market Structure Dynamics: In-Depth Analysis of Fish Markets in Punjab

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Abstract: A comprehensive fish market survey spanning a year, from September 2021 to August 2022, was conducted in five pivotal markets Amritsar, Jalandhar, Ludhiana, Mohali, and Bathinda in Punjab. The primary objectives of this survey were to collect data concerning Punjab's existing domestic fish markets. The survey was conducted covering uniformly the four seasons i.e. post-monsoon, winter, pre-monsoon, and monsoon. Total 54 fish species were recorded during this survey. The family Cyprinidae emerged as a significant contributor, accounting for 48.86% of the market share by weight. An overwhelming 75.41% of the market share was attributed to fish originating from inland culture and capture fisheries within the state, underscoring the local significance of this sector. Furthermore, approximately 16.71% of the fish available in Punjab markets were sourced from other states, predominantly consisting of freshwater species. Ludhiana exhibited the most diverse range of fish species, boasting a total of 45 fish species, followed by Amritsar with 22 fish species. However, despite the promising market dynamics, several challenges loom large for fish vendors in Punjab. Resolution of these pressing issues is imperative to facilitate further progress and development within the fisheries sector in Punjab.

Keywords: Fish markets, Catch composition, Cyprinidae, Market channels, Constrains

In India and other developing nations, millions of individuals grapple with two pressing challenges: malnutrition and starvation. Fish, renowned for its exceptional attributes as a source of high-quality animal protein and a wealth of essential minerals such as calcium, phosphorus, iron, magnesium, iodine, zinc, and potassium, emerges as a pivotal solution. Notably, fish stands as a nutritious food option, boasting ample digestible protein, polyunsaturated fatty acids (PUFA), and vital vitamins like vitamin D and B2. The fisheries and aquaculture sector possess immense potential to address food and nutritional security, spur entrepreneurship and livelihood opportunities, and is poised for further growth due to heightened public awareness of its health benefits (Ghosh et al 2020). In fact, fish protein already accounts for approximately 31% of animal protein consumption in Asian countries (Sreenivasa 2017). India, with its vast and diverse fisheries resources encompassing fresh, brackish, and marine water species, represents a significant player on the global stage. These resources contribute to over 10% of the world's fish and shellfish species diversity. Presently, India ranks as the world's third-largest fish producer and aquaculture provider, contributing around 16% of the global inland fish production and 5% of marine fish production. In the 2021-22 fiscal year, India achieved a total fish production of approximately 162.48 lakh tonnes, with inland and marine sectors contributing 121.21 lakh tonnes and 41.27 lakh tonnes, respectively (Government of India 2023).

The prosperity of the fishery sector fundamentally hinges on the evolution and modernization of fish marketing systems. Regrettably, India's domestic fish marketing system is plagued by inefficiency and antiquation, heavily reliant on individual dealers and intermediaries (Jha et al 2010). This ecosystem encompasses wholesale markets, retail markets, and retail outlets, where the prevailing norm often involves the sale of fish with insufficient regard for desired quality and hygiene standards, especially in roadside establishments (Deshmukh and Jawale 2014). Due to the landlocked geographical location of Punjab, fish production is limited solely to inland water sources. Freshwater fish, which are raised in both individual and community ponds, as well as obtained from natural sources such as rivers (Sutlej, Beas, Ravi, and Ghaggar), canals, and tiny reservoirs/wetlands, are delivered to market shelves in an unspoiled condition. Moreover, there is a significant demand for frozen freshwater and marine fish originating from remote regions such as Andhra Pradesh, West Bengal, Gujarat, Maharashtra, and Karnataka (Datta et al 2017). The current investigation of the fish market aims to describe the wide range of species present and the prevailing market dynamics, including distribution techniques and the notable obstacles faced by fish dealers.

MATERIAL AND METHODS

Selection of the site for conducting the present study and sample collection: The present study focused on the selection of fish markets in five districts of Punjab, namely Amritsar (31º37′ 50.969″N, 74º52′ 30.93″E), Jalandhar (31º20′ 2.605″N, 75º34′ 13.205″E), Ludhiana (30º55′ 17.501″N, 75º54′ 5.642″E), Mohali (30º43′ 49.67″N, 76º42′ 2.46″E), and Bathinda (30º12′ 29.399″N, 74º 57′ 56.785″E). The data collection spanned a period of one year, from September 2021 to August 2022, with sampling conducted at regular intervals corresponding to different seasons, including post-monsoon, winter, pre-monsoon, and monsoon. The selection process took into consideration the marketing of fish obtained from both culture and capture fisheries in Punjab, as well as fish imported from other states. Data on species assemblage, catch composition, demand and supply, market structure, and market chain were collected at fish markets. The identification of the fish was done using a widely accepted taxonomic key, enabling classification of the fish to the species level. The study emphasized on multiple facets encompassing the diversity of fish species accessible, the composition of fish captures, the structural arrangement of fish markets, waste management systems, marketing channels, and the obstacles faced by fish sellers in the trade.

RESULTS AND DISCUSSION

Marketing trend of fish from capture and culture fisheries: The fish species available in these markets originated primarily from capture fisheries within the state. Cyprinidae family holds a substantial market presence, 48.86% of the total weight of fish species, encompassing 16 species (Fig. 1). During various seasons, shellfish species primarily *Macrobrachium rosenbergii, Scylla serrata,* and *Penaeus monodon* were imported into different fish markets from coastal states like West Bengal; whereas *Litopenaeus vannamei* was marketed after harvesting from Punjab and neighboring states (Table 1).

Marketing trend of fish exclusive from capture fisheries: Capture fisheries predominantly sourced catch from key locations such as Harike wetland (31°13'N and 75°12'E), Nangal (31°23' N and 76°22' E), and Pong dams (31°97' N and 75°94' E), accounting for approximately 70-75% of the supply. The remaining 25-30% of the capture fisheries was typically harvested from rivers. *C. catla, L. rohita, C. mrigala* and *C. carpio* of the Cyprinidae family and *Wallago attu* of the Siluridae family were found throughout the year. Fish species under family Siluridae (10.49 %) (*W. attu* and *Ompok pabda*), followed by Bagridae (4.92 %), Channidae (4.04 %) and Notopteridae (3.01 %) contributed significantly in culture fisheries sector (Fig. 2).

Low-value fish species: Seven fish species have been identified within various marketplaces, characterized by low consumer demand and consequently, diminished market value (*Puntius. sarana, P. ticto, P. sophore, Salmostoma phulo, Xenentodon cancila, A. mola* and *Osteobrama cotio*). These species are typically introduced to the market as by-catches of other targeted species from the state's capture and culture fishery. Datta et al (2017) recorded low-value

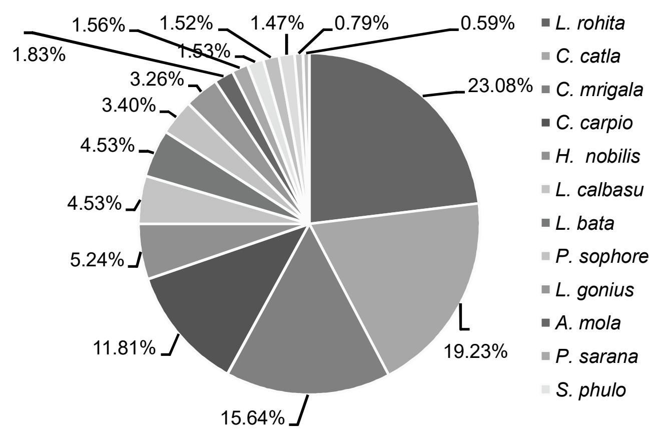

Fig. 1. Share of different fish species under family Cyprinidae (% weight basis) from both capture and culture sector in fish markets of Punjab

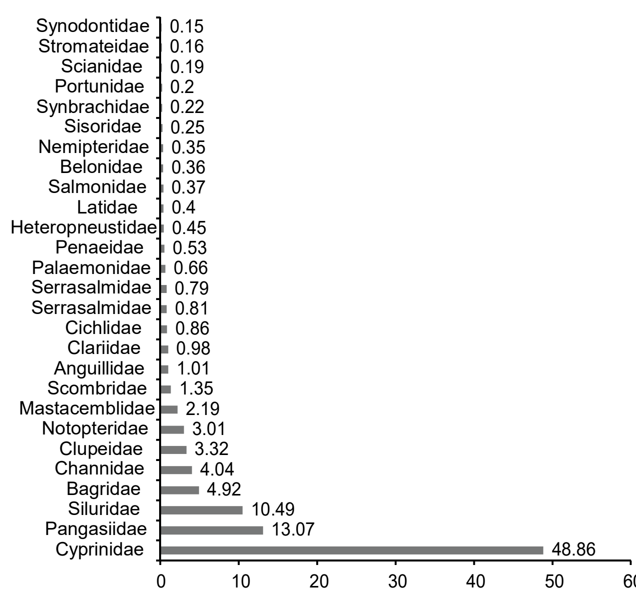

Fig. 2. Share of different families (% weight basis) in fish markets of Punjab

Table 1. Seasonal abundance of fish species from different markets of Punjab

Species name	Amritsar (Cap + Cul)				Jalandhar (Cap + Cul)				Ludhiana (Cap + Cul)				Mohali (Cap + Cul)				Bathinda (Cap + Cul)			
	PoM	W	Prm	M	PoM	W	Prm	M	PoM	W	Prm	M	PoM	W	Prm	M	PoM	W	Prm	M
Fish from culture and capture fishery within the state																				
Catla	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Labeo rohita	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Labeo bata	*	*	-	*	-	-	-	-	*	*	*	*	-	-	-	-	-	-	-	-
Cirrihinus mrigala	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Hypophthalmichthys molitrix	-	-	-	-	-	-	-	-	*	*	*	*	-	-	-	-	-	-	-	-
Ctenopharyngodon idella	-	-	-	-	-	-	-	-	*	*	*	*	-	-	-	-	-	-	-	-
Hypophthalmichthys nobilis	*	*	*	*	-	-	-	-	*	*	*	*	*	*	*	*	*	*	*	*
Cyprinus carpio	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Puntius sarana **	-	-	-	-	-	-	-	-	*	*	-	*	-	-	-	-	-	-	-	-
Puntius ticto **	-	-	-	-	-	-	-	-	*	*	-	*	-	-	-	-	-	-	-	-
Salmostoma phulo **	-	-	-	-	-	-	-	-	*	*	-	*	-	-	-	-	-	-	-	-
Oreochromis niloticus	-	-	-	-	*	*	*	*	-	-	-	-	-	-	-	-	*	*	*	*
Clarius gariepinus	-	-	-	-	-	-	-	-	*	*	*	*	-	-	-	-	-	-	-	-
Clarias batrachus	-	-	-	-	-	-	-	-	-	-	-	-	*	*	*	*	*	*	*	*
Sperata seenghala	*	*	*	*	*	*	*	*	*	*	*	*	-	-	-	-	-	-	-	-
Mystus cavasius	-	-	-	-	-	-	-	-	*	*	-	*	-	-	-	-	-	-	-	-
Mystus vittatus	-	-	-	-	-	-	-	-	*	*	-	*	-	-	-	-	-	-	-	-
Wallago attu	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Ompok pabda	-	-	-	-	-	-	-	-	-	*	*	-	-	-	-	-	-	-	-	-
Heteropneustes fossilis	-	-	-	-	-	-	-	-	*	-	*	-	-	-	-	-	-	-	-	-
Gadusia chapra	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*	*	-	*
Channa marulius	-	-	-	-	-	-	-	-	*	*	-	*	-	-	-	-	-	-	-	
Channa striata	-	-	-	-	-	-	-	-	*	*	-	*	-	-	-	-	-	-	-	
Channa punctate	-	-	-	-	-	-	-	-	*	*	-	*	-	-	-	-	-	-	-	
Xenentodon cancila **	-	-	-	-	-	-	-	-	*	*	-	*	-	-	-	-	-	-	-	
Notopterus	*	*	-	*	*	*	*	*	*	*	*	*	-	-	-	-	-	-	-	
Rita	*	*	*	*	-	-	-	-	-	-	*	*	-	-	-	-	-	-	-	
Macrobrachium rosenbergii #	*	*	*	*	-	-	-	-	*	*	*	*	*	*	*	*	-	-	-	
Litopenaeus vannamei #	-	-	-	-	-	-	-	-	*	-	*	*	*	-	*	*	*	-	*	
Fish from capture fishery within the state																				
Puntius sophore **	*	*	-	*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Labeo gonius	*	*	-	*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Labeo calbasu	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Amblypharyngodon mola **	-	-	-	-	-	-	-	-	*	*	-	*	*	*	-	*	-	-	-	
Osteobrama cotio **	-	-	-	-	-	-	-	-	*	*	-	*	-	-	-	-	-	-	-	

Cont...

Table 1. Seasonal abundance of fish species from different markets of Punjab

Species name	Amritsar (Cap + Cul)				Jalandhar (Cap + Cul)				Ludhiana (Cap + Cul)				Mohali (Cap + Cul)				Bathinda (Cap + Cul)			
	PoM	W	Prm	M	PoM	W	Prm	M	PoM	W	Prm	M	PoM	W	Prm	M	PoM	W	Prm	M
Bagarius bagarius	-	-	-	-	-	-	-	-	-	*	-	-	-	-	-	-	-	-	-	-
Mystus bleekari	-	-	-	-	-	-	-	-	*	*	-	*	-	-	-	-	-	-	-	-
Anguilla anguilla	*	*	-	*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Macrognathus pancalus	-	-	-	-	-	-	-	-	*	*	-	*	-	-	-	-	-	-	-	-
Monopterus cuchia	-	-	-	-	-	-	-	-	*	*	-	*	-	-	-	-	-	-	-	-
Oncorhynchus mykiss	*	*	-	*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Scylla serrate #	-	-	-	-	-	-	-	-	-	*	-	-	-	-	-	-	-	-	-	-
Fish outside from state																				
Pangasianodon hypophthalmus	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Piaractus brachypomus	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	-	-	-	-
Tenualosa illisha	*	*	-	*	-	-	-	-	*	*	-	*	-	-	-	-	*	*	-	*
Lates calcarifer	-	-	-	-	-	-	-	-	*	*	-	*	-	-	-	-	-	-	-	-
Nemipterus japonicus	-	-	-	-	-	-	-	-	*	*	-	*	-	-	-	-	*	*	-	*
Johnius dussumieri	-	-	-	-	*	*	*	*	*	*	-	*	-	-	-	-	-	-	-	-
Pampus chinensis	*	*	-	*	*	*	*	*	*	*	-	*	-	-	-	-	*	*	-	*
Rastrelliger kanagurta	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Auxius thazard	-	-	-	-	-	-	-	-	*	*	-	*	-	-	-	-	*	*	-	*
Scomberomorus guttatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*	*	-	*
Sardinella longiceps	*	*	-	*	-	-	-	-	-	-	-	-	-	-	-	-	*	*	-	*
Harpodon nehereus	-	-	-	-	-	-	-	-	*	*	-	*	-	-	-	-	-	-	-	-
Penaeus monodon #	-	-	-	-	-	-	-	-	-	-	-	-	*	*	-	*	*	*	-	*

* Present, - Absent, PoM- Post-monsoon, W- Winter, PrM- Pre-monsoon and M- Monsoon, Cap- Capture fisheries, Cul- Culture fisheries, ** Low value fish, # Shellfish species

species were typically by-catch of other targeted fish species from both commercial fishing and aquaculture. *Boleophthalmus pectinirostris, Esomus danricus, P. sarana, P. ticto, Oreochromis mossambicus, Chanda nama, Xenentodon cancila* and *Colisa fasciatus* were the species with poor customer demand in fish markets.

Fish procured from outside state: Thirteen species have higher consumer demand in Punjab specially those people who are migrated from other coastal states. Among these *P. hypopthalamus* has the highest demand (Table 2).

Sector wise contribution in fish market (Weight basis): The inland culture and capture fisheries within the state contributed 75.41% of the market share. A total of 16.71 % of the fish transported to Punjab from other states were freshwater species, while 7.88% contributed from marine fisheries resources. Datta et al (2017) observed that the culture and capture fisheries in Punjab accounted around 90 % of total catch while rest was contributed by fish imported from other states. A total of 2 to 3% of the fish marketed in Punjab were contributed by the marine sector (Table 2). The analysis of the fish marketing structure in Ludhiana, Amritsar, and Jalandhar markets in Punjab reveals several notable trends. Firstly, there has been an increase in the variety of fish species available in these markets compared to the previous study conducted by Datta et al (2017), indicating a potentially widening consumer preference. Secondly, there is a significant rise in total daily fish sales across all markets, suggesting a growing demand for fish in the region. Despite these positive trends, the presence of banned fish species in the markets raises concerns about regulatory oversight, highlighting the need for stricter measures to ensure food safety and ecosystem protection. Overall, these trends

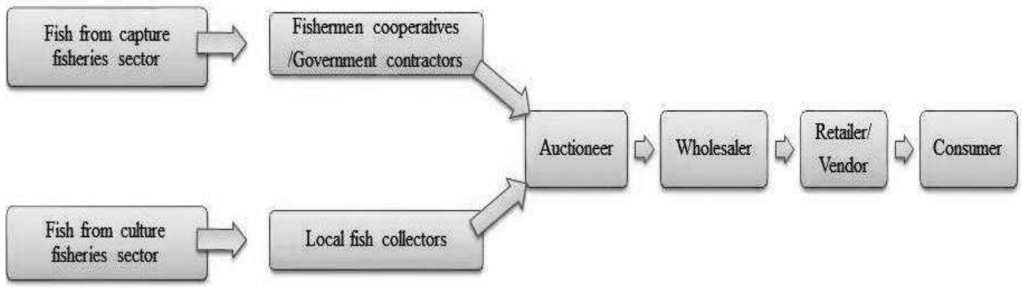

Fig. 3. Fish marketing channels in Punjab

Table 2. Demand and supply of fish species from different areas in Punjab during the study period

Parameters	Ludhiana	Amritsar	Mohali	Jalandhar	Bathinda
Total fish sale (ton/day)	2.0 -12.0	0.5- 4.5	1.0-5.5	2.5-5.5	0.75- 5.0
Fish from capture fisheries sector (%)	35-40	40-45	30-35	30-35	25-30
Fish from culture fisheries sector (%)	20-30	25-30	30-35	35-40	30-35
Fish imported from other States (%)	10-20	15-20	15-25	20-25	30-35
Low value/ non- economic fish mainly from capture fisheries sector (%)	5-10	0-5	0-5	0	0
Banned species (%)	5-7*	2-5**	2-5*	2-5**	2-5**
Total spp marketed (Nos)	35	22	12	13	19
Dominant species/groups (Maximum demand in consumer levels)	Carps	Carps	Carps	Pangas	Carps

* All three banned species Big head, Pacu and Thai Magur, ** Two banned species Big head and Pacu

indicate a dynamic and evolving fish market in Punjab, emphasizing the importance of continuous monitoring and adaptation to meet consumer demand while ensuring sustainability and regulatory compliance.

Marketing channels: Various fish marketplaces, fishermen/producers, commission agents, wholesalers, retailers, and consumers were mostly involved with the marketing channel (Fig. 3). Fish are purchased in live condition from fish farms by fish venders or fish auctioneers in the early morning and then carried to fish markets (especially in Ludhiana).

CONCLUSIONS

Ludhiana fish market recorded the highest fish sale as compared to other fish markets and highest percentage of imported fish was marketed at Bathinda fish market. Locally produced Rohu (*L. rohita*) and imported Pangas catfish (*P. hypophthalmus*) from Andhra Pradesh have the highest demand among consumers. Marketing routes can be made simple so that fish grown in farms or caught in the wild can be delivered straight to consumers without the involvement of numerous middlemen. Unregulated fish supply in the markets, lack of proper storage and waste disposal facilities are the major constrains in fish markets of Punjab. Special emphasis should be given to Bathinda fish markets to improve its basic facilities like electricity, toilets, waste disposals etc.

Received 21 January, 2024; Accepted 21 May, 2024

AUTHORS CONTRIBUTION

Pargi Narendrakumar Arjunsinh conducted sampling and analysed the data and wrote the manuscript. Surjya Narayan Datta conceptualized the theme, helped in sampling, interpreted the results and wrote the manuscript. Prabjeet Singh and Grishma Tewari helped in sampling.

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Indian Journal of Ecology (2024) 51(4): 926-932
DOI: https://doi.org/10.55362/IJE/2024/4332

Manuscript Number: 4332
NAAS Rating: 5.38

Impact of Pollutants on Water Quality and Distribution of Macrophytes in Tuikual River, Aizawl, Mizoram

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Abstract: The current investigation was conducted in Aizawl, Mizoram, from upstream to downstream of the Tuikual river. It is a major tributary of the Tlawng river, which supplies water to Aizawl, Lunglei, and a number of neighbouring settlements. The primary goal of the research is to determine the influence of contaminants on the water quality and distribution of aquatic macrophytes in the Tuikual river. Site 1 is located near the river's source, and the river also obtains discharge from Aizawl Civil Hospital, the state's major hospital. Site 2 is in downstream of the river following the confluence of streams at Site 1 polluted by discharge of domestic trash from cities as well as discharges from Ebenezer Hospital. Site 3 is in downstream of Site 2 and includes overflow from sandstone rocks. Site 4 is downstream from Site 3 in the area where the river enters the Tlawng river The DO, turbidity, and phosphate-P levels were not within the limitations established by several organizations. Twenty-six macrophytes were recorded from 15 families. The aquatic plants with the highest importance value index (IVI) at Sites 1, 2, 3, and 4 were *Commelina benghalensis* (57.0), *Commelina benghalensis* (65.9), *Echinochloa stagnina* (50.1), and *Equisetum hyemale* (45.7), respectively. The Shannon-Weiner diversity index (H'), species evenness (J'), and species richness (D_{mg}) were highest (H'=2.548; J'=0.9; D_{mg}=2.46) at the least polluted site (Site 4), whereas Simpson dominance (D) was highest (D=0.186) at the most polluted site (Site 2). The polluted areas (Sites 1 and 2) had the highest similarity index (88%). The findings indicate that the values of macrophyte-based indices reflect water quality at different sample sites and may be used to measure river ecological health.

Keywords: Tuikual river, Water quality, Parameters, Aquatic macrophytes, Quantitative

Water quality refers to its physical, chemical, and biological qualities (Spellman 2013) and water at high concentration render it unfit for human consumption. It compromises the long-term survival of marine ecosystems as well as water quality (Banadda et al 2009). Industrial waste and sewage discharges are the main causes of river contamination. Anthropogenic activities include urbanisation, industrial processes, agricultural practices, and a fast rising population (Akhtar et al 2021). Water quality has declined over the past few decades due to a number of factors, including the fast growing human population, an increase in anthropogenic activities, changes in land use, and the discharge of sewage and municipal garbage into water bodies (Rana et al 2016). Excess nutrients are released into the water system which greatly accelerates the growth of weeds before severely suffocating ecosystems (Sudhira and Kumar 2000).

Macrophyte are aquatic photosynthetic organism large enough to be visible with the naked eye, growing constantly or occasionally submerged beneath, floating on, or rising through the water surface. They spend at least part of their lives in water, either fully immersed or exposed. Aquatic macrophytes can help improve water quality by removing excess nutrients and pollutants like nitrogen and phosphorus from the water and are important components of aquatic ecosystems and serve critical roles in protecting the health and functionality of aquatic ecosystems. The diversity and quantity of macrophytes reflect the overall quality of an ecosystem. Macrophytic plants, which have a high capacity to bind toxins from sewage, are the best evidence of water pollution (Mishra and Tripathi 2004). The Tuikual river is becoming polluted as a result of the discharge of household and municipal waste from Aizawl's western areas, as well as biomedical discharges from Civil Hospital and Ebenezer Hospital. The river catchment region, which has a total population of 21694 and conveys sewage from roughly 5100 homes at a rate of 694192 liters per day, is located on the western side of Aizawl city. Because there is no adequate sewage treatment facility in the area, domestic waste continues to run untreated into the river. The objective is to determine the influence of contaminants on the water quality and distribution of aquatic macrophytes in the Tuikual river.

MATERIAL AND METHODS

Study area: The Tuikual river passes through the middle of Aizawl City and is located at 23˚ 43 ' 49.8" N Latitude and 92˚ 42 ' 26.6" E Longitude. It is a major tributary of the Tlawng river, which supplies water to Aizawl, Lunglei, and several nearby settlements. The research area, which is around 9.45 kilometers long. Four sample locations were evaluated based on the types of contaminants discharged into river water. The following are the features of the sampling sites:

Site 1: It is located near the river's source, and the river also obtains discharge from Aizawl Civil Hospital, the state's major hospital.

Site 2: Located downstream of the river following the confluence of streams at Site 1, it is distinguished by the discharge of domestic trash from cities as well as discharges from Ebenezer Hospital.

Site 3: It is located downstream of Site 2 and includes overflow from sandstone rocks.

Site 4: This site is located downstream from Site 3 in the area where the river enters the Tlawng river (also known as the Tuithum river).

Water sampling: The water samples were collected at the same time as the macrophyte survey for physical and chemical analysis using the procedures outlined in the "Standard Methods for Examination of Water and Wastewater" (APHA 2005). For measuring DO, water samples were instantly fixed in BOD bottles. The other water samples were collected using an opaque plastic bottle. The water samples were carefully collected and labelled before being delivered to the laboratory within 24 hours for measurement of dissolved oxygen, turbidity, acidity, nitrite-N, phosphate-P, nitrate-N, and sulphate. Titration was used to determine dissolved oxygen (DO) and acidity, while a nephelometer was used to measure turbidity. Nitrite-N (NO_2^-), phosphate-P (PO_4^{3-}), nitrate-N (NO_3^-), and sulphate (SO_4^{2-}) concentrations were determined using spectrophotometric methods.

Aquatic macrophytes sampling: During the vegetative season (rainy season), the distribution of aquatic macrophytes was examined along the river. The rainy season appears to be the most advantageous season for emerging macrophytes buried seed germination (Rai and Munshi 1982). The quadrat (1m x 1m in size) was randomly used to observe the spread of aquatic macrophytes (30 at each sampling site). The standard methods described by Misra (1968) and Mueller-Dombois and Ellenberg (1974) were used for the field investigation. Field observations were carried out to collect, count, and identify the aquatic macrophytes identified in each quadrat to the species level. It was further researched with the assistance of professionals from the Botanical Survey of India, Eastern Circle, Shillong, and checked using reference material (Cook 1996).

Analysis of phytosociological characteristics: Several quantitative parameters were thoroughly investigated, including frequency, density, abundance, abundance frequency ratio (A/F), relative frequency, relative density, relative abundance, and important value index (IVI). The frequency, density, and abundance of each species were calculated separately (Misra 1968, Ambasht 1969). These are then used to express the diversity and dispersal of the community.

RESULTS AND DISCUSSION

Water Quality Assessment

Dissolved Oxygen: The DO content of the water ranged from 4.57 mgL^{-1} (Site 2) to 6.72 mgL^{-1} (Site 4). DO levels were low at Sites 1 and 2 due to the significant discharge of organic waste that was decomposed by microorganisms (Table 1). Compared to the upstream, the downstream had a slightly higher DO level (Souilmi and Tahraoui 2021). During the decomposition process, microbes consume a significant amount of DO, reducing the amount of DO in the water body (Kataria et al 2006). Many fish and invertebrates require DO for health and reproduction; nevertheless, chronic exposure to low DO levels causes stress, diseases, and, in some cases, organismal death (Ali et al 2022). The DO levels at Sites 1 and 2 were lower than the BIS/ICMR acceptable limit.

Turbidity: The turbidity of the water ranged from 11.4 NTU (Site 3) to 28 NTU (Site 2). The turbidity of water samples was found to be highest at Site 2 (Table 1), which could be attributed to heavy rainfall that carries sediment, organic and inorganic material, suspended particles, and other contaminants into the water body from the catchment area (Jehamalar et al 2010). Suspended debris can clog or harm fish gills, reducing disease resistance, growth rates, egg and larval maturation, and the effectiveness of fish capture methods (Tarras-Wahlberg et al 2003). The turbidity values were above the USPH/WHO permitted limit.

Acidity: The acidity content of the water ranged from 26.5 mgL^{-1} (Site 4) to 87.2 mgL^{-1} (Site 2). Water acidity was found to be higher at Sites 1 and 2 (Table 1), which could be attributed to an increase in organic content, which encourages microbial breakdown and releases carbon dioxide (Singh et al 2010). Carbonic acid is generated as a result of the respiratory processes of biological organisms that emit carbon dioxide.

Table 1. Physicochemical parameters of water samples in Tuikual river

Parameters	Site 1	Site 2	Site 3	Site 4
DO (mg L^{-1})	4.87	4.57	6.47	6.72
Turbidity (NTU)	25.8	28.0	11.4	12.7
Acidity (mg L^{-1})	83.2	87.2	32.5	26.5
Nitrite-N (mg L^{-1})	0.44	0.42	0.33	0.17
Phosphate-P (mg L^{-1})	0.34	0.37	0.21	0.16
Nitrate-N (mg L^{-1})	0.35	0.37	0.287	0.28
Sulphate (mg L^{-1})	3.78	4.20	2.79	2.60

Nitrite-N: The nitrite-N content of the water ranged from 0.17 mgL^{-1} (Site 4) to 0.44 mgL^{-1} (Site 1). NO_2^- levels were high throughout Sites 1 and 2 as a result of excessive runoff from fertilisers, sewage, septic systems, industrial chemicals, and nitrite-containing food preservatives (Table 1).

Phosphate-P: The phosphate-P content of the water ranged from 0.16 mgL^{-1} (Site 4) to 0.37 mgL^{-1} (Site 2). Phosphate-P readings were high at Sites 1 and 2 (Table 1), which might have been caused by agricultural runoff containing phosphate fertilisers brought on by heavy rain as well as sewage influx because sewage generally raises phosphate-P levels in water. Phosphorus-P causes eutrophication when mixed with nitrate-N (Lalchhingpuii 2011). The phosphate-P was higher than the USPH permitted level at all sites.

Nitrate-N: The nitrate-N content of the water ranged from 0.28 mgL^{-1} (Site 4) to 0.37 mgL^{-1} (Site 2). The nitrate-N level was at its highest at Sites 1 and 2 due to runoff from fertilised agricultural regions and septic tank leakage entering the water body (Table 1). The amount of nitrate in the water is increased by sewage discharge into the open water and soil erosion. When there is too much nitrate in surface water, algae can bloom quickly, and the water's quality suffers.

Sulphate: The sulphate content of the water ranged from 2.60 mgL^{-1} (Site 4) to 4.20 mgL^{-1} (Site 2). Increased agricultural land and sewage runoff containing sulphate minerals, which is brought into the water body by heavy precipitation, could be the cause of higher sulphate content during the rainy season at Sites 1 and 2 (Table 1) (Rizvi et al 2015).

Impact of pollutants on the water quality of the Tuikual river: The vast majority of water pollutants are chemicals that remain dissolved or suspended in water and have a negative impact on the ecosystem. Upstream sites 1 and 2 had high parameter values due to the catchment area's high pollution load. Due to domestic sewage, runoff from agricultural fields, washed fertiliser from agricultural fields, and other pollutants entering the river's water body from the catchment area, the river was severely contaminated. Continuous industry monitoring and awareness are essential for improving public health in this area (Deoli and Nauni 2021). The unplanned and direct release of trash from multiple sources has significantly deteriorated water quality at all research sites.

Diversity and distribution of aquatic macrophytes: Twenty-six 26 macrophytes belonging to 15 families were identified at the four study sites (Table 2). Site 2 was the most polluted study site, with only 11 species represented, followed by Site 1, Site 3 and Site 4. The Poaceae family had the highest number of macrophytes (Fig. 1). The aquatic macrophytes found in the Tuikual river were all emergent. *Alternanthera philoxeroides, Brachiaria mutica, Canna indica*, *Colocasia esculenta, Ipomoea aquatica, and Polygonum glabrum* were present only at Sites 1 and 2. All stands contain *Drymaria cordata, Polygonum barbatum, and Polygonum hydropiper. Neptunia oleracea* and *Juncus effusus* were found only at the least polluted site (Site 4).

Diversity Indices: The Shannon-Weiner diversity index (H'), species evenness (J'), and species richness (D_{mg}), were highest (H'=2.548; J'=0.9; D_{mg}=2.46) at Site 4, whereas Simpson dominance (D) was highest (D=0.186) at Site 2 (Table 3). The polluted sites (Sites 1 and 2) were more similar, with a similarity index of 88%, followed by Sites 3 and 4, with a similarity index of 78.7%. Site 2, on the other hand, has the least similarity to Sites 3 and 4, with a similarity index of 29% (Table 4).

Phytosociological Characteristics of Aquatic Macrophytes

Frequency: *Commelina benghalensis* had the highest frequency at Sites 1 (77%) and 2 (100%) and *Echinochloa stagnina* highest frequency at Site 3 (100%) and *Pogonatherum crinitum* at Site 4 (100%) (Tables 6-9).

Density: *Commelina benghalensis* had the highest density values at Sites 1 (3.7 plants/m^2) and 2 (3.5 plants/m^2), *Echinochloa stagnina* (4.1 plants/m^2) at Site 3, and *Equisetum hyemale* (4.8 plants/m^2) at Site 4.

Abundance: *Drymaria cordata* (4.9 plants/m^2) had the highest abundance value at Sites 1 and 2. *Echinochloa stagnina* had the highest abundance value at Site 3 (4.1 plants/m^2) and *Equisetum hyemale* had the highest abundance value at Site 4 (7.5 plants/m^2).

Importance Value Index (IVI): Depending on the ratios, the distribution may be a regular (<0.025), random (0.025–0.05), or contagious (>0.05) distribution (Curtis and Cottam, 1956). *Commelina benghalensis* had the highest Importance Value Index at Sites 1 (57) and 2 (65.9). *Echinochloa stagnina* at Site 3 (50.1) and *Equisetum hyemale* at Site 4 (45.7) .

Abundance to frequency ratio (A/F): *Alternanthera sessilis* exhibits the highest abundance to frequency ratio at Sites 1 (0.097) and 3 (0.075). *Colocasia esculenta* (0.151) at Site 2 and *Drymaria cordata* (0.301) at Site 4. The abundance to

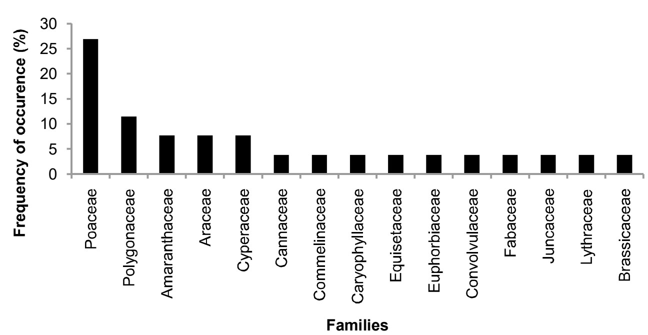

Fig. 1. Family-wise percent distribution of macrophytes

frequency ratio revealed that a regular (<0.025) distribution of macrophytes occurs only at Sites 3 and 4, while a random (0.025–0.05) and contagious (>0.05) distribution of macrophytes occurs at all sites. The majority of the analysed aquatic macrophyte species had a random distribution pattern at all sites.

Impact of pollutants on the distribution of macrophytes: *Alternanthera philoxeroides, Brachiaria mutica, Canna indica*, *Colocasia esculenta, Ipomoea aquatica, and*

Table 4. Aquatic macrophytes similarity index at selected study sites (Per cent)

Sites	4	3	2	1
1	38	40	88	1
2	29	29	1	
3	78.7	1		
4	1			

Table 2. Aquatic Macrophytes recorded during the study period from Tuikual river

Scientific names	Family	Common name	Site 1	Site 2	Site 3	Site 4
Alternanthera philoxeroides (Mart) Griseb	Amaranthaceae	Aligator weed	+	+	-	-
Alternanthera sessilis (L.)	Amaranthaceae	Sessile joyweed	+	-	+	+
Brachiaria mutica (Forsk). Stapf.	Poaceae	Water grass	+	+	-	-
Canna indica L.	Cannaceae	Indian shot	+	+	-	-
Colocasia affinis Schott.	Araceae	Dwarf elephant ear	-	-	+	+
C. esculenta (L.) Schott	Araceae	Elephant ear plant	+	+	-	-
Commelina benghalensis Linn.	Commelinaceae	Bengal day flower	+	+	-	+
Cuphea carthagenesis J.F.Macbr.	Lythraceae	Colombian waxweed	-	-	+	-
Cynodon dactylon (L.) Pers	Poaceae	Bermuda grass	-	-	+	+
Cyperus scariosus R.BR.	Cyperaceae	Umbrella-sedges	+	-	-	+
Drymaria cordata Linn.	Caryophyllaceae	Tropical chickweed	+	+	+	+
Echinochloa stagnina (Retz.) P.Beauv.	Poaceae	Hippo grass	-	-	+	+
Equisetum hyemale L. var. affine (Engelm.)	Equisetaceae	Rough horsetail	-	-	+	+
Homonia riparia Lour.	Euphorbiaceae	Willow leaved water croton	-	-	+	+
Hygroyza aristata (Retz.) Nees.	Poaceae	Asian watergrass	-	-	+	+
Hymenachne pseudointerrupta C. Muell.	Poaceae	Marsh grass	+	-	+	-
Ipomoea aquatica Forssk.	Convolvulaceae	Water spinach	+	+	-	-
Juncus effuses L.	Juncaceae	Soft rush	-	-	-	+
Kyllinga tenuifolia Steud.	Cyperaceae	Low spikesedge	-	-	+	+
Neptunia oleracea	Fabaceae	Water mimosa	-	-	-	+
Phragmites karka (Retz.) Trin. Ex Stand	Poaceae	Tall reed	-	-	+	+
Pogonatherum crinitum (Thunb.) Kunth	Poaceae	Bamboo grass	-	-	+	+
Polygonum barbatum L.	Polygonaceae	Knotweed	+	+	+	+
P. glabrum Willd.	Polygonaceae	Dense flower knotweed	+	+	-	-
P. hydropiper L.	Polygonaceae	Water pepper	+	+	+	+
Rorippa laciniata (F. Muell.)	Brassicaceae	Jagged bitter-cress	+	+	+	-

Symbols: + for "present" and - for "absent"

Table 3. Aquatic macrophytes diversity-dominance indices at selected study sites

Diversity indices	Site 1	Site 2	Site 3	Site 4
Shannon-Weiner diversity index	2.089	1.904	2.472	2.548
Simpson dominance index	0.176	0.186	0.106	0.101
Species evenness	0.790	0.790	0.890	0.900
Species richness	2.140	1.690	2.400	2.460

Table 5. Phytosociological characteristics of aquatic macrophytes at Site 1

Name of the species	Freq (%)	Density	Abundance	Relative Freq	Relative density	Relative abundance	IVI	A/F ratio
Alternanthera philoxeroides	23.3	0.23	1	4.4	1.6	3.5	9.6	0.042
Alternanthera sessilis	13.3	0.2	1.3	2.5	1.2	4.4	8.1	0.097
Brachiaria mutica	40	0.5	1.3	7.5	3.5	4.4	15.4	0.032
Canna indica	23	0.3	1.1	4.4	1.9	4.1	10.3	0.047
Colocasia esculenta	16.6	0.2	1	3.1	1.2	3.5	7.8	0.06
Commelina benghalensis	77	3.7	4.8	14.4	25.8	16.9	57	0.062
Cuphea carthagenesis	20	0.23	1.2	3.8	1.6	4.1	9.5	0.06
Drymaria cordata	70	3.4	4.9	13	23.9	17.2	54.2	0.07
Hymenachne pseudointerrupta	37	0.6	1.6	6.9	4	5.5	16	0.043
Ipomoea aquatica	16.6	0.2	1	3.1	1.2	3.5	7.8	0.06
Polygonum barbatum	57	1.7	3.1	10.6	12.2	10.8	33.6	0.054
Polygonum glabrum	46.6	0.6	1.2	8.8	4	4.3	17	0.025
Polygonum hydropiper	30	0.5	1.8	5.6	3.7	6.3	15.6	0.06
Rorippa laciniata	63.3	2	3.2	11.8	14.1	11.2	37.1	0.05
Total	533.7	14.3	28.5	100	100	100	300	

Table 6. Phytosociological characteristics of aquatic macrophytes at Site 2

Name of the species	Freq (%)	Density	Abundance	Relative Freq	Relative density	Relative abundance	IVI	A/F ratio
Alternanthera philoxeroides	26.6	0.3	1.1	5.9	2.5	4.8	13.2	0.041
Brachiaria mutica	36.6	0.6	1.5	8.2	4.6	6.6	19.4	0.04
Canna indica	20	0.2	1	4.4	1.6	4.3	10.4	0.05
Colocasia esculenta	6.6	0.1	1	1.5	0.5	4.3	6.3	0.151
Commelina benghalensis	100	3.5	3.5	22.2	28.7	15	65.9	0.035
Drymaria cordata	63	3.1	4.9	14.1	25.7	21.2	61	0.077
Ipomoea aquatica	10	0.1	1.3	2.2	1.1	5.7	9	0.13
Polygonum barbatum	56.6	1.7	3.1	12.6	14.2	13.1	39.9	0.054
Polygonum glabrum	43.3	0.6	1.3	9.6	4.6	5.6	19.9	0.03
Polygonum hydropiper	40	0.6	1.6	8.9	5.2	6.8	20.9	0.04
Rorippa laciniata	46.6	1.4	2.9	10.4	11.2	12.6	34.1	0.062
Total	499.3	12.2	23.2	100	100	100	300	

Polygonum glabrum were found only at Sites 1 and 2 (polluted sites) and have a high ecological amplitude. Despite the fact that all of the study sites were polluted, species from the worst water quality sites (Sites 1 and 2) may be considered highly pollution-tolerant due to their high tolerance to extremely polluted water. *Drymaria cordata, Polygonum barbatum,* and *Polygonum hydropiper* were present in all stands, indicating high stress tolerance and being suggested for extracting contaminants from polluted water. Pollution-sensitive species may include *Neptunia oleracea* and *Juncus effusus*, which were found only at the least polluted site (Site 4). Pollutants and unwanted compounds collect in many areas of plants, and the removal tendency of a species depends on the nature of the substance, which varies from species to species. Pollution-tolerant species such as *Drymaria cordata*, *Polygonum barbatum*, and *Polygonum hydropiper* are suggested for removing pollutants from polluted water.

CONCLUSION

The severely disturbed regions (Sites 1 and 2) were polluted by significant anthropogenic systems such as dumping sewage, detergents, rubbish, faulty drainage systems, waste disposal, bathing, and clothes washing directly into water sources. The worst water quality was observed at Sites 2 and 1, followed by Sites 3 and 4. The intensity of pollutants has a significant impact on the diversity and distribution of species. The findings suggest management of the drainage system, diversion of sewer to the sewage treatment plant, and proper treatment of river

Table 7. Phytosociological characteristics of aquatic macrophytes at Site 3

Name of the species	Freq (%)	Density	Abundance	Relative Freq	Relative density	Relative abundance	IVI	A/F ratio
Alternanthera sessilis	13.3	0.1	1	1.5	0.8	3.8	6	0.075
Colocasia affinis	66.6	0.8	1.3	7.3	4.9	4.8	16.8	0.019
Cynodon dactylon	50	0.6	1.1	5.4	3.3	4.3	13.1	0.022
Cyperus scariosus	40	0.4	1.2	4.4	2.7	4.5	11.5	0.03
Drymaria cordata	63.3	0.9	1.4	6.9	5.1	5.2	17.1	0.022
Echinochloa stagnina	100	4.1	4.1	10.9	23.7	15.5	50.1	0.041
Equisetum hyemale	53.3	1.1	2	5.8	6.2	7.6	19.6	0.037
Homonia riparia	90	1.5	1.7	9.8	8.7	6.4	24.8	0.018
Hygroyza aristata	36.6	0.4	1.2	4	2.5	4.5	11	0.032
Hymenachne pseudointerrupta	83.3	1.5	1.8	9.1	8.5	6.7	24.3	0.021
Kyllinga tenuifolia	70	1.2	1.6	7.6	6.8	6.4	20.7	0.022
Phragmites karka	76.6	1.7	2.3	8.3	10.1	8.6	27.1	0.03
Pogonatherum crinitum	73.3	1.4	2	8	8.5	7.6	24.1	0.027
Polygonum barbatum	16.6	0.2	1	1.8	1	3.8	6.6	0.06
Polygonum hydropiper	23.3	0.3	1.1	2.5	1.6	4.4	8.5	0.047
Rorippa laciniata	63.3	1	1.5	6.8	5.6	5.8	18.3	0.023
Total	919	17.2	26.3	100	100	100	300	

Table 8. Phytosociological characteristics of aquatic macrophytes at Site 4

Name of the species	Freq (%)	Density	Abundance	Relative Freq	Relative density	Relative abundance	IVI	A/F ratio
Alternanthera sessilis	40	1.1	2.6	5.4	4.9	5.5	15.7	0.065
Colocasia affinis	50	2	4	6.7	9.1	8.2	24	0.08
Commelina benghalensis	36.6	1	2.8	4.9	4.7	5.8	15.4	0.076
Cyperus scariosus	43.3	1.8	4.1	5.8	8.1	8.3	22.2	0.094
Cuphea carthagenesis	26.6	0.4	1.4	3.6	1.7	2.8	8.1	0.052
Drymaria cordata	16.6	0.8	5	2.2	3.8	10.2	16.3	0.301
Echinochloa stagnina	56.6	0.7	1.2	7.6	3	2.4	13	0.021
Equisetum hyemale	63.3	4.8	7.5	8.5	21.8	15.4	45.7	0.118
Homonia riparia	70	1.6	2.3	9.4	7.3	4.7	21.3	0.032
Hygroyza aristata	50	0.9	1.8	6.7	4.1	3.7	14.5	0.036
Juncus effuses	30	0.5	1.8	4	2.4	3.6	10.1	0.06
Kyllinga tenuifolia	23.3	0.6	2.5	3.1	2.7	5.3	11.1	0.107
Neptunia oleracea	33.3	0.4	1.2	4.5	1.8	2.5	8.7	0.036
Phragmites karka	20	0.9	4.5	2.7	4.1	9.2	16	0.225
Pogonatherum crinitum	100	3.1	3.1	13.4	14.3	6.4	34.1	0.031
Polygonum barbatum	46.6	0.7	1.5	6.3	3.4	3.2	12.8	0.032
Polygonum hydropiper	40	0.5	1.4	5.4	2.6	2.9	10.9	0.035
Total	746	21.8	48.7	100	100	100	300	

water before supply for drinking purposes. Moreover, hospital discharge needs to be checked, as it has a severe health impact on people consuming river water. This research could lead to more in-depth water resource studies as well as the development and execution of effective water management plans. Pollution-tolerant plants can be effectively employed to extract various sorts of contaminants from waste water. Environmental mass awareness campaigns and public involvement should be implemented, and particularly in watershed areas, to educate people about the adverse impacts of water pollution on human health. To prevent future degradation of monitoring river water should be regulated.

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Received 18 February, 2024; Accepted 20 June, 2024

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Date of Publication 01.08.2024