Print ISSN: 2348-4721
Online ISSN: 2349-610X

Journal of Agriculture and Technology

Volume 12 Number 2 September 2025

Cooch Behar Association for Cultivation of Agricultural Sciences

Secretariat

Department of Genetics and Plant Breeding
Uttar Banga Krishi Viswavidyalaya
Pundibari, Cooch Behar 736 165
West Bengal, India

Journal of Agriculture and Technology

Volume 12 Number 2 September 2025

Print ISSN: 2348-4721
Online ISSN: 2349-610X

DISCLAIMER

The authors are solely responsible for the contents of the paper compiled in this volume. The publisher or editors do not take any responsibility for the same in any manner. Errors, if any, are purely unintentional and readers are requested to communicate such errors to the editors or publisher to avoid discrepancies in future.

Journal of Agriculture and Technology (JAT)

Editorial Board for March, 2025 to February, 2027

Journal of Agriculture and Technology (JAT) is a biannual double blind peer reviewed print and online journal published by the **Cooch Behar Association for Cultivation of Agricultural Sciences** in English. The contribution to the journal, except in case of invited articles, is open to the members of the association only. Any non-members submitting a manuscript will be required to become at least annual member for publishing their article. All authors are required to become members. Members are entitled to voting privileges and receipts of publications of the COBACAS. All payments may be paid either in the form of Demand Draft of any national bank drawn in favour of the **Cooch Behar Association for Cultivation of Agricultural Sciences** or may be directly transfer to the account No. 33026323337, SBI, UBKV Pundibari, IFSC Code: SBIN0018606 and MICR code 736002527 and send the electronic receipt copy along with the Membership form and business matters concerning the journal should be address to the Secretary, **Cooch Behar Association for Cultivation of Agricultural Sciences**, Department of Genetics and Plant Breeding, Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar 736 165, West Bengal, India; E-mail: cobacas2013@gmail.com.

The membership fees and journal subscription rate are as follows:

i) Life Member	: Rs. 3000.00
ii) Institutional Member	: Rs. 6000.00
ii) Annual/Ordinary Member	: Rs. 500.00
iii) Farmer Life Member	: Rs. 1000.00
iv) Single copy	: Rs. 400.00

Contents

J. Agric. Technol., 12(2): 1-22 (2025)
Print: ISSN: 2348-4721; Online: ISSN: 2349-610X

Women's Role in Non-Timber Forest Products: Ecological Stewardship and Livelihoods in Northeast India

Shalini Pradhan[1], Sajitha Siril[2], Gemo Tacha[1], Pooja Boro[1], Xena Miksera P Marak[1], Kalkame Ch Momin[3], Gopal Shukla[1*], Sumit Chakravarty[4]

[1]*Department of Forestry, North-Eastern Hill University, Tura Campus, Tura-794 002, Meghalaya, India*
[2]*Department of Silviculture and Agroforestry, College of Forestry, Kerala Agricultural University, Vellanikkara- 680 656, Thrissur, Kerala, India*
[3]*Department of Horticulture, North-Eastern Hill University, Tura Campus, Tura-794 002, Meghalaya, India*
[4]*Department of Forestry, Uttar Banga Krishi Viswavidyalaya, Pundibari-736 165, Cooch Behar, West Bengal, India*

[*]***E-mail***: *gopalshukla12@gmail.com*

Received: 30-03-2025; **Revised:** 23-05-2025; **Accepted:** 01-06-2025

Citation: Pradhan S, Siril S, Tacha G, Boro P, Marak XMP, Momin KC, Shukla G, Chakravarty S. 2025 Women's Role in Non-Timber Forest Products: Ecological Stewardship and Livelihoods in Northeast India. J Agric Technol. 12(2): 1-22.

Non-Timber Forest Products (NTFPs) form the backbone of livelihood for North East Hill (NEH) region indigenous people in India, and women contribute significantly to this in their usually unsung and unseen roles of managing forest resources. This wide-ranging review addresses the multiple ways women contribute in NTFP collection, processing, and trading in eight northeast Indian states and delves into their ecological awareness, economic contributions, and what challenges they face. Based on large literature review and state-level research, the study shows that women provide 70-80% of domestic NTFP harvest, with items extending from medicinal herbs and wild vegetables to bamboo, fibres, and resins. These forest products account for 15-40% of domestic income, acting as important safety nets during agricultural off-seasons. Although they play a central position, women encounter severe structural constraints, such as restricted market access, absence of formal rights over resources, and non-inclusion in policy-making processes. There is limited research on the northeastern hill region, especially with regard to women's involvement in NTFP collection and use. The study highlights the importance of gender-transformative interventions in forest governance, such as skill building, eco-friendly harvesting techniques, collective strengthening of women and policy reforms acknowledging women's contributions. Through the integration of varied scholarly insights and empirical data, this review offers a holistic examination of women's contributions to forest-based economies, presenting critical insights for policymakers, researchers, and development practitioners dedicated to sustainable, inclusive rural development in India's northeastern states.

Keywords: NTFP, Women, Northeast India, Forest Livelihoods, Gender, Ecological Knowledge

INTRODUCTION

Non-timber Forest Products (NTFPs) are all living materials, barring timber, harvested from forests such as edible goods, medicinal crops, fibres, resins, gums, dyes, bamboo, canes, etc., and other plant and animal-based resources (Lepcha *et al*., 2023). These items possess great ecological, economic, and socio-cultural significance, most importantly for communities that depend upon forests (Lepcha *et al*., 2023). NTFPs play a pivotal role in global indigenous populations' subsistence strategies, earning and livelihood, as well as socio-cultural activities (Lepcha *et al*., 2018). In India, particularly in forest-covered areas, NTFPs form a part of the livelihood system of rural and tribal families. NTFPs play an important role in maintaining the rural economy by ensuring food security, additional income, and job opportunities for the people, especially during off-seasons of agriculture (Lepcha *et al*., 2020, 2021; Gurung *et al*., 2022). It has been stated by the Forest Survey of India (Anon., 2023) that about 275 million Indians are dependent on NTFPs for their livelihoods, and a large number of those belong to women and are collectors and processors. The products are usually utilized as a form of safety net for the poor, particularly in backward and inaccessible regions with less accessibility to formal work (Lepcha *et al*., 2018).

The North East Hill (NEH) area of India, including states such as Meghalaya, Nagaland, Manipur, Mizoram, Tripura, Assam, Arunachal Pradesh, and Sikkim, is one of the most bountiful stores of NTFPs because of its rich ecological zones and high forest cover. The area has richly diverse indigenous populations with a strong reliance on forest resources for economic livelihood and cultural practices. Women in this area are the main keepers of traditional ecological knowledge and are pivotal in the collection, processing, and exchange of NTFPs (Chiphang *et al*., 2020; Lepcha *et al*., 2020). Their contribution is not just about gendered labour divisions but also a key element of community resilience and forest-based economy. With the growing significance of NTFPs in sustainable livelihood diversification and the central role played by women in the sector, the review seeks to review and integrate available literature on the contribution of women in the collection of NTFPs in the NEH region. The aims are to critically assess the category of NTFPs harvested, the socio-economic value added by female collectors, the threats they encounter, and the policy and institutional settings that affect their involvement. The review also identifies possible opportunities to enhance women's empowerment and support sustainable forest-based livelihoods through gender-responsive approaches.

The methodology for this review involved a systematic search of peer-reviewed journals, books, and grey literature focused on women’s roles in Non-Timber Forest Products (NTFPs) within the Northeast Hill (NEH) region of India. Databases such as Scopus, Web of Science, and Google Scholar were searched using keywords like “NTFPs,” “women,” “livelihood,” “tribal communities,” and specific state names (e.g., “Meghalaya,” “Arunachal Pradesh”). Literature published between 2000 and 2024 was prioritized to capture both historical and recent trends. Studies were selected based on relevance, methodological rigour, and regional specificity. Qualitative and quantitative findings were synthesized to identify recurring themes such as gendered roles, market participation, policy impacts, and ecological sustainability. Special attention was given to studies highlighting barriers and opportunities for women’s empowerment through NTFP-based livelihoods. This approach ensured a comprehensive and context-specific understanding of the intersection between gender and forest-based economies in the NEH region.

HISTORICAL ASPECT OF NTFPS AND WOMEN IN THE NEH REGION

The history of women and NTFPs in the NEH region goes very deep. It is inextricably intertwined with subsistence economies, indigenous culture, and traditional ecological knowledge systems. For centuries, tribal women like Garo, Khasi, Jaintia, Mizo, Ao, Angami, Apatani, and Adi have been the major collectors and keepers of NTFPs, which has been passed down through oral traditions and matrilineal or clan-based systems of knowledge transmission. In the past, the forests were considered not just natural resources but as sacred commons maintained jointly under customary norms. Women, particularly in matrilineal societies such as the Khasis and Garos of Meghalaya, enjoyed a great degree of autonomy with regard to land and natural resource utilization (Jamir and Nongkynrih, 2002; Nongkynrih, 2012). They practiced seasonal collection of wild edibles, herbs, medicinal plants, fibres, and dyes, which are essential in fulfilling household requirements and traditional healing practices.

Women's role was also seen in customary barter networks and local weekly markets (haats), through which they marketed excess NTFPs such as broom grass (*Thysanolaena maxima*), turmeric, honey, and bamboo products. These customary economic systems date back prior to formal state actions and have long helped to ensure rural household sustainability and women's social agency (Yadav and Misra, 2012). In tribal agricultural societies like jhum (shifting cultivation), women supplemented agricultural yields with forest gathering, providing diversified nutrition and buffer during crop failure. Their experience of wild food plants and medicinal plants was important for community health and nutrition (Jeeva *et al*., 2006). With the passage of time, and after the arrival of colonial forest laws and post-independence forest control, women's traditional rights over forests and their access to forest resources started diminishing, restricting their involvement in decision-making and market processes (Agrawal and Chhatre, 2006). However, customary forest use and gendered task allocation in the collection of NTFPs also persisted unofficially, maintaining rural livelihoods in spite of institutional abandonment. Over the past decades, researchers and development practitioners have stressed reviving and institutionalizing women's customary roles in forest-based livelihoods by acknowledging the historical continuity of their ecological knowledge, conservation ethics, and informal economies.

COMMUNITIES OF THE NEH REGION: A SOCIO-CULTURAL OVERVIEW

The North East Hill (NEH) area of India is one of the most ethnically rich areas of South Asia, consisting of different indigenous communities and tribes, each having distinct languages, customs, and socio-political institutions. The populations of this area are largely tribal in nature, with a considerable number falling under Scheduled Tribes (STs). According to the Census of India (2011), tribal populations make up more than 85% in Mizoram, 86% in Nagaland, 94% in Arunachal Pradesh, and approximately 86% in Meghalaya. These people mainly engage in traditional subsistence livelihoods like shifting cultivation (jhum), horticulture, animal rearing, and forest-based practices, including harvesting Non-Timber Forest Products (NTFPs) (Table 1).

The NEH region societies have a strong cultural heritage, expressed through their traditional folkways, matrilineal societies (e.g., Khasis and Garos of Meghalaya), clan control, oral literature, and customary laws (Nongbri, 2014). Social institutions like Village Councils, Nokmas (Garo), Dolois (Jaintia), and Anghs (Naga) feature prominently in local government and conflict resolution. Traditional gender relations differ considerably. While the majority of NEH tribal societies are patrilineal, some communities such as Khasis, Jaintias, and Garos practice matrilineal systems of inheritance in which women inherit family property and have significant roles in economic and cultural life (Jamir and Nongkynrih, 2002; Sruthi and Mukherjee, 2020).

Table 1. Demographic, cultural, and livelihood features of indigenous communities in northeast India

State	Major communities	Special features	Dominant livelihoods
Arunachal Pradesh	Apatani, Nyishi, Adi, Monpa, Galo	Clan-based societies, shifting cultivation, festivals (Solung)	Jhum farming, forest produce, handicrafts
Nagaland	Ao, Angami, Sumi, Lotha, Chakhesang	Village councils, traditional morung systems	Agriculture, hunting, weaving
Manipur	Tangkhul, Mao, Maram, Meitei (non-tribal), Thadou-Kuki	Mixed tribal-nontribal structure, weaving traditions	Horticulture, forest products, livestock
Mizoram	Mizo (Lusei, Hmar, Lai, Mara)	Christianity influence, community cooperation, broom grass trade	Jhum farming, broom grass, bamboo-based economy
Meghalaya	Khasi, Garo, Jaintia	Matrilineal system, Nokma/Doloi governance, forest cooperatives	Forest NTFPs, horticulture, traditional healing
Tripura	Tripuri, Reang, Jamatia, Halam	Cultural diversity, traditional dance and musical heritage	Bamboo, weaving, shifting cultivation
Sikkim	Bhutia, Lepcha, Limboo	Indigenous conservation ethos, sacred groves	Horticulture, ecotourism, medicinal plant use
Assam (Hill areas)	Karbi, Mishing, Dimasa, Bodo	Hill-plain interactions, mixed ethnic zones	Mixed farming, forest gathering, fisheries

The NEH region societies have a strong cultural heritage, expressed through their traditional folkways, matrilineal societies (e.g., Khasis and Garos of Meghalaya), clan control, oral literature, and customary laws (Nongbri, 2014). Social institutions like Village Councils, Nokmas (Garo), Dolois (Jaintia), and Anghs (Naga) feature prominently in local government and conflict resolution. Traditional gender relations differ considerably. While the majority of NEH tribal societies are patrilineal, some communities such as Khasis, Jaintias, and Garos practice matrilineal systems of inheritance in which women inherit family property and have significant roles in economic and cultural life (Jamir and Nongkynrih, 2002; Sruthi and Mukherjee, 2020).

Language and Ethnic Diversity

Linguistically, the NEH region falls within the Tibeto-Burman and Austroasiatic language families with dozens of mutually unintelligible languages spoken on various hills and valleys (DeLancey, 2010; Post *et al.*, 2015; Post, 2022). This ethnolinguistic diversity renders the region one of India's most intricate socio-cultural landscapes.

Socio-Economic Profile

Despite high cultural endowments, the area continues to experience long-standing development challenges such as poor infrastructure, low industrialization, natural resource dependence, and geographical remoteness. Livelihoods are still very agrarian and forest-based, and access to modern services (education, health, markets) is uneven across districts (Planning Commission, 2014; Singh *et al*., 2020). NTFP-based livelihoods form the core of household economies, particularly among marginalized communities. Women, especially, are the dominant users of forest resources but have restricted institutional support and market access (TRIFED, 2020).

SOCIO-ECONOMIC AND CULTURAL CONTEXT OF WOMEN IN THE NEH REGION

The North East Hill (NEH) region presents a distinctive socio-cultural landscape characterized by remarkable ethnic diversity (Table 2) and varied gender systems significantly influencing women's engagement with forest resources. Unlike much of mainland India, several communities in this region, particularly the Khasi, Jaintia, and Garo tribes of Meghalaya, maintain matrilineal traditions where women inherit property, determine lineage, and exercise significant economic agency (Nongbri, 2014; Nongkynrih, 2020). It is different from the patrilineal systems of Apatani people of Arunachal Pradesh or Adi groups, giving rise to a diverse gender environment in the region.

Table 2. Socio-demographic and cultural parameters influencing women's engagement in NTFP activities in northeast India

Parameter	Details	Source
Demographic background	Predominantly tribal population, rural and scattered habitations	Roy *et al*., 2024
Cultural role of women	Key participants in household economy, food production, weaving, and cultural practices	Ellena and Nongkynrih, 2017
Traditional livelihood activities	Agriculture, weaving, animal husbandry, food processing, and NTFP collection	Kuhnlein *et al*., 2013; Ellena and Nongkynrih, 2017
Dependence on forests and NTFPs	High dependence for food, medicine, fuelwood, income; women manage the collection NTFPs	Seal *et al*., 2015; ICIMOD, 2023
Ecological knowledge	Women hold indigenous knowledge of wild edibles, herbal medicine, and sustainable harvesting	Chiphang *et al*., 2020
Constraints faced	Limited access to formal markets, training, credit, land/resource rights	Bhatnagar and Barman, 2023

Females in NEH tribal societies provide around 65-78% of labour in farm activities and 70-85% in NTFP collection and processing. Such wide participation contributes immensely to economic value, as women-headed NTFP production earns household income in Manipur and Meghalaya (Bordoloi, 2021; Gangmei and Sophia, 2024). Of special significance is their contribution during periods of ecological stress when income from women's

NTFP work raises the income level to counter farm losses (Singha, 2018; Hazarika *et al*., 2024). Local gender dynamics have specific differences in NTFP value chains. In Meghalaya due to matrilineal societies, women exert control over collection, processing and markets of NTFPs (Keeni *et al*., 2018; Shangpliang, 2018$_{a,\ b}$). In Manipur, majority of the population is dependent on forest products for their livelihood, while about women are involved in their collection (FAO 1992; Uniyal et al., 2023). The same trend is witnessed in Arunachal Pradesh, where women are engaged in non-timber forest product (NTFP) collection and sale in 70 % of the instances. Women's participation is high in the majority of the districts, though, except in Changlang, where men are primarily responsible for NTFP activities (Sharma et al., 2015). This imbalance illustrates how cultural systems tend to impact the economic empowerment of women way beyond just the collection activity.

Traditional ecological knowledge (TEK) passing has gendered pathways in the region. Ethnobotanical research by Zhasa *et al*. (2015) recorded 241 plant species belong to 142 families were documented for traditional medicine employed by eight Naga tribes. Martemjen (2017) reported that women have much greater medicinal plant knowledge than men. Likewise, female elderly in Arunachal Pradesh's Adi communities preserve specialized information about wild edible vegetables, such as their nutritional characteristics, how they are harvested, and how to preserve them (Singh *et al*., 2020). This information cache is cultural and economic value that could be used in new markets for natural products. Women are confronted with systematic obstacles to accessing formal institutions of conservation and development despite their efforts. These gaps have in recent times been addressed by new policy innovations. The Meghalaya Community NTFP Cooperative model, created in 2022, has established women-run processing centres that have raised women collectors' income through value addition and enhanced market linkages (Government of Meghalaya, 2023).

DEPENDENCE ON NTFPS IN THE NEH REGION

The NEH region relies heavily on forest resources and is known for its rich biodiversity, with over 8,000 flowering plant species and 400 medicinal plants found across different ecological zones (Chakravarty *et al*., 2012). This biodiversity supports local livelihoods, where non-timber forest products (NTFPs) are not just extra resources but essential for survival, income, food, healthcare, and cultural identity (Sharma *et al*., 2015; Chiphang *et al*., 2020; Lepcha *et al*., 2020). Studies show that NTFPs make up a significant part of annual household income for tribal communities; although this varies between states and depends on how easily they can access markets (Mahapatra *et al*., 2005; Tynsong *et al*., 2012; Jamir, 2015; Lepcha *et al*., 2021; Uniyal *et al*., 2023; Hazari *et al*., 2024). In remote areas of Arunachal Pradesh and Nagaland, people rely more on forest products during times when farming is not possible, making these resources their main source of income. This reliance is especially important in isolated forest villages where there are few other job options. Different communities depend on NTFPs for basic needs, healthcare, earning a living, nutrition, and cultural traditions (Mahapatra *et al*., 2005; Yadav and Misra, 2012; Uniyal *et al*., 2023; Hazari *et al*., 2024).

Multidimensional Dependence Patterns

Subsistence and daily use

Communities often gather wild vegetables, tubers, fruits, bamboo shoots, mushrooms, firewood, and medicinal herbs for their own use. Items like canes, resins, dyes, broom grass, and leaves are also important parts of their material culture (Jeeva *et al*., 2006; Hazari *et al*., 2024). Among the edible plants, cooked leaves were the most commonly used. Species such as *Wendlandia glabrata* (inflorescence, ₹120–150/kg), *Rhus chinensis* (dried fruits, ₹100–150/kg), *Litsea cubeba* (fruits, ₹100–120/kg), *Cycas pectinata* (shoots, ₹80–100/kg), and *Zanthoxylum acanthopodium* (leaves, ₹40–50/kg) were frequently mentioned and had good market value, showing strong potential to improve local livelihoods through sustainable use (Leisembi *et al*., 2024).

Medicinal and health care needs

Traditional herbal medicine remains the primary form of treatment in many villages, with about 65% of basic healthcare needs in remote areas met through traditional remedies (Kongsai *et al*., 2011; Bushi *et al*., 2021). Women and local healers often use plants from the forest, like *Coptis teeta*, *Gentiana chirata*, and *Zanthoxylum species* (Perme *et al*., 2015).

Livelihood and income generation

Non-timber forest products (NTFPs) like broom grass (*Thysanolaena maxima*), bay leaf (*Cinnamomum tamala*), bamboo, turmeric, lac, and honey are important sources of income, especially for women and landless families (Tynsong *et al*., 2012; Yadav and Misra, 2012; Chiphang *et al*., 2020; TRIFED, 2020). Growers start benefiting from the second year. From one hectare, they can earn between INR 500 to 11,000 annually just by selling broom grass flowers. The profit depends on factors like labor efficiency, wages, soil quality, farming practices, market prices, and demand (Tynsong *et al*., 2012).

Seasonal employment and food security

Collecting NTFPs offers important seasonal jobs, especially when farming work is low. In areas with high food insecurity, wild edible plants and forest products help fill key nutritional gaps (Lalramnghinghlova and Jha, 1997; Lalramnghinghlova, 2002). Wild fruits are especially important for the Karbi people, meeting their health, food, and livelihood needs. These fruits provide year-round dietary and nutritional support for communities in Karbi Anglong (Kar *et al*., 2008).

Cultural and religious practices

Many NTFPs play a vital role in rituals, crafts, community events, and festivals, showing their cultural importance beyond money in tribal life. Studies have found plant species used only in rituals by the Nyishi tribe and others key to traditional crafts among the Khasi people (Rawat and Choudhury, 1998; Nath and Dutta, 2000; Tynsong *et al*., 2020; Marbaniang *et al*., 2024).

Regional variation in NTFP dependence

Dependence on NTFPs varies widely across states (Table 3). In Mizoram, broom grass collection has grown from a basic activity into an organized industry with market links that boost household incomes (Lawmchullova and Lalngaihawma, 2021). In Tripura, bamboo-based livelihoods are mostly for subsistence but have growing commercial potential through artisan programs (Jenner and Selvan, 2020; Sil *et al*., 2020). Despite their economic importance, policies have not fully recognized NTFPs' key role in local livelihoods. Access to resources is often limited by regulations, especially affecting women collectors (Shangpliang, 2012).

Table 3. State-wise analysis of major NTFPs and household dependence patterns in northeast India

State	Major NTFPs Used	Dependency	References
Arunachal Pradesh	Cane, bamboo, medicinal plants, wild edibles	Local communities depend on NTFPs for food and medicine.	Sharma *et al*., 2015
Meghalaya	Broom grass, bay leaf, honey, tubers	Rural households highly depend on NTFP collection and trade.	Jeeva *et al*., 2006
Nagaland	Wild fruits, mushrooms, medicinal herbs	Widespread use for domestic and barter trade.	Martemjen, 2017
Manipur	Bamboo, resins, wild edibles, medicinal plants	Integral to hill tribes' seasonal livelihood strategies.	Uniyal *et al*., 2023
Mizoram	Broom grass, turmeric, forest fruits, bamboo	Broom grass alone contributes major chunk of income in some villages.	Lalramnghinghlova, 2002; TRIFED, 2020
Sikkim	Spice, medicinal plants, edible flower and shoots. *Diploknema butyracea* used cosmetic and seed for butter.	Critical role of NTFPs in the socio-economic fabric of rural Sikkimese communities.	Pradhan and Singh, 2019
Tripura	Bamboo, wild tubers, leaves, cane-based crafts	Livelihood dependence among Reang and Jamatia tribes. Approximate 30 % annual household income form NTFPs.	Hazari *et al*., 2024

DIVERSITY AND TYPES OF NTFPS COLLECTED BY WOMEN

Women in the NEH region of India play a key role in gathering, processing, and using a wide variety of non-timber forest products (NTFPs). These products are essential for household needs, traditional healthcare, food security, and earning income. The variety of NTFPs collected reflects the region's rich biodiversity and the deep traditional ecological knowledge of Indigenous communities. The NTFPs gathered by women fall into several categories, such as edible items (wild fruits, tubers, leafy greens, mushrooms), medicinal plants, fibers and leaves (used for weaving and mat-making), resins and gums, natural dyes, bamboo and cane, honey and bee products, aromatic plants, lac and natural polymers, fodder, and fuelwood (Table 4).

Table 4. Diversity, seasonal availability, indigenous knowledge, and distribution of NTFPs collected by women in northeast India

Category of NTFP	Common species	Availability	Indigenous knowledge	Distribution	References
Edible Products	Wild fruits (*Myrica esculenta*, *Elaeagnus latifolia*, *Garcinia* spp., *Docynia indica*, *Zizyphus* spp.), wild tubers (*Dioscorea* spp.), leafy greens, bamboo shoots, mushrooms (*Termitomyces* spp.)	Mostly monsoon and post-monsoon	Selective plucking, knowledge of edible vs. toxic varieties, seasonal harvesting patterns	All NEH states, especially Arunachal Pradesh, Meghalaya, Nagaland	Jeeva *et al*., 2006; Acharya *et al*., 2015
Medicinal Plants	*Zingiber officinale*, *Centella asiatica*, *Phyllanthus emblica*, *Acorus calamus*, *Gentiana chirata*, *Coptis teeta*, *Zanthoxylum armatum*, *Hedychium* spp., *Paris polyphylla*, *Taxus baccata*	Year-round, with seasonal peaks	Traditional healing practices, harvesting roots without damaging mother plant, ethnomedicinal knowledge	Arunachal Pradesh, Sikkim, Manipur, Meghalaya	Sharma *et al*., 2015
Fibers and Leaves	Broom grass (*Thysanolaena maxima*), palm leaves (*Phoenix acaulis*), banana fiber (*Musa* spp.), *Sterculia villosa*	Primarily dry season	Harvesting mature leaves without uprooting; drying and curing techniques	Assam, Tripura, Mizoram, Nagaland	Jamir, 2015; ICIMOD, 2023
Resins and Gums	Pine resin, sal resin (*Shorea robusta*), *Canarium strictum*, *Sterculia urens* (karaya gum), lac	Dry season	Controlled tapping to avoid tree damage, use of natural containers, sustainable extraction methods	Meghalaya, Assam, Arunachal Pradesh	Sharma *et al*., 2015; TRIFED, 2020
Natural Dyes	Indigo leaves, turmeric, tree barks (*Terminalia* spp.), *Bixa orellana* (annatto), *Rubia cordifolia*, *Morus alba*	Seasonal depending on species	Extraction techniques, colour fixation using minerals and fermentation	Meghalaya, Manipur, Mizoram, Arunachal Pradesh	Jeeva *et al*., 2006
Bamboo and Cane	*Dendrocalamus hamiltonii*, *Bambusa tulda*, *Dendrocalamus giganteus*, *Calamus tenuis*, *Calamus floribundus*	Throughout the year, peak in summer	Age-specific harvesting, use of sharp tools to prevent plant injury, sustainable cutting practices	All NEH states, especially Tripura, Meghalaya, Mizoram, Arunachal Pradesh	Acharya *et al*., 2015

Aromatic Plants	*Cymbopogon flexuosus* (lemongrass), *Mentha arvensis*, *Ocimum* spp	Year-round with seasonal variations	Traditional distillation techniques, sustainable leaf harvesting	Assam, Arunachal Pradesh, Manipur	Planning Commission, 2014; Sharma *et al*., 2015
Honey and Bee Products	Wild honey, bee wax	Seasonal, peaks in flowering periods	Traditional beekeeping, knowledge of hive locations, sustainable harvesting	Nagaland, Meghalaya, Manipur	TRIFED, 2020
Fodder and Fuelwood	Wild grasses, twigs, dry branches	Year-round	Drying methods, collection from fallen branches to reduce forest degradation	All NEH states	Rai and Chakrabarti, 1996
Lac and Natural Polymers	*Kerria lacca* (lac insects on *Schleichera oleosa*, *Butea monosperma*)	Seasonal	Traditional inoculation and harvesting techniques	Manipur, Assam, Tripura	TRIFED, 2020

Many of these items are used at home or sold in local markets, playing an important role in the local economy (Yadav and Misra, 2012; Chiphang *et al*., 2020; Lepcha *et al*., 2020; Gangmei and Sophia, 2024). The availability of these NTFPs depends on the season, climate, forest type, and harvesting cycles. For example, wild fruits and mushrooms are mostly collected during the monsoon, while medicinal roots and resins are gathered more in the dry season (ICIMOD, 2023). Women have detailed knowledge of sustainable harvesting methods—like selective picking, rotating harvest areas, and timing collection to avoid overuse—that has been passed down through generations. This knowledge helps protect forest ecosystems in the long run and highlights women's important role as caretakers of forest biodiversity and community strength (Jeeva *et al*., 2006).

Market demand strongly influences which NTFPs women focus on collecting. Products with higher commercial value, such as broom grass (*Thysanolaena maxima*), tamarind, bay leaves, mushrooms, and wild fruits, are collected more intensively, especially in areas close to markets (Sharma *et al*., 2015; Chiphang *et al*., 2020). The closer a household is to a market; the more likely it is to collect NTFPs for sale, while remote households mainly collect for their own use. Women also adjust when and how much they harvest based on seasonal market trends and price changes. However, this market-driven collection can sometimes lead to overharvesting, which raises concerns about sustainability and threatens biodiversity if not managed well (Sharma *et al*., 2015). Climate change is increasingly affecting the availability and seasonal patterns of NTFPs, changing how communities depend on them, especially in forest-dependent areas like Northeast India. Rising temperatures, unpredictable rainfall, and shifts in natural cycles have disrupted the growth and fruiting of important NTFPs like wild mushrooms, medicinal herbs (*Paris polyphylla*), and bamboo shoots. For instance, in Arunachal Pradesh, earlier flowering and lower regeneration of *Illicium griffithii* a valuable medicinal NTFP have been linked to changes in temperature and rainfall, causing reduced harvests and changes in collection timing (Saha and Sundriyal, 2010). This affects the income and food security of tribal households and pushes communities to either increase harvesting pressure or look for other livelihoods, adding more stress to forest ecosystems. This combination of ecological challenges and social vulnerability shows the urgent need for climate-resilient strategies to manage NTFPs.

GENDERED ROLE IN NTFP VALUE CHAIN

Women in the NEH region play a key role at many stages of the NTFP value chain, including collecting, processing, storing, adding value, and selling. Although their work is often informal, it is very important for household income, food security, and local economies. However, the way tasks are divided by gender in this sector shows deeper inequalities in access to resources, market benefits, and decision-making power (ICIMOD, 2023; Thapa and Singh, 2023). Women mainly collect NTFPs, often traveling long distances into forests to gather wild foods, medicinal plants, leaves, fibers, resins, and aromatic plants. They have detailed knowledge about plants, sustainable harvesting, and the best times to collect to protect resources (Thapa and Singh, 2023). After gathering, women handle basic processing like cleaning, drying, curing, grinding, and bundling. In many communities, they also add value by making herbal products, fermented foods, natural dyes, woven fibers, bamboo crafts, and herbal teas, which increase the products' market value (Jeeva *et al*., 2006; Sarker, 2017).

Women are very active in local markets and informal trade. They sell NTFPs at rural weekly markets, roadside stalls, and community fairs. Items like wild fruits, mushrooms, broom grass, turmeric, bamboo baskets, honey, lac products, and fermented foods are often sold directly by women, providing important income, especially when farming income is low (Sarmah *et al*., 2008; Chiphang *et al*., 2020; Peerzada *et al*., 2022; Hazari *et al*., 2024). Still, they face challenges like poor infrastructure, restrictions on movement, and limited bargaining power, which make it hard to reach bigger markets and get fair prices. Despite their large contributions, women usually have little control or ownership over forest resources and the income they generate. In many tribal areas, traditional land rights don't always give women formal resource rights. Their role in community decision-making, forest management groups, or cooperatives is often small or only symbolic. Without formal inclusion in forest governance, their voices are often ignored in resource management and benefit sharing (Sarker, 2017; ICIMOD, 2023). Supporting gender-inclusive value chains—through training, women's cooperatives, better access to credit, market facilities, and resource rights—can greatly improve women's social and economic status and help sustain forest livelihoods (Agarwal, 1992).

NTFPs are vital for the livelihoods of tribal and rural communities in the NEH region. Women, as main collectors and processors, earn significant income and support their families with these forest activities. For many households, NTFP income helps during farming off-seasons and is sometimes the only income for landless or marginal families (Peerzada *et al*., 2022; Hazari *et al*., 2024). Many NTFPs like wild vegetables, mushrooms, medicinal plants, fruits, tubers, and honey are eaten directly, reducing the need to buy food. Women's involvement in informal trade and small businesses has built strong community forest economies across the region. Looking at states, NTFP livelihoods make a big economic impact (Table 5). In Meghalaya, broom grass collection and processing bring in a large part of household income in the Garo and Khasi Hills, with about 60 % of rural women involved (Nongkynrih, 2012; Lahiri, 2016). In Manipur, women-led markets are important centers for NTFP trade, with women vendors earning a significant share of their household income from NTFPs in hill districts (Mishra 2012; Uniyal *et al*., 2023).

Table 5. State-wise economic contribution of NTFPs to women's livelihoods in northeast India

State	NTFPs collected by women	Contribution to household income	Livelihood activity	Reference
Meghalaya	Broom grass, turmeric, bay leaf, wild fruits, mushrooms	Annual income enhanced in Garo and Khasi Hills	60% of rural women engage in broom grass trade; ₹ 10,000–15,000 per family/year income from NTFPs	Nongkynrih, 2012
Nagaland	Bamboo, cane, wild tubers, edible insects, medicinal herbs	Household income in Tuensang and Mon districts has increased	NTFP sale supports traditional barter markets and provides food security during lean months	ICIMOD, 2023
Manipur	Wild leafy vegetables, mushrooms, bamboo shoots, medicinal plants	House hold income improved	Women-led markets like Ima market or mother market are a hub for NTFP trade and women vendors depend on NTFPs	Sinha and Sinha, 2013; Uniyal *et al*., 2023
Mizoram	Bamboo, ginger, wild fruits, medicinal roots	Enhanced of income for smallholders	Bamboo-based microenterprises and women's self-help groups contribute significantly to livelihoods	Ramundanga and Ramswamy, 2017
Assam (Hills)	Lac, medicinal herbs, bamboo, mushrooms	Significantly income increased among tribal households	Women's cooperatives in lac processing and herbal medicine production improving incomes	Dutta, 2014
Sikkim	Wild herbs, broom grass, medicinal plants, bamboo	10–15% in rural households	NTFPs integrated into eco-tourism and organic farming; women involved in high-value herbal products	Pradhan and Singh, 2019; Tamang *et al*., 2024
Tripura	Bamboo, broom grass, honey, mushrooms, sal leaves	Income enhanced in Tribal belts	Women participate in minor forest produce collection and rural haats; SHGs engaged in bamboo craft	ICIMOD, 2023

CHALLENGES FACED BY WOMEN IN NTFP COLLECTION

Women in the Northeast Hill (NEH) region of India play a key role in collecting, processing, and trading NTFPs. However, they face many challenges that affect their economic growth, health, and the long-term sustainability of their forest-based work. These challenges come from environmental, policy, and social factors. Despite being the main collectors of NTFPs, women encounter social and cultural barriers that limit their involvement in decision-making, access to resources, and fair benefits. Poor infrastructure, gender bias in trade, and lack of transparent pricing make it harder for them to participate fully in the market. Still, efforts like forming women-led Self-Help Groups (SHGs) and providing training on adding value to products in states like Meghalaya and Nagaland have helped increase their income and bargaining power. On top of this, many women struggle with limited access to mobile networks, digital skills, and online marketplaces, which keeps them out of new market opportunities and information sources, widening the gender gap. To truly empower these women and support sustainable NTFP livelihoods, targeted policies, skill development, and better digital access are essential.

Physical burden and health risks

Women collectors often face tough physical work, like walking long distances over rough land, carrying heavy loads, and working many hours without enough food or rest. This can cause chronic tiredness, muscle and joint problems, and exposure to wild animals and harsh weather (Thapa and Singh, 2023). Also, handling wild or medicinal plants without protective gear can lead to skin infections, breathing problems, and accidental poisoning. In the Garo Hills (Meghalaya), a study found that women spend number of hours a day during busy collection times, carrying lot of loads, which impacts their health over time (Borah, 2019).

Limited access to markets and fair pricing

Women often have limited mobility and less access to formal markets, which makes them rely on middlemen or local traders who offer low prices (Agarwal, 1992). They lack market knowledge, negotiation skills, and transport options, which restrict their earning potential (ICIMOD, 2023). Their products are often undervalued because of poor quality grading and few chances to add value. In Manipur, women who sell non-timber forest products (NTFP) face exploitation due to the absence of collective bargaining, resulting in lower incomes compared to urban retail markets (Samantroy, 2006; Devi and Singh, 2013).

Lack of policy support, recognition, and land/resource rights

Although women play a key role in forest-based economies, they are often excluded from forest governance, policy planning, and benefit-sharing. Customary land tenure systems and patriarchal norms prevent women from owning or inheriting forest lands, even though they rely heavily on these resources (Agarwal, 2009). Additionally, forest laws and programs like the Forest Rights Act (2006) often fail to address gender-specific rights because of lack of awareness or administrative obstacles. In Arunachal Pradesh, few women knew about their rights under the FRA, and even fewer participated in Joint Forest Management Committees.

Degradation of forest resources and climate vulnerability

Women collectors are being hit harder by deforestation, overharvesting, forest fires, and climate-related loss of biodiversity. These changes are making non-timber forest products (NTFPs) like wild fruits, medicinal herbs, and broom grass harder to find and lower in quality. Climate change is also shifting when these resources are available, which impacts their income and food security.

POLICY FRAMEWORK AND INSTITUTIONAL SUPPORT

The policy and institutional landscape governing NTFP collection and trade in India, including the North East Hill (NEH) region, comprises a combination of central laws, state-level regulations, welfare schemes, and development programs. These frameworks aim to support forest-dependent communities but often fall short in gender inclusivity, implementation efficiency, and localized adaptation to the unique socio-cultural contexts of NEH states.

Existing policies and schemes related to NTFPs

Several central and state-level policies recognize the importance of NTFPs for rural and tribal livelihoods, with varying degrees of success in addressing the role of women (Table 6).

Table 6. Key policies and institutional support for NTFP management in northeast India

Policy/Scheme	Relevance to NTFPs and Women
Forest Rights Act (FRA), 2006	Recognizes community rights over forest resources and Minor Forest Produce (MFP); aims to empower forest dwellers including women.
National Policy on NTFPs (Proposed Draft, 2022)	Focuses on sustainable NTFP management, equitable benefit sharing, and strengthening value chains. Gender inclusion emphasized but not operationalized.
Mechanism for Marketing of Minor Forest Produce (MSP-MFP)	Launched by TRIFED under Van Dhan Yojana—provides Minimum Support Price (MSP) and market access for tribal collectors, including women SHGs.
National Bamboo Mission (NBM)	Supports bamboo-based livelihoods; in NEH, it promotes women-run nurseries and bamboo craft enterprises.
State Forest Policy (Various NE States)	Some NE states (e.g., Mizoram 2019, Meghalaya Draft Forest Policy 2023) have NTFP-specific clauses, but enforcement is inconsistent.

Implementing institutions and their effectiveness

A diverse array of institutions contributes to NTFP development, capacity building, and market facilitation across the Northeast region. Forest Departments handle resource management, training, and joint forest management, but often face challenges in applying gender-sensitive methods and reaching out effectively at the village level. At the same time, Cooperatives and Self-Help Groups have become strong grassroots models that help with collective bargaining, access to credit, and small business growth in the NTFP sector. Women-led SHGs in Meghalaya, Manipur, and Mizoram have been successful in producing and selling broom grass, herbal teas, and bamboo crafts. Groups like North East Network, Action Aid India, and WWF-India work to boost women’s skills, promote ecological sustainability, and encourage gender-inclusive forest governance. TRIFED runs important programs like Van Dhan Yojana and Minimum Support Price schemes for Minor Forest Produce in the Northeast. However, involvement is still limited due to lack of gender-focused outreach.

Implementation gaps

Although community participation and gender roles are recognized in policies, putting them into practice faces many challenges. In the NEH region, very meager numbers of women-run SHGs are linked to formal forest livelihood programs or markets (ICIMOD, 2023). Without gender-specific data, policies often overlook the unique roles and labor women contribute in NTFP value chains. This leads to poor representation in planning and funding. Tribal women’s limited awareness of their rights under various schemes makes the situation worse. Additionally, patriarchal land systems and traditional laws often exclude women from owning resources and being part of decision-making. Women’s involvement is mostly limited to collecting and selling raw products, with few chances to engage in processing, branding, or reaching high-value markets.

To better support women in NTFP management, several actions are needed: integrating gender perspectives in forestry policies and FRA implementation; strengthening women’s SHGs and cooperatives by improving access to credit, infrastructure, and training; increasing awareness, literacy, and market knowledge through local capacity-building; ensuring women have real roles in Forest Management Committees and Van Dhan Vikas Kendras; and creating gender-responsive monitoring and evaluation systems for NTFP programs. These steps can help break down barriers and provide fairer opportunities for women across the NTFP value chain.

OPPORTUNITIES AND RECOMMENDATIONS

Women play a central role in the NTFP value chain, and there is great potential to improve their forest-based livelihoods through focused efforts on empowerment, sustainability, and fair development. The following strategies can help remove barriers and promote gender-sensitive forest governance.

Skill development and capacity building

Women in the NEH region have rich traditional knowledge but often lack formal skills in value addition, quality control, and entrepreneurship. Studies show that skill training can boost women's income in Meghalaya and Nagaland. Regular training programs on post-harvest management and value addition, along with vocational centers working with Krishi Vigyan Kendras, TRIFED, and NGOs, can greatly improve women's technical and business skills. Adding lessons on forest rights and sustainable harvesting will also help women understand their legal entitlements under government schemes.

Sustainable harvesting and conservation practices

Overharvesting NTFPs harms the environment and threatens long-term livelihoods. ICIMOD (2023) suggests combining traditional ecological knowledge with modern sustainable methods through women-led forest user groups. Teaching women resource assessment, rotational harvesting, and nursery development supports conservation while securing income. Growing high-value NTFPs in agroforestry or community plantations and involving women in resource monitoring keeps them active in protecting the environment.

Strengthening women's collectives and market linkages

Women's roles often stop at collection, with little involvement in trade or decision-making. Building stronger women-led SHGs and Producer Groups can boost their bargaining power and marketing skills. Helping women access markets through *rural haats*, e-commerce, and ties with Van Dhan Vikas Kendras (VDVKs), as well as supporting credit and branding efforts can change their role in the value chain.

Gender-sensitive forest governance and policy reforms

Institutions often overlook gender in forest rights and benefit-sharing. TRIFED (2020) highlighted that gender balance in VDVKs improves transparency and women's leadership. Ensuring women have seats on Joint Forest Management and Biodiversity Management Committees, and updating policies under the Forest Rights Act to be gender-responsive, will bring lasting change. Creating gender-disaggregated data and legally recognizing women's resource ownership, especially in tribal areas, will promote fair governance and sustainable forest livelihoods. The figure 1 highlights four key areas: skill development, sustainable harvesting, market linkages, and governance reforms. Each area includes clear steps and responsible institutions. This combined approach addresses both immediate economic needs and deeper structural challenges, helping tribal women move from subsistence activities to sustainable livelihoods while strengthening their decision-making power in the NTFP sector.

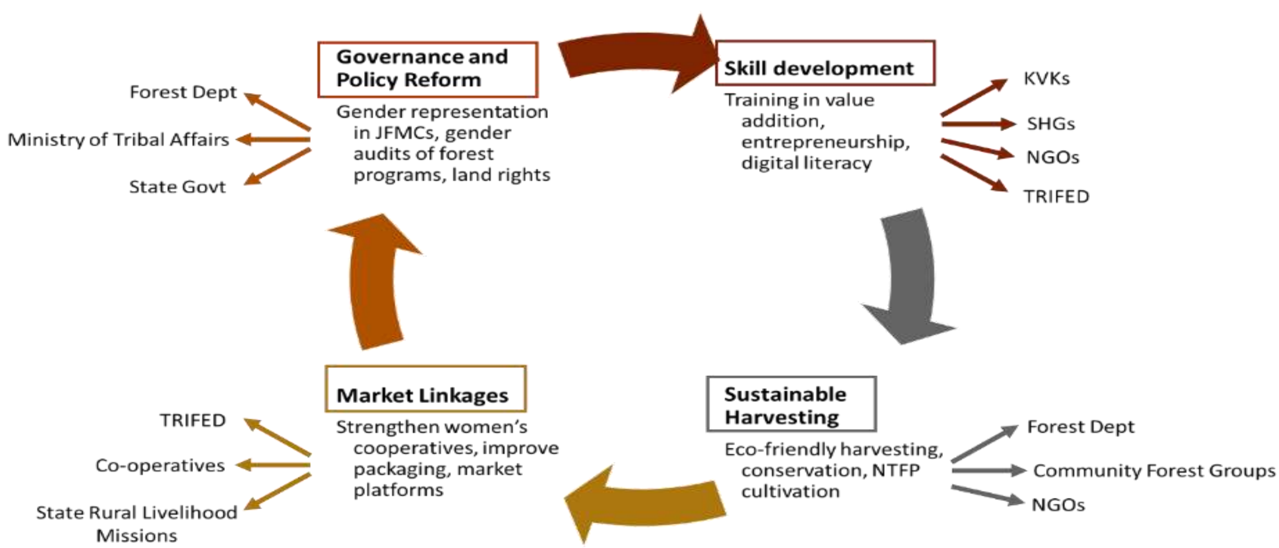


Figure 1. Strategic recommendations for tribal women's empowerment through NTFP

Future research on Non-Timber Forest Products (NTFPs) and women in the Northeast Hill (NEH) region of India should focus on analyzing the value chains with a gender perspective. This means looking closely at women's roles in collecting, processing, and selling important NTFPs like broom grass and bay leaves. It's important to study how climate change affects women's livelihoods, especially how changes in resource availability impact their income, workload, and ways of adapting. Research should also explore how digital tools, like mobile apps and e-commerce, can help women in remote forest areas access markets more easily. Understanding local forest governance systems is key to seeing how traditions and institutions affect women's participation and their rights to resources (Agarwal, 2009). Lastly, evaluating government programs such as the Van Dhan Yojana and Self-Help Group (SHG) enterprises is necessary to understand their long-term effects on tribal women's socio-economic status. This research will support the creation of gender-inclusive policies and sustainable management of NTFPs in the region.

CONCLUSION

This review emphasizes the critical role that women play in the NTFPs sector in the hill regions of Northeast India. Through their full participation in NTFP value chains, women not only contribute significantly to household income but also act as pillars of community resilience, guardians of traditional ecological knowledge, and more. Their contributions cover a wide range of goods, such as natural dyes, bamboo, medicinal plants, and wild edibles. Despite structural obstacles like restricted resource rights, limited market access, and exclusion from decision-making, they provide income, healthcare resources, and food security. In this ecologically sensitive area, women's ecological knowledge and stewardship are essential to preserving biodiversity and promoting livelihoods that are climate resilient. For inclusive rural development and sustainable forest economies, women's empowerment in the NTFP sector is crucial. Gender-transformative strategies are needed for this, such as enhanced collectives, capacity building in value addition and sustainable harvesting, equitable forest governance, and gender-sensitive policy reforms.

REFERENCES

Acharya SK, Gupta G, Biswas A, Mishra GC. 2015. Bamboo in North-East India the Ecology, Economy, and Culture. Krishi Sanskriti Publications. https://www.nhbs.com/bamboo-in-north-east-india-book.

Agarwal B. 2009. Gender and forest conservation: The impact of women's participation in community forest governance. Ecological Economics 68: 2785–2799.

Agarwal, B. 1992. The gender and environment debate: Lessons from India. Feminist Studies 18: 119–158.

Agrawal A, Chhatre A. 2006. Explaining Success in the Commons: Community Forest Governance in the Indian Himalayas. World Development 34: 149–166. https://doi.org/10.1016/j.worlddev.2005.07.013.

Anonymous. 2023. India State of Forest Report 2023. Forest Survey of India, Ministry of Environment, Forest and Climate Change, Government of India.

Bhatnagar P, Barman R. 2023. Role of non-timber forest products (NTFPs) in rural livelihoods: A study of Dabhaura Forest Range in Rewa district of Madhya Pradesh (India). Journal of Non-Timber Forest Products 30: 223-229. https://doi.org/10.54207/bsmps2000-2024-X1HLS4.

Borah S. 2019. Determining drudgery prone household activities performed by hilly tribal women of West Garo hills of Meghalaya. Indian Journal of Hill Farming 32: 227-230.

Bordoloi P. 2021. Women in agriculture: An ecological and socio-economic study of Meghalaya, North East India. Biological Forum -An International Journal 13: 532-536.

Bushi D, Bam K, Mahato R, Nimasow G, Nimasow OD, Tag H. 2021. Ethnomedicinal plants used by the indigenous tribal communities of Arunachal Pradesh, India: a review. Ethnobotany Research and Applications 22: http://dx.doi.org/10.32859/era.22.34.1-40.

Census of India. 2011. Primary Census Abstract for Scheduled Tribes. Office of Registrar General & Census Commissioner, Ministry of Home Affairs, GoI, New Delhi.

Chakravarty S, Suresh CP, Puri A, Shukla G. 2012. North East India the geographic gateway of India phytodiversity. Indian Forester 138: 702-709.

Chiphang S, Singh R, Feroze SM, Singh NU, Chauhan JK, Devarani L. 2020. Determinants of food security for the organic farm households in Sikkim: a logistic approach. Indian Journal of Economics and Development 8(2): 83–90. https://doi.org/10.17485/ijed/2020/v01i01/149882.

DeLancey S. 2010. Language replacement and spread of Tibeto-Burman. Journal of South-East Asian Linguistics Society 3: 40-55.

Devi CN, Singh RKB. 2013. Role of Women in the socio-economic development of Manipur. In: Women in North East India: Status Empowerment and Development Perspectives, eds. Sinha H, Sinha S. Akanksha Publishing House, Guwahati.

Dutta P. 2014. Fostering economic development through MSMEs: A study of the Barpeta. Indian Stream Research Journal 4: 1-6.

Ellena R, Nongkynrih KA. 2017. 2Changing gender roles and relations in food provisioning among matrilineal Khasi and patrilineal Chakhesang Indigenous rural People of North-East India. Maternal & Child Nutrition 13(S3): e12560. https://doi.org/10.1111/mcn.12560.

FAO. 1992. Forests, Trees and Food. FAO, Rome.

Gangmei P, Sophia A. 2024. Economic empowerment of tribal women through non-timber forest products. Economic Affairs 69: 769-775. http://doi.org/10.46852/0424-2513.2.2024.37.

Government of Meghalaya. 2023. Annual Report on Community Forest Management Initiatives. Department of Forests and Environment, Shillong.

Gurung T, Tamang, M, Shukla G, Panwar P, Chakravarty S. 2022. NTFP and homegarden vis-à-vis land degradation neutrality: sustainable livelihood and development. In: Land Degradation Neutrality: Achieving SDG 15 by Forest Management, eds. Panwar P, Shukla G, Bhat JA, Chakravarty S. Springer Nature Singapore Pte Ltd. Pp. 419-436. http://dx.doi.org/10.1007/978-981-19-5478-8_22.

Hazari S, Kalita M, Lahiri B. 2024. Non-timber forest products and their contribution to tribal households' income of West Tripura, India. Agricultural Research Journal 61: 101-107. http://dx.doi.org/10.5958/2395-146X.2024.00015.9.

Hazarika A, Nath AJ, Reang D, Pandey R, Sileshi GW, Das AK. 2024. Climate change vulnerability and adaptation among farmers practicing shifting agriculture in the Indian Himalayas. Environmental and Sustainability Indicators 23: 100430. https://doi.org/10.1016/j.indic.2024.100430.

ICIMOD. 2023. Gender and Forest-Based Livelihoods in the Eastern Himalayas: Status and Challenges. International Centre for Integrated Mountain Development, Kathmandu.

Jamir A 2015. Shifting options: a case study of shifting cultivation in Mokokchung district in Nagaland, India. In: Shifting Cultivation, Livelihood and Food Security, New and Old Challenges for Indigenous Peoples in Asia, ed. Christian E. The Food and Agriculture Organization of the United Nations and International Work Group for Indigenous Affairs and Asia Indigenous Peoples Pact, Bangkok.

Jamir AA, Nongkynrih K. 2002. Understanding Land Ownership and Management Systems of the Khasi–Jaintia and Garo Societies of Meghalaya. International Fund for Agricultural Development, Rome.

Jeeva S, Mishra BP, Venugopal N, Laloo RC 2006. Traditional knowledge and bio-resource utilization among tribes of Meghalaya. Indian Journal of Traditional Knowledge 5: 501–509.

Jenner VG and Selvan T. 2020. Prospects of bamboo in livelihood enhancement of rural women through incense stick and its role in mitigating rural poverty – a model. ISTF News Letter http://doi.org/10.13140/RG.2.2.24065.22889.

Kar A, Borkataki S, Borthakur SK. 2008. Wild edible fruits of the Karbi's of Karbi Anglong district of Assam, India. Pleione 2: 175-181.

Keeni M, Takashino N, Nongkynrih AK, Fuyuki K. 2018. Women empowerment in a rural matrilineal society of Meghalaya, India. Journal of Asian Rural Studies 2: 144-152.

Kongsai M, Saikia SP, Kayang H. 2011. Ethnomedicinal plants used by different tribes of Arunachal Pradesh. Indian Journal of Traditional Knowledge 10: 541-546.

Kuhnlein HV, Erasmus B, Spigelski D, Burlingame B. 2013. Indigenous peoples' food systems and well-being: Interventions and policies for healthy communities. Food and Agricultural Organization, Rome.

Lahiri B. 2016. Agricultural information seeking behaviour of Garo tribal farmers of Meghalaya, India. Ecology, Environment and Conservation 22: 227-236.

Lalramnghinghlova H, Jha LK. 1997. Forest Resources: An Overview. In: Natural Resource Management, Vol I, eds. Jha LK, Nangia SB. A.P.H. Publishing Corporation, New Delhi. Pp. 203-255.

Lalramnghinghlova H. 2002. Bioresources of Mizoram: An overview. Journal of the North Eastern Council 56-64.

Lawmchullova I, Lalngaihawma J. 2021. Jhum and broom cultivation in Saipum village, Mizoram: A comparative study. Geographic 16: 68-74.

Leisembi MM, Panmei R, Adhikary P, Dilip S, Loushambam RS. 2024. A review of wild edible plants in Manipur: enhancing sustainable livelihoods and economic development in the Indo-Myanmar hotspot region Ethnobotany Research and Applications 29: 59. http://doi.org/10.32859/era.29.59.1-50.

Lepcha LD, Sarkar BC, Shukla G, Chakravarty S. 2023. Non-Timber Forest Products: Diversity, Utilization, and Dependency in Fringe Areas of Jaldapara National Park in Indian Sub-Himalayan Region. In: Floristic Diversity - Biology and Conservation, eds. Shukla G, Bhat JA, Chakravarty S, Almutairi AW, Li, M. Intech Open. http://dx.doi.org/10.5772/intechopen.113271.

Lepcha LD, Shukla G, Moonis M, Vineeta, Bhat JA, Kumar M, Chakravarty S. 2021. Seasonal relation of NTFPs and socio-economic indicators to the household income of the forest-fringe communities of Jaldapara National Park. Acta Ecologica Sinica https://doi.org/10.1016/j.chnaes.2021.03.002.

Lepcha LD, Shukla G, Pala NA, Vineeta, Pal PK, Chakravarty S. 2018. Contribution of NTFPs on livelihood of forest-fringe communities in Jaldapara National Park, India. Journal of Sustainable Forestry 38: 213-229. https://doi.org/10.1080/10549811.2018.1528158

Lepcha LD, Vineeta, Shukla G, Chakravarty S. 2020. Livelihood dependency on NTFPs among forest dependent communities: an overview. Indian Forester 146(7): 603-612. https://doi.org/10.36808/if/2020/v146i7/154254.

Mahapatra AK, Albers HJ, Robinson EJZ. 2005. The impact of NTFP sales on rural households' cash income in India's dry deciduous forest. Environmental Management 35: 258–265.

Marbaniang KW, Narzary D, Kumar H. 2024. Ecological attributes of sacred groves in West Khasi Hills, Meghalaya, India. Current World Environment 19: http://dx.doi.org/10.12944/CWE.19.3.24.

Martemjen. 2017. Biodiversity Conservation, Indigenous Knowledge and practices: A Naga Perspective. Notion Press Media Pvt Ltd., Chennai.

Nath B, Dutta BK. 2000. A study of agricultural practices of some North East tribes settled in Barak Valley: UGC sponsored state level seminar on biodiversity of Assam and their conservation, Abstract Vol.6-7.

Nongbri T. 2014. Development, ethnicity and gender: Select essays on tribes in India. Rawat Publications, www.rawatbooks.com.

Nongkynrih AK. 2012. Development, Environment and Broom Grass. In: Social Exclusion and Adverse Inclusion, eds. Nathan D, Xaxa V. Oxford University Press. New Delhi, Pp. 36-51.

Peerzada IA, Islam MA, Chamberlain J, Dhyani S, Reddy M, Saha S. 2022. Potential of NTFP based bioeconomy in livelihood security and income inequality mitigation in Kashmir Himalayas. Sustainability (Switzerland) 14(4): 2281. http://doi.org/10.3390/su14042281.

Perme N, Choudhury SN, Choudhury R, Natung T, De B. 2015. Medicinal plants in traditional use at Arunachal Pradesh, India. International Journal of Phytopharmacy 5:86-98. http://doi.org/10.7439/IJPP.V5I5.2863.

Planning Commission. 2014. Report of the Working Group on Development and Welfare of Scheduled Tribes during the Twelfth Five Year Plan. Government of India, New Delhi.

Post WM, Morey S, DeLancey S 2015. Language and Culture in Northeast India and Beyond in Honor of Robbins Burling. Asia-Pacific Linguistics College of Asia and the Pacific. The Australian National University, Canberra ACT 2600, Australia. http://hdl.handle.net/1885/38458

Post WM. 2022. Upland Languages. In: The Routledge Companion to Northeast India, eds. Wouters JJP, Subba TB, Eds. Routledge, London. Pp. 469-474.

Pradhan P, Singh M. 2019. Role of non-timber forest products (NTFPs) in sustaining forest-based livelihoods: A case study of Ribdi village of West Sikkim, India. Indian Journal of Traditional Knowledge 18: 595-609.

Rai SN, Chakrabarti SK. 1996. Demand and supply of fuelwood, timber and fodder in India, Forest Survey of India, Ministry of Environment and Forests, Government of India, New Delhi.

Ramundanga, Ramswamy R. 2017. Clustering of Bamboo Enterprises in NE India: Bairabi Cluster, Mizoram. SEDME (Small Enterprises Development Management & Extension Journal) A worldwide window on MSME Studies 44(1):

Rawat MS, Choudhury S. 1998. Ethnomedicobotany of Arunachal Pradeesh (Nishi and Apatani Tribes). Bishen Singh Mahender Pal Singh, New Delhi.

Roy N, Debnath A, Nautiyal S. 2024. An Overview on Northeastern States of India. In: Climate Change, Shifting Cultivation and Livelihood Vulnerabilities in India. Springer, Cham. https://doi.org/10.1007/978-3-031-54927-4_3.

Saha D, Sundriyal RC. 2010. Stand structure, phenology and fruit yield of *Illicium griffithii* in western Arunachal Pradesh, North-East India. Indian Journal of Forestry 33: 475-483.

Samantroy E. 2017. Understanding Women’s Work: Gendered Analysis of Women’s Participation in Domestic Duties in North East India. V.V. Giri National Labour Institute, Sector – 24, Noida – 201301, U.P.

Sarker T. 2017. Biodiversity: The Role of Women in North East India. Journal of Research in Humanities and Social Science 5: 71-74.

Sarmah R, Adhikari D, Majumder M, Arunachalam A. 2008. Traditional medicobotany of Chakma community residing in the Northwestern periphery of Namdapha National Park in Arunachal Pradesh. Indian Journal of Traditional Knowledge 7(4): 587-593.

Seal T, Pillai B, Chaudhuri K. 2015. Nutritional potential of wild edible fruits, traditionally used by the local people of Meghalaya state in India. Indian Journal of Natural Products and Resources 5: 359–364.

Shangpliang RM. 2012. Forest legislations and livelihood strategies: Khasi Women in rural Meghalaya. Sociological Bulletin 61: 479-493

Shangpliang RM. 2018a. Livelihood and gender: marginalization of Khasi rural women in land and forest rights. The NEHU Journal XVI: 86-99.

Shangpliang RM. 2018b. Tribal women and natural resource management: the Khasi women of Meghalaya in India. Echoes from the Hills II: 36-51.

Sharma D, Tiwari BK, Chaturvedi SS, Diengdoh E. 2015. Status, utilization and economic valuation of non-timber forest products of Arunachal Pradesh, India. Journal of Forest and Environmental Science 31: 24-37. http://dx.doi.org/10.7747/JFES.2015.31.1.24.

Sil A, Sarkar SR, Kumari A. 2020. Traditional bamboo craft of Tripura: Its diversification and conservation. International Journal of Current Microbiology and Applied Science 9: 1714-1719. https://doi.org/10.20546/ijcmas.2020.906.212.

Singh RK, Kumar A, Singh A, Singhal P. 2020. Evidence that cultural food practices of *Adi* women in Arunachal Pradesh, India, improve social-ecological resilience: insights for Sustainable Development Goals. Ecological Processes 9: https://doi.org/10.1186/s13717-020-00232-x.

Singha S. 2018. Assessing vulnerability and resilience in the face of climate change: a case study of north-east India. European Journal of Sustainable Development 7: 53. https://doi.org/10.14207/ejsd.2018.v7n3p53.

Sinha H, Sinha S. 2013. Women in North East India: Status Empowerment and Development Perspectives. Akanksha Publishing House, Guwahati.

Sruthi P, Mukherjee S. 2020. Mujeres, naturaleza y cultura: una lectura ecofeminista de la cultura matrilineal de las tribus khasis, jaintia y garo de Meghalaya. Cultura de los Cuidados (Edición digital), 24 (58). Recuperado de http://dx.doi.org/10.14198/cuid.2020.58.15

Tamang W, Ghosh A, Sarkar S, Gurung N, Subba S, Sahu S. 2024. Broom grass: A valuable yet overlooked crop in Sikkim and Darjeeling Himalayas. Agri-India TODAY 4: 148-153.

Thapa A, Singh K. 2023. Livelihood and socio-economic challenges in medicinal and non-timber forest product management in India: A Review. Journal of Hunan University (Natural Sciences) 50(9): 87-99. https://doi.org/10.55463/issn.1674-2974.50.9.9.

TRIFED 2020. Annual Report on Van Dhan Vikas Kendras. Ministry of Tribal Affairs, Government of India, New Delhi.

Tynsong H, Dkhar M, Tiwari BK. 2020. Review: Traditional ecological knowledge of tribal communities of North East India. Biodiversitas 21: 3209-3224. http://doi.org/10.13057/biodiv/d210743.

Tynsong H, Tiwari BK, Dkhar M. 2012. Contribution of NTFPs to cash income of the War Khasi community of southern Meghalaya, North-East India. Forestry Studies in China 14(1): 47–54. http://doi.org/10.1007/s11632-012-0104-7.

Uniyal AK, Silvia K, Singh V, Chamoli RT. 2023. Potential of non-timber forest products in the household income of Tengnoupal district, Manipur, India. Research Journal of Agriculture and Forestry Sciences 11: 28-32.

Yadav M, Misra S. 2012. Sustainable development: a role for market information systems for non-timber forest products. Sustainable Development 20: 128–140. http://doi.org/10.1002/sd.470.

Zhasa NN, Hazarika P, Tripathi YC. 2015. Indigenous knowledge on utilization of plant biodiversity for treatment and cure of diseases of human beings in Nagaland, India: A case study. International Research Journal of Biological Sciences 4: 89-106.

J. Agric. Technol., 12(2): 23-35 (2025)
Print: ISSN: 2348-4721; Online: ISSN: 2349-610X

Geospatial Mapping of Sheath Blight Severity in Rice: Application of IDW, KDE and Statistical Analysis

Amit Bijlwan[1*], Manendra Singh[2]

[1]*G. B. Pant University of Agriculture of Agriculture and Technology, Pantnagar, Uttarakhand*
[2]*WOTR Centre for Resilience Studies (W-CReS), Watershed Organization Trust, Pune, Maharashtra*

***E-mail**: amitbijlwan07@gmail.com*

Received: 29-03-2025; **Revised:** 21-05-2025; **Accepted:** 02-06-2025

Citation: Bijlwan A, Singh M. 2025. Geospatial Mapping of Sheath Blight Severity in Rice: Application of IDW, KDE and Statistical Analysis. J Agric Technol. 12(2): 23-34.

Sheath blight is a destructive fungal disease of rice, causing significant yield loss worldwide. This study explores the spatial distribution of sheath blight in Udham Singh Nagar and Nainital districts of Uttarakhand, India, using advanced geospatial tools including Inverse Distance Weighting (IDW) interpolation and Kernel Density Estimation (KDE) heatmaps. The analysis shows spatial patterns influenced by environmental factors such as temperature, humidity, and altitude. In Udham Singh Nagar, central regions viz. Pantnagar and Gadarpur showed the highest disease severity, while Bajpur emerged as a cold spot with minimal disease severity. In Nainital, higher-altitude areas experienced negligible severity, whereas lower-altitude foothills like Haldwani and Ramnagar showed moderate disease intensity. Statistical validation using the Kruskal-Wallis test indicated significant variation in sheath blight severity across locations ($\chi^2 = 83.682$, df = 29, $p = 3.31\times10^{-7}$). Post-hoc Dunn's test with Bonferroni adjustment further identified significant pairwise differences. Narayanpur differed significantly from Chakarpur ($p = 0.042$), Haripur Roopsingh ($p = 0.030$), and Pantnagar ($p = 0.022$), while Pantnagar also differed from Haripur Roopsingh ($p = 0.016$) and Ratanpur Isai ($p = 0.036$). These results confirm a strong spatial heterogeneity in disease severity, emphasizing the need for site-specific disease management strategies. Although several area pairs showed statistical similarity, localized hotspots and cold spots suggest differential disease pressure across the study area.

Keywords: *Spatial Analysis, IDW interpolation, KDE, Kruskal-Wallis and Dunn test*

INTRODUCTION

Rice, as a staple food crop, holds unparalleled importance in ensuring global food security, feeding over half of the world's population. This vital crop is grown extensively across Asia, Africa, and parts of South America, forming the dietary foundation for billions of people (Fukagawa and Ziska 2019). However, rice cultivation faces significant challenges due to various biotic stresses, among which diseases play a pivotal role in reducing productivity. Sheath blight, caused by the fungal pathogen *Rhizoctonia solani*, is one of the most devastating diseases affecting rice. The disease thrives under favourable environmental conditions such as high humidity and moderate temperatures, leading to substantial yield losses. Sheath blight can reduce rice yield by up to 50% in severe cases, making it a critical concern for researchers, policymakers, and farmers (Chen *et al.,* 2023). The growing prevalence of sheath blight necessitates advanced monitoring and management techniques to mitigate its impact effectively.

Spatial analysis has emerged as an invaluable tool for understanding the distribution patterns of diseases like sheath blight. Traditional methods of disease management often rely on point observations and generalized control measures, which may not address localized variations in disease prevalence. By contrast, spatial analysis provides insights into the geographic spread and intensity of diseases, allowing for targeted interventions. Techniques such as IDW interpolation and KDE heatmaps are particularly suited for analyzing and visualizing the spatial distribution of sheath blight (Amoghavarsha *et al.,* 2022; Huded *et al.,* 2022). IDW interpolation estimates disease intensity at unsampled locations by considering the spatial proximity of observed data points. This method is especially useful for generating continuous disease maps from discrete field observations, enabling researchers to identify areas of high infection risk. On the other hand, KDE heatmaps complement IDW by visualizing disease density across a region, highlighting clusters or hotspots where sheath blight is most severe. These maps provide an intuitive and actionable representation of the disease's spatial dynamics, aiding precision agriculture practices (Shi *et al.,* 2019; Zheng *et al.,* 2023).

The integration of spatial analysis with robust statistical methods further enhances our ability to interpret and validate disease patterns. Statistical tests such as Tukey's test, Kruskal-Wallis test, and Dunn's test are critical for assessing the significance of variations in sheath blight intensity across different geographical zones or environmental conditions. Tukey's test is particularly useful for pairwise comparisons among groups, while the non-parametric Kruskal-Wallis test evaluates differences across multiple groups, even when the data does not follow a normal distribution. Dunn's test complements these by providing detailed post-hoc analysis to pinpoint specific group differences (Castellano *et al.,* 2022). Together, these tests strengthen the reliability of spatial analysis, ensuring that observed patterns are statistically robust and not mere artifacts of data distribution.

By combining spatial visualization techniques and rigorous statistical validation, this study aims to provide a comprehensive understanding of the spatial distribution of sheath blight in rice in Udham Singh Nagar and Nainital district of Uttrakhand. The insights gained from such an analysis are crucial for developing localized disease management strategies, reducing pesticide overuse, and promoting sustainable farming practices. In an era of increasing climate variability and disease pressure, these methods offer a proactive approach to safeguarding rice productivity, ensuring food security for millions worldwide. This research underscores the importance of integrating spatial tools and statistical techniques in tackling complex agricultural challenges like sheath blight.

MATERIALS AND METHOD

Geographic Information Systems (GIS) play a crucial role in characterizing disease-affected fields and facilitate a range of analyses, including geostatistical modeling, hot spot identification and spatial interpolation. These tools provide valuable insights into the spatial and temporal dynamics of plant diseases. Spatial autocorrelation techniques are used to assess the correlation of spatial data across different intervals, enabling the development of spatial dependence models expressed through semi-variograms. These models support accurate disease occurrence predictions with minimal variance, particularly when applied with IDW interpolation methods

(Viggiano *et al.,* 2019). Furthermore, IDW interpolation provides an alternative approach for estimating disease severity across a field by assigning greater importance to nearby observations.

Study Area

The study was conducted during the Kharif seasons (June to September) of 2022 and 2023, collecting data from 19 sampling sites across 8 tehsils (Bajpur, Gadarpur, Jaspur, Kashipur, Khatima, Kichha, Rudrapur, and Sitarganj) in Udham Singh Nagar district, as well as from 15 sampling sites in Nainital district. Sheath blight severity was assessed using the Standard Evaluation System (SES) developed by IRRI (IRRI 1996), which rates disease severity on a scale from 0 (no symptoms) to 9 (severe infection).

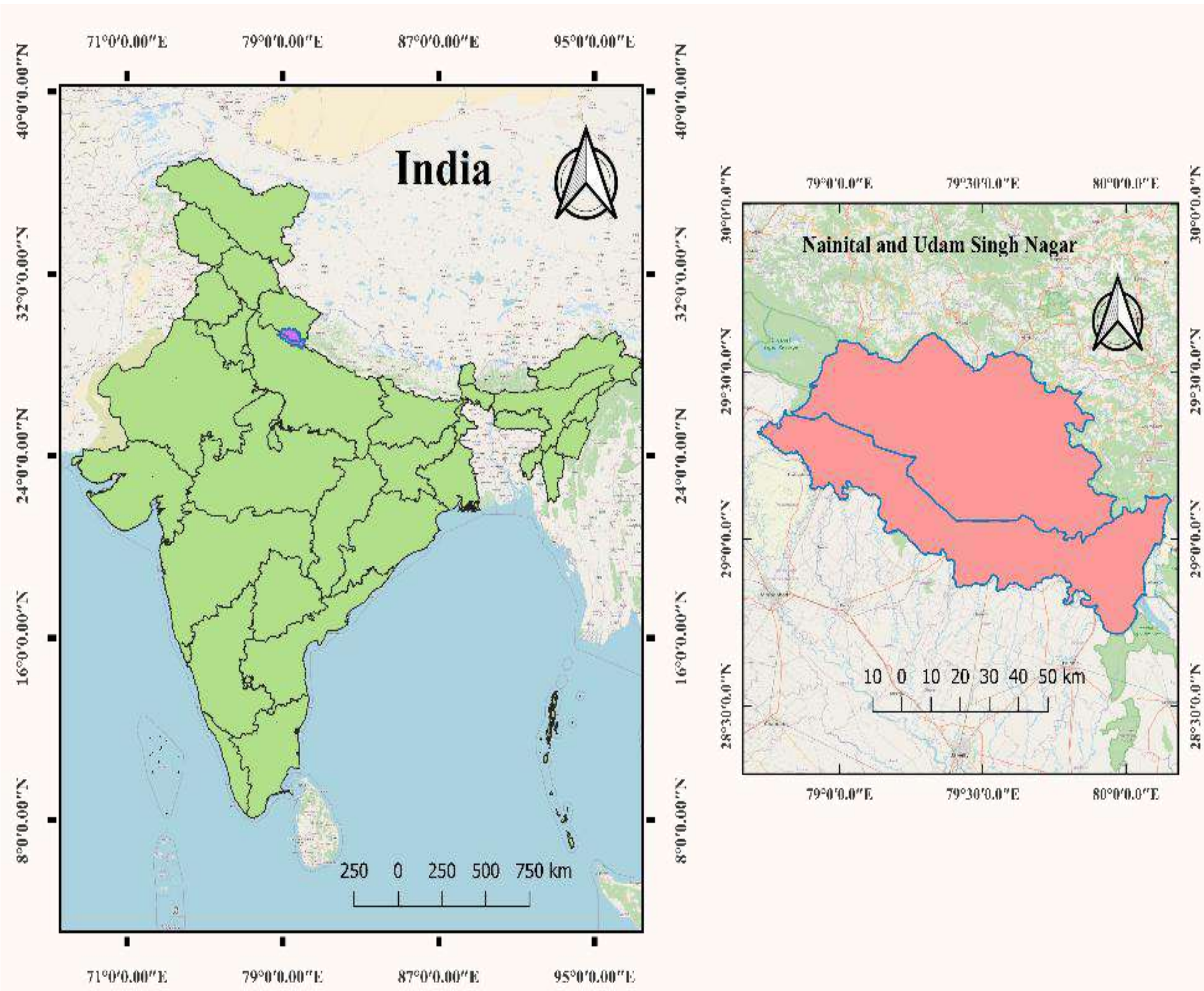


Figure 1. Spatial layout map of the study area

IDW Interpolation

The spatial analysis of sheath blight was conducted using the IDW interpolation technique, a widely recognized method for mapping spatial variables. IDW is known for its precision and applicability in modeling continuous spatial variation. Originally developed for applications in mining and geological sciences, this technique operates on the principle that the influence of a known point diminishes with distance from the estimation site. The method estimates values at unmeasured locations by calculating a weighted average of nearby sample points, assigning greater influence to points that are closer. IDW ensures a smooth spatial transition by using a linear weighted combination of the surrounding points, making it a valuable tool for generating accurate surfaces. This technique not only provides detailed maps of disease severity but also supports spatial decision-making by helping to identify high-risk areas for sheath blight management in rice fields.
The general equation used for the IDW is as follows

$$\hat{I} = \frac{\sum_{i=1}^{n} z(x_i).\, {d_{ij}}^{-p}}{\sum_{i=1}^{n} {d_{ij}}^{-p}}$$

where, $\hat{I}$ is the interpolated value of a grid node, $z(x_i)$ are the neighboring data points, d_{ij} are the distances between the grid node and data points.

KDE-Based Heat-Map Generation

KDE was employed to generate heatmaps for visualizing the spatial distribution of sheath blight in rice fields. KDE is a non-parametric statistical method that estimates the probability density function of a variable based on spatial point data. The method assigns weights to data points within a specified bandwidth, with closer points contributing more to the density estimation. The analysis was conducted by overlaying the spatial coordinates of disease sampling sites onto a QGIS, where KDE was applied to calculate the density of sheath blight occurrences. The resulting heatmaps highlight areas of high and low disease intensity, providing an intuitive visualization of disease hotspots. This approach enables the identification of spatial clusters and supports targeted disease management strategies.
A general equation for Kernel Density Estimation (KDE) is as follows:

$$\hat{f}(x) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{x - x_i}{h}\right)$$

$\hat{f}(x)$= Estimated density at point x
n=Total number of data points
h=Bandwidth (smoothing parameter)
K= Kernel function
x_i= Location of the i^{th} data point

Tukey Test

The Tukey test is a post-hoc analysis method that performs pairwise comparisons between all possible group means to detect significant differences. This method uses the studentized range distribution to evaluate differences, ensuring control over the Type I error rate when making multiple comparisons. In this study, the Tukey test was implemented using the `Tukey HSD` function in RStudio, which is part of the `stats` package. The test is particularly effective in analyzing datasets where numerous groups are compared, providing a detailed breakdown of significant mean differences. This robust statistical method helps identify specific group pairs that show statistically significant variations, contributing to a deeper understanding of the dataset.

Kruskal-Wallis Test and Dunn's Test

The Kruskal-Wallis test is a non-parametric alternative to one-way ANOVA, designed to analyze differences in a dependent variable across multiple groups when the assumption of normality is violated. This test ranks the data and calculates a chi-squared statistic to determine whether there are overall differences among groups. In this study, the Kruskal-Wallis test was conducted using the `Kruskal test` function in RStudio from the `stats` package. Post-hoc analysis was performed using Dunn's test, which identifies specific group differences following a significant Kruskal-Wallis result. Dunn's test employs adjustments for multiple comparisons, such as the Bonferroni correction, to minimize Type I error rates. The `dunn. test` package in RStudio was used to compute Z-scores and adjusted p-values, enabling precise identification of statistically significant differences between group pairs. This combination of tests offers a comprehensive approach to evaluating group variability in non-parametric data.

RESULTS AND DISCUSSION

IDW Interpolation

This spatial variability highlights the critical role of local environmental factors, such as temperature, humidity, and altitude, in influencing the severity and distribution of sheath blight. Understanding these patterns is crucial for developing targeted disease management strategies tailored to the specific needs of different regions. During the study period, variations in sheath blight disease severity were observed across both districts in both years (Figure 2). In Udham Singh Nagar district, the highest disease severity was consistently recorded in the Pantnagar and Gadarpur regions. Conversely, the lowest severity, forming a distinct cold spot, was observed in the Bajpur region, located in the lower part of the district. Overall, Udham Singh Nagar exhibited significantly higher disease severity compared to the neighbouring Nainital district. In Nainital district, regions at higher altitudes, particularly the northern areas, reported minimal disease severity, likely due to cooler temperatures and less favourable environmental conditions for pathogen development. However, comparatively higher disease severity was noted in the southern and foothill regions, particularly around Ramnagar and Haldwani, where the environmental conditions were more conducive to the proliferation of sheath blight.

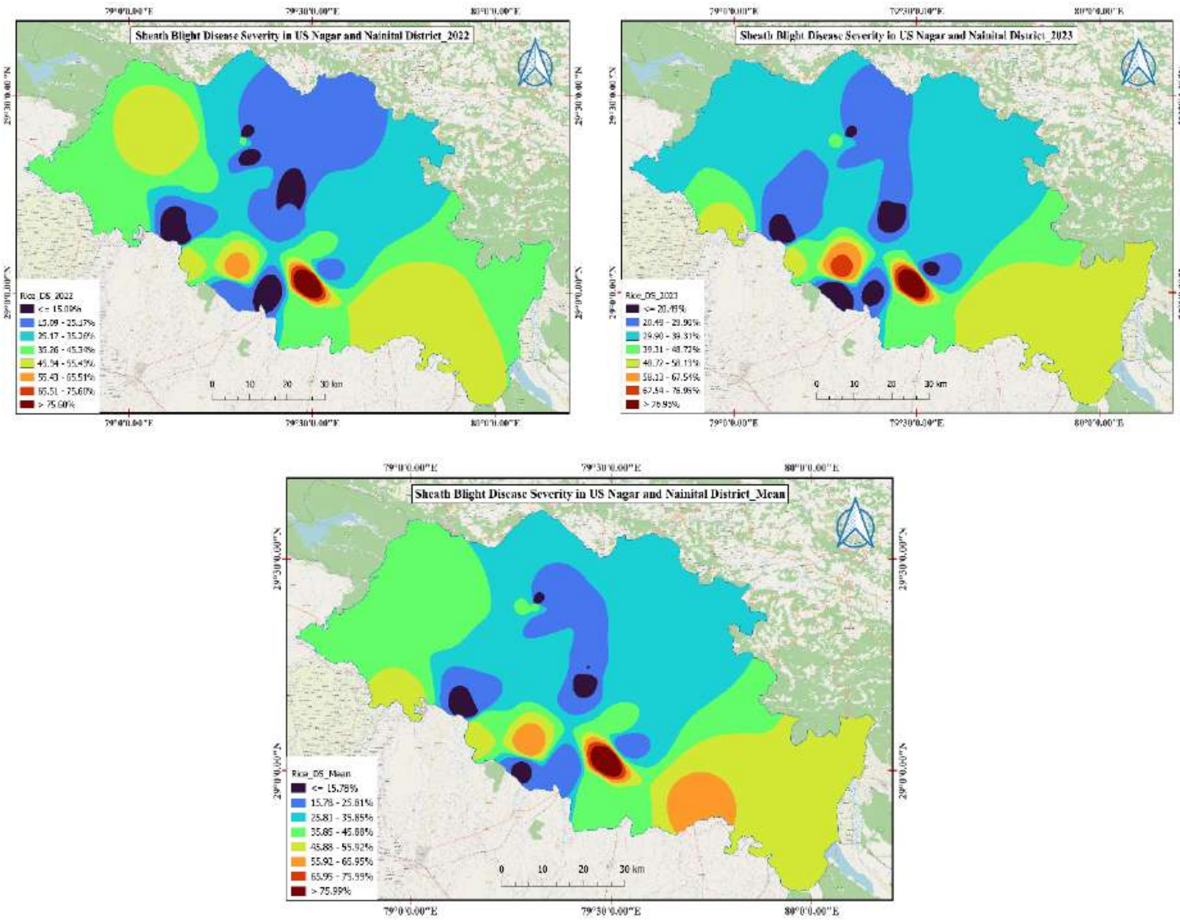


Figure 2. Sheath blight disease severity (%) estimation using IDW interpolation in US Nagar and Nainital districts

KDE

The heatmap represents the spatial distribution of sheath blight disease severity in Udham Singh Nagar and Nainital districts of Uttarakhand, India (Figure 3), created using Kernel Density Estimation (KDE). The colour gradient vividly illustrates the variation in disease severity, with red and orange regions signifying areas of high severity and blue and purple zones indicating low severity. The central parts of Udham Singh Nagar, particularly Pantnagar and Gadarpur, exhibit the highest disease severity, attributed to favourable environmental conditions such as optimal temperature, humidity, and rainfall. Conversely, the lower parts of Bajpur in Udham Singh Nagar act as cold spots with minimal disease impact. In the Nainital district, the higher-altitude regions in the northern part show minimal disease severity, reflecting the influence of cooler temperatures that are less conducive for the proliferation of sheath blight. However, moderate severity is observed in the foothill regions of Nainital, including areas like Haldwani and Ramnagar, as indicated by the transition from green to orange zones. Overall, Udham Singh Nagar experiences a more extensive and intense spread of sheath blight compared to Nainital, underlining the importance of region-specific disease management interventions to mitigate its impact on rice production. This spatial analysis effectively highlights the hotspots and cold spots of disease severity, providing valuable insights for targeted agricultural planning and resource allocation.

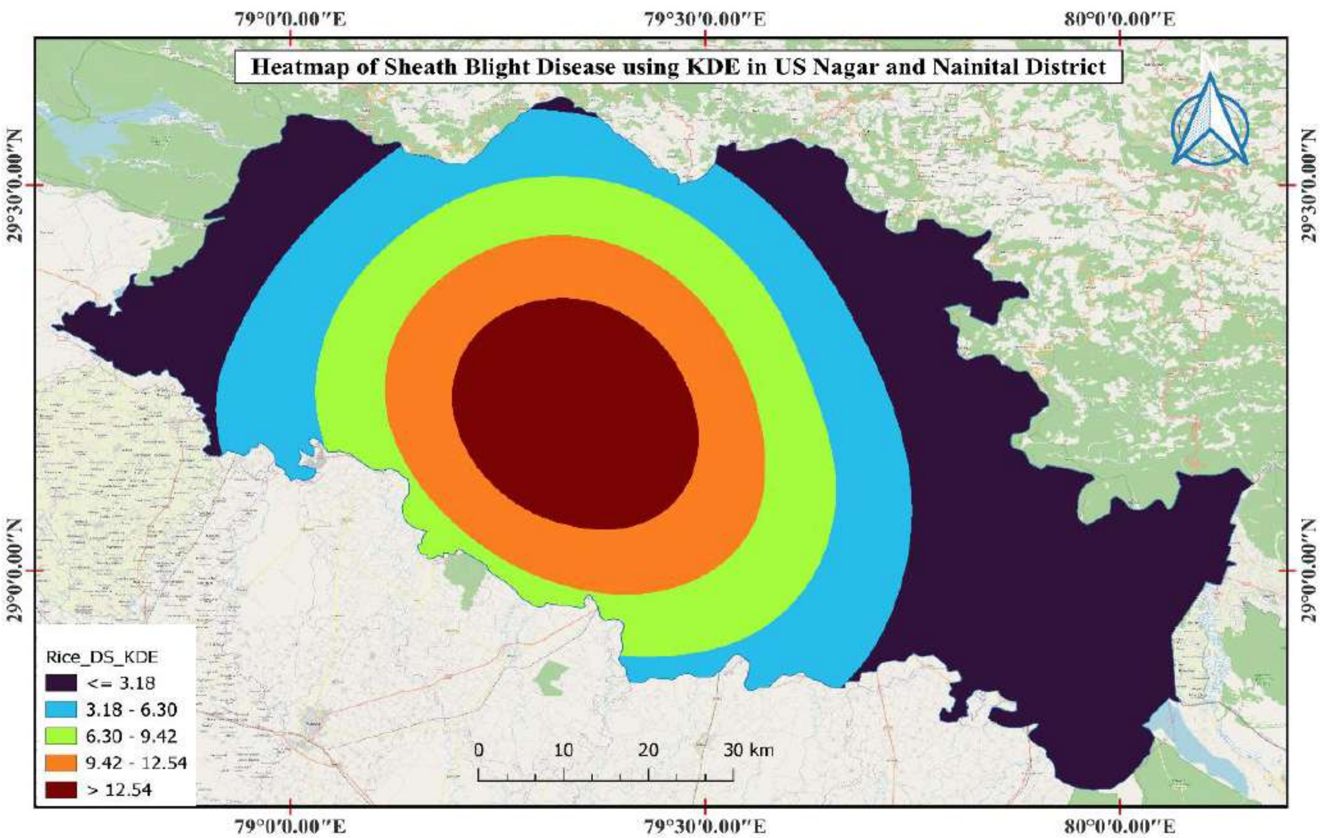


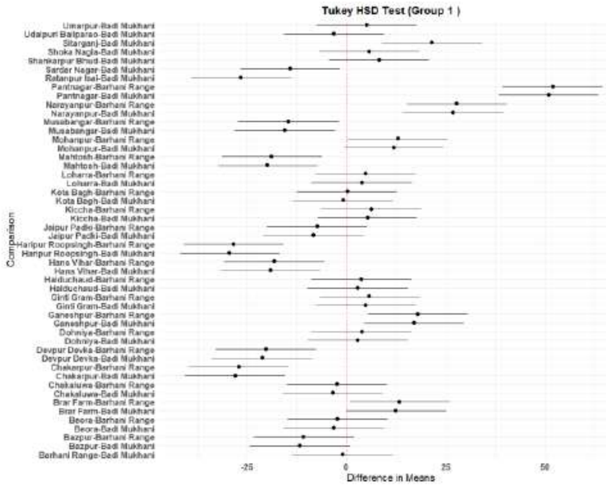
Figure 3. Heatmap of sheath blight using KDE method in US Nagar and Nainital district

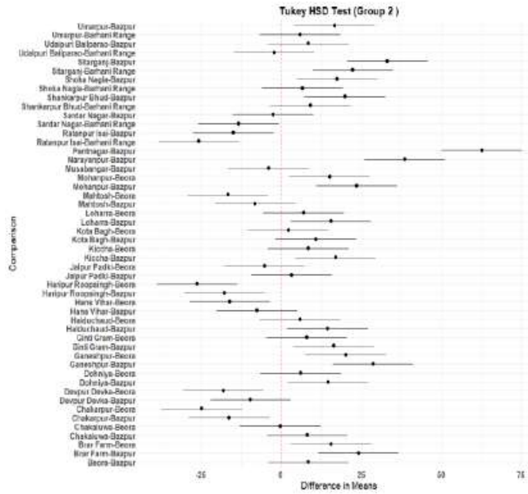
Tukey Test

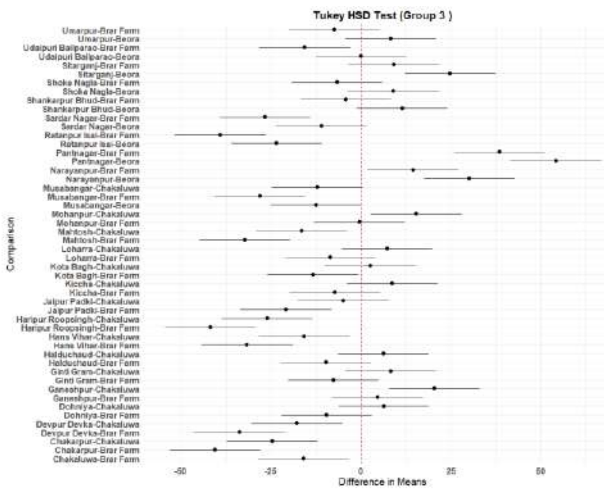
The severity of sheath blight disease in rice was compared across different areas using Tukey's post-hoc test. The analysis revealed significant variations ($p < 0.05$) in disease severity among the regions. These findings indicate that environmental factors or agronomic practices might contribute to the observed differences, emphasizing the need for localized management strategies to mitigate sheath blight severity effectively Figure 4.

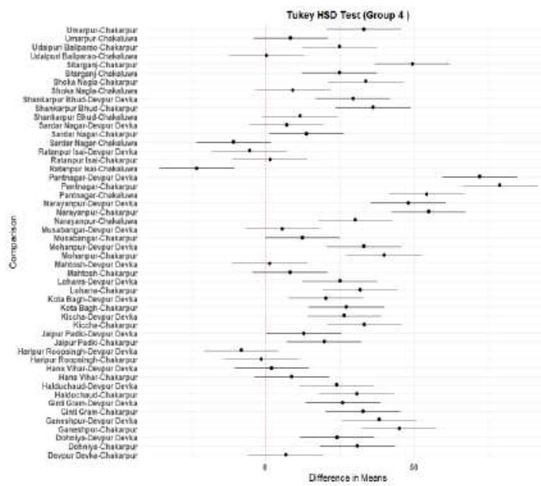
Kruskal Wallis and Dunn Test

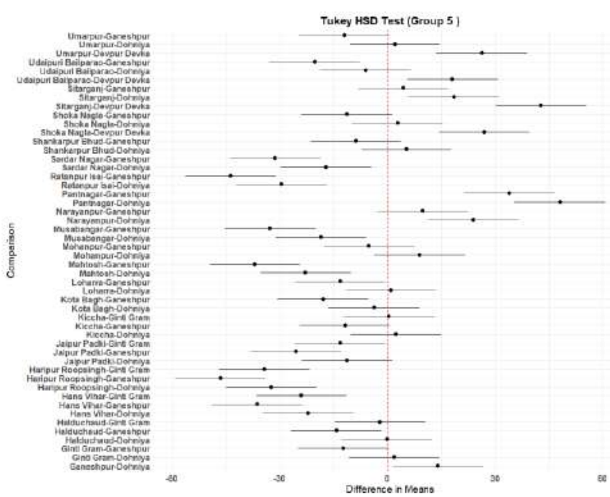
The Kruskal-Wallis test revealed significant differences in sheath blight disease severity across regions (χ^2 = 83.682, df = 29, p-value = $3.307e^{-07}$). The results of the Kruskal-Wallis test and post-hoc Dunn test with Bonferroni adjustment revealed significant differences in sheath blight severity among certain area pairs (Table 1). Notably, Narayanpur displayed significant differences when compared with Chakarpur (p = 0.042), Haripur Roopsingh (p = 0.030), and Pantnagar (p = 0.022). Similarly, Pantnagar exhibited significant differences with Haripur Roopsingh (p = 0.016) and Ratanpur Isai (p = 0.036).

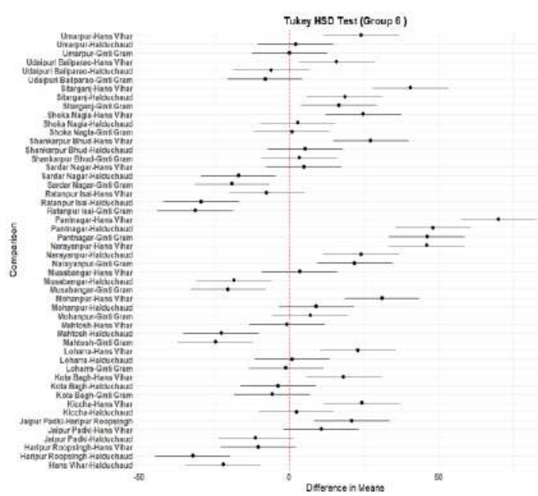

Tukey HSD Test (Group 1)
Comparison
Difference in Means


Tukey HSD Test (Group 2)
Comparison
Difference in Means


Tukey HSD Test (Group 3)
Comparison
Difference in Means


Tukey HSD Test (Group 4)
Comparison
Difference in Means


Tukey HSD Test (Group 5)
Comparison
Difference in Means


Tukey HSD Test (Group 6)
Comparison
Difference in Means

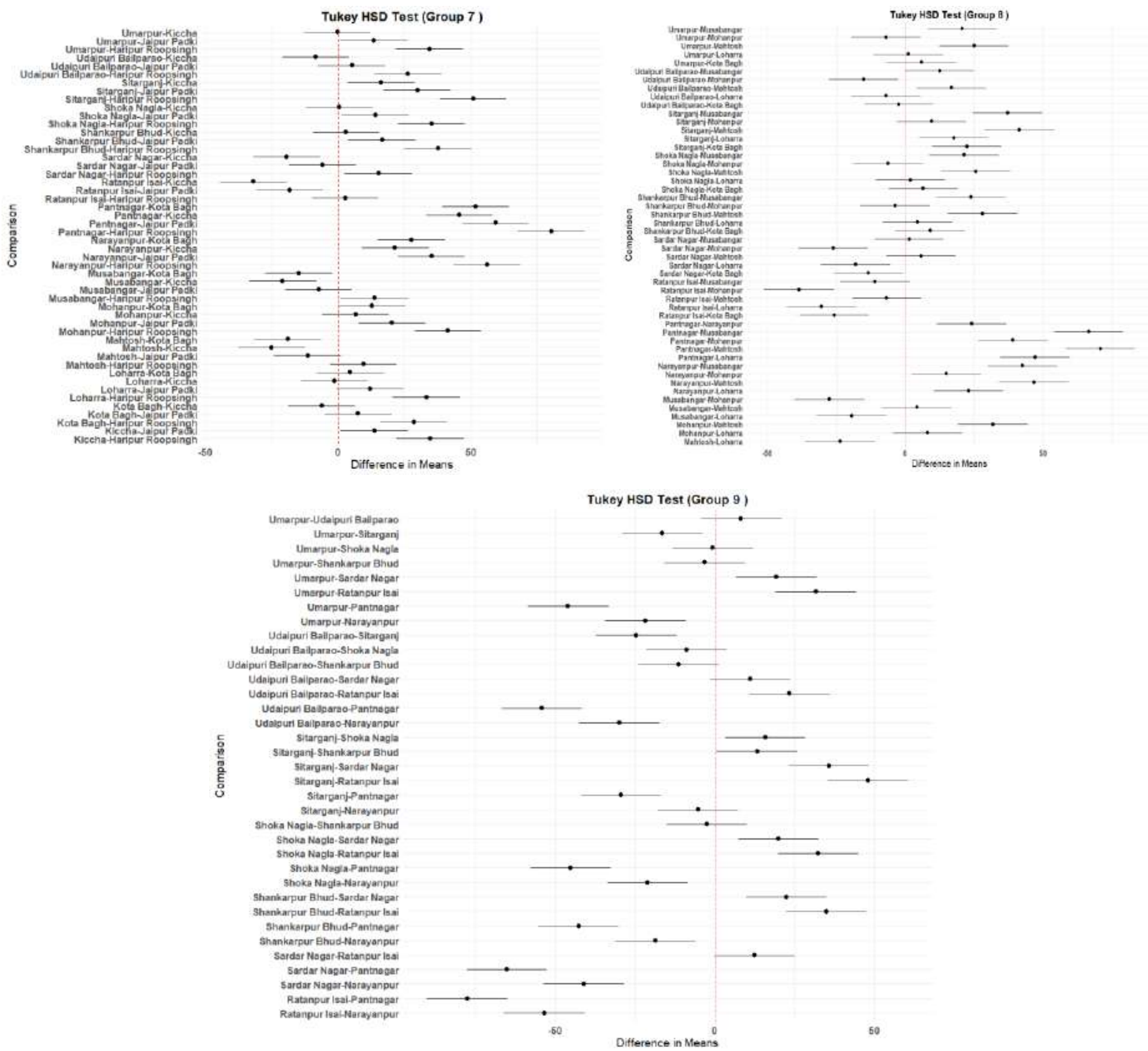


Figure 4. Tukey HSD Test for group wise comparison for rice disease severity

These findings indicate that the severity of sheath blight varies significantly between specific locations, emphasizing spatial variability in disease intensity. However, many other area pairs did not show statistically significant differences, reflecting homogeneity in sheath blight severity across those regions. This spatial heterogeneity underscores the need for targeted disease management strategies tailored to high-severity zones. Other comparisons showed varying degrees of differences but were not statistically significant at α = 0.05, including Brar Farm - Mahtosh (Z = 2.860, p = 0.922), Sardar Nagar - Sitarganj (Z = -2.836, p = 0.992), Ganeshpur - Hans Vihar (Z = 2.977, p = 0.633), Devpur Devka - Mohanpur (Z = -2.914, p = 0.775), and Bazpur - Pantnagar (Z = -2.954, p = 0.683), among others. Bouwmeester *et al.,* (2016) use of indicator regression kriging produced high-resolution maps of bacterial wilt of banana (BWB) incidence and severity, revealing significant patterns across the East African highlands.

Table 1. Kruskal-Wallis rank sum test and post-hoc Dunn test with Bonferroni adjustment for comparison among different groups of areas for sheath blight in rice

Comparison	Z_statistic	p_value
Brar Farm - Chakarpur	3.227036	0.272048
Brar Farm - Devpur Devka	2.961372	0.666141
Chakarpur - Ganeshpur	-3.41456	0.138948
Devpur Devka - Ganeshpur	-3.1489	0.356453
Ganeshpur - Hans Vihar	2.976999	0.633109
Brar Farm - Haripur Roopsingh	3.312986	0.200765
Ganeshpur - Haripur Roopsingh	3.500514	0.100999
Brar Farm - Mahtosh	2.859795	0.922016
Ganeshpur - Mahtosh	3.047322	0.502186
Chakarpur - Mohanpur	-3.18015	0.320153
Devpur Devka - Mohanpur	-2.91449	0.774887
Haripur Roopsingh - Mohanpur	-3.2661	0.237158
Chakarpur - Narayanpur	-3.72711	0.042127
Devpur Devka - Narayanpur	-3.46145	0.116859
Hans Vihar - Narayanpur	-3.28955	0.21826
Haripur Roopsingh - Narayanpur	-3.81306	0.029853
Mahtosh - Narayanpur	-3.35987	0.169606
Musabangar - Narayanpur	-3.10983	0.407147
Bazpur - Pantnagar	-2.95356	0.683239
Chakarpur - Pantnagar	-3.88338	0.022405
Devpur Devka - Pantnagar	-3.61772	0.064643
Hans Vihar - Pantnagar	-3.44582	0.12383
Haripur Roopsingh - Pantnagar	-3.96933	0.015676
Mahtosh - Pantnagar	-3.51614	0.095236
Musabangar - Pantnagar	-3.2661	0.237158
Brar Farm - Ratanpur Isai	3.109831	0.407147
Ganeshpur - Ratanpur Isai	3.297359	0.212277
Mohanpur - Ratanpur Isai	3.06295	0.476688
Narayanpur - Ratanpur Isai	3.609905	0.066622
Pantnagar - Ratanpur Isai	3.766178	0.036054
Narayanpur - Sardar Nagar	2.945745	0.700737
Pantnagar - Sardar Nagar	3.102018	0.418049
Haripur Roopsingh - Shoka Nagla	-2.85979	0.922016
Chakarpur - Sitarganj	-3.61772	0.064643
Devpur Devka - Sitarganj	-3.35205	0.174466
Hans Vihar - Sitarganj	-3.18015	0.320153
Haripur Roopsingh - Sitarganj	-3.70367	0.04622
Mahtosh - Sitarganj	-3.25048	0.250585
Musabangar - Sitarganj	-3.00044	0.586357
Ratanpur Isai - Sitarganj	-3.50051	0.100999
Sardar Nagar - Sitarganj	-2.83635	0.992493

The method, combining logistic regression with spatial interpolation of residuals, showed higher predictive accuracy compared to conventional averaging, with lower Root Mean Squared Errors (0.30, 0.36 and 0.34 for conventional methods). The maps highlighted widespread disease presence, particularly severe in Northern Uganda, and indicated BWB in all districts, including unsampled areas where conventional methods predicted zero incidence. These results provided smoother, more accurate spatial patterns and actionable insights, enabling better-targeted interventions for disease control and management. Similarly, a remote sensing and modeling-based approach was used to monitor yellow rust disease in wheat crop in U.S. Nagar district of Uttarakhand (Jha *et al.,* 2019). A study was conducted to identify suitable potential areas for willow plantations under wastelands of Haryana. IDW interpolation technique was employed to create thematic layers of temperature and rainfall (Ranjan *et al.,* 2018). Geospatial interpolation, specifically Kriging, used to analyze and map the spatial distribution of factors influencing oil palm yields in Peninsular Malaysia. The purpose of using this method was to generate accurate predictive surfaces for variables such as soil properties, climate conditions, and topographic features, which directly affect crop performance. The results demonstrated that Kriging effectively highlighted spatial variability, enabling targeted management strategies to improve oil palm productivity across different regions (Abubakar *et al.,* 2023).

CONCLUSION

This study highlights the spatial variability of sheath blight in rice across Udham Singh Nagar and Nainital districts, revealing significant differences in disease severity influenced by local environmental factors. The use of IDW interpolation and KDE heatmaps effectively identified hotspots of high severity and cold spots with minimal disease impact. In Nainital, the northern high-altitude regions exhibited minimal disease severity, while the southern foothill regions, showed moderate severity due to conducive environmental conditions. Statistical analyses using the Kruskal-Wallis test, Tukey's test, and Dunn's test confirmed significant spatial heterogeneity in disease severity among various locations. These findings underscore the importance of integrating spatial analysis with robust statistical methods to enhance the understanding of disease dynamics. The identification of high-risk zones provides valuable insights for developing region-specific and targeted disease management strategies. Implementing such approaches can optimize resource allocation, reduce pesticide misuse, and improve disease control efficiency, contributing to sustainable rice production. This study demonstrates the potential of spatial and statistical tools in advancing precision agriculture and addressing the challenges posed by sheath blight in rice cultivation.

ACKNOWLEDGEMENT

The authors are grateful to the Department of Agrometeorology, G.B. Pant University of Agriculture and Technology, Pantnagar and India Meteorological Department for providing laboratory facilities and meteorological data in carrying out this research.

Funding: The research work was conducted without external funding; however, it benefitted from the support of a university fellowship and resources.

Conflict of Interests: The authors declare that there is no conflict of interest related to this manuscript.

Data availability: Data will be available through corresponding author on reasonable ground.

Author's contribution: Amit Bijlwan: Methodology, Writing original draft and editing; Manendra Singh: Review and editing.

REFERENCES

Abubakar A, Ishak MY, Bakar AA, Uddin MK, Umar NK. 2023. Geospatial mapping and biophysical analysis of factors that affect oil palm (Elaeis guineensis) yields in Peninsular Malaysia. Journal of Agrometeorology 25(1): 128-133. https://doi.org/10.54386/jam.v25i1.1871.

Amoghavarsha C, Pramesh D, Sridhara S, Patil B, Shil S, Naik GR, Naik MK, Shokralla S, El-Sabrout AM, Mahmoud EA, Elansary HO, Nayak A, Prasannakumar MK. 2022. Spatial distribution and identification of potential risk regions to rice blast disease in different rice ecosystems of Karnataka. Scientific Reports 12: 7403. https://doi.org/10.1038/s41598-022-11453-9.

Bouwmeester H, Heuvelink GBM, Stoorvogel JJ. 2016. Mapping crop diseases using survey data: The case of bacterial wilt in bananas in the East African highlands. European Journal of Agronomy 74: 173-184. http://doi.org/10.1016/j.eja.2015.12.013.

Castellano C, Bruno D, Comín FA, Benayas JMR, Masip A, Jiménez JJ. 2022. Environmental drivers for riparian restoration success and ecosystem services supply in Mediterranean agricultural landscapes. Agriculture, Ecosystems & Environment 337(3): 108048. http://doi.org/10.1016/j.agee.2022.108048.

Chen J, Xuan Y, Yi J, Xiao G, Yuan DP, Li D. 2023. Progress in rice sheath blight resistance research. Frontiers in Plant Science 14: 1141697. https://doi.org/10.3389/fpls.2023.1141697.

Fukagawa NK, Ziska LH. 2019. Rice: Importance for global nutrition. Journal of Nutritional Science and Vitaminology (Tokyo) 65(S2): S2-S3. https://doi.org/10.3177/jnsv.65.S2.

Huded S, Pramesh D, Chittaragi A, Sridhara S, Chidanandappa E, Prasannakumar MK, Shamshiri RR. 2022. Spatial distribution patterns for identifying risk areas associated with false smut disease of Rice in southern India. Agronomy 12(12): 2947. https://doi.org/10.3390/agronomy12122947.

IRRI. 1996. Standard Evaluation System for Rice. 4th Edition, IRRI, The Philippines.

Jha A, Ranjan R, Nain AS. 2019. Spectro-meteorological integration for monitoring wheat stripe rust in Tarai regions of Uttarakhand. Journal of Agrometeorology 21(Special Issue- III): 28-33.

Ranjan R, Nain AS, Jha A. 2018. Assessment of land suitability potentials of Willow for enhancing green cover under wastelands of Haryana using geospatial technology. Journal of Agrometeorology 20(Special Issue): 44-48.

Shi X, Li M, Hunter O, Guetti B, Andrew A, Stommel E, Karagas M. 2019. Estimation of environmental exposure: interpolation, kernel density estimation or snapshotting. Annals of GIS 25(1): 1-8. https://doi.org/10.1080/19475683.2018.1555188.

Viggiano M, Busetto L, Cimini D, Di Paola F, Geraldi E, Ranghetti L, Romano F. 2019. A new spatial modeling and interpolation approach for high-resolution temperature maps combining reanalysis data and ground measurements. Agricultural and Forest Meteorology 276: 107590. http://doi.org/10.1016/j.agrformet.2019.05.021.

Zheng Q, Huang W, Xia Q, Dong Y, Ye H, Jiang H, Huang S. 2023. Remote sensing monitoring of rice diseases and pests from different data sources: A review. Agronomy 13(7): 1851. https://doi.org/10.3390/agronomy13071851.

J. Agric. Technol., 12(2): 36-48 (2025)
Print: ISSN: 2348-4721; Online: ISSN: 2349-610X

Cross-Cultural Therapeutic Analysis of Ethnomedicinal Plants Among the Indigenous Communities of Cooch Behar and Alipurduar Districts in West Bengal, India

Basab Kanti Dinda

Senior Ayurvedic Medical Officer, Natabari Block Primary Health Center, Cooch Behar- 736 156, West Bengal, India

E-mail: *drbasab77@gmail.com*

Received: 16-08-2025; **Revised:** 25-08-2025; **Accepted:** 15-09-2025

Citation: Dinda BK. 2025. Cross-Cultural Therapeutic Analysis of Ethnomedicinal Plants Among the Indigenous Communities of Cooch Behar and Alipurduar Districts in West Bengal, India. J Agric Technol. 12(2): 36-48.

Medicinal plants are being used for the treatment of various diseases all over the world since ancient time. This study is an attempt to document the use of 27 medicinal plants by 16 different ethnic communities living in remote rural areas of Cooch Behar and Alipurduar districts of West Bengal, India. Due to awareness, the traditional use of herbs has been increased in Cooch Behar. Different medicinal plants are known by different names by the people of different community, and there is also diversity in the use of different parts of medicinal plants for health.

Keywords: Ethnic community, Ethnomedicine, Cross-cultural analysis, Terai

INTRODUCTION

Since ancient times, people have been getting relief from diseases by using plants based on their own knowledge and experience. This trend of using plants has been passed down from one generation to the next in a traditional way. Just as the diseases of a particular region depend on the geographical environment of that region, so too does the diversity of plants and folk medicine there. Therefore, a different pattern of using plants can be observed in different regions. All the systems of medicine including the Indian systems of medicine 'Ayurveda', 'Sidha', 'Unani' entirely, and homeopathy to some extent, depend on plant materials or their derivatives for treatment of human ailments (Prajapati *et al*., 2003). Around 88% or 170 countries are estimated to use traditional medicine in the form of herbal medicines, acupuncture, yoga, and indigenous therapies (WHO, 2019). A number of drugs discovered through research and experiments from different plants that have been used in Indian traditional medicine, like vasicine and vasicinone from Adhatoda vasica, bacosoids from Bacopa monnieri, morphine and codeine from Papaver somniferum, sarsasapogenin, asparanin A and asparanin B from Asparagus adscendens, shatavarin from Asparagus racemosus, atropine from Atropa belladonna, glycyrrhizin from Glycyrrhiza glabra, aloin from Aloe vera, quinine from Cinchona spp. etc. So, the efficacies of these medicinal plants are already established (Sen and Chakraborty, 2017).

The trend of using herbs in family first aid is increasing due to availability of herbs in the homegardens (Dinda, 2025). Different ethnic groups like Mech, Garo, Oraon, Rava, Munda, Asur, Santal, Limbu, Rajbangshi, Toto, Khariya, Lohara, Kharoar, Chikbaraik, Dupka, and Tamang represents the districts of Cooch Behar and

Alipurduar in West Bengal. They are mostly forest dependents and reside adjacent to forests. They use plants extensively in their rituals, culture, religious ceremonies, auspicious ceremonies, festivals, food habits, and folk medicine. This study was carried out to document the cross-cultural folk therapeutic knowledge by these different ethnic communities of the district

The trend of using herbs in family first aid is increasing due to availability of herbs in the home gardens. Women are also earning income by selling seedlings, raw and dry herbs from their gardens (Dinda, 2025). Use of medicinal plants among indigenous communities of Cooch Behar district in treatment of various diseases has definitely been out numbered today by the allopathic treatment. But still their dependence on plants of their surroundings to get relieved from day-to-day ailments is unquestionable. (Dutta et al., 2014). Ethnomedicinal plants and their utilization in the region were documented but none performed their cross-cultural analysis (Shukla and Chakravarty, 2013; Dey *et al*., 2015; Mandal *et al*., 2020$_{a,\ b}$, 2021; Rakshit, 2022; Adhikari *et al*., 2023). Therefore, the objective of the present documentation is to perform cross-cultural analysis of ethnomedicinal plants used by the indigenous communities of Cooch Behar and Alipurduar districts of West Bengal.

MATERIALS AND METHOD

Being an Ayurvedic doctor in this area, people from different communities come to me for treatment at different times. Taking this opportunity, I conducted personal interview of my patients (on prior inform consent) who visited me from October 2018 to March 2025 representing different communities of Cooch Behar and Alipurduar districts in Terai region of West Bengal using pre-tested questionnaires. Primary data were also based on my field records. A total of 105 patients agreed to share their traditional knowledge of ethnomedicinal plants and its associated folk therapy. These respondents were mostly from Garopara of Cooch Behar-1 block, Patlakhawa of Cooch Behar-2 block, Natabari and Ravha para of Tufanganj-1 block, Atiamochar of Tufanganj-2 block, Toto para of Madarihat block, Panijhora village of Kalchini block. Research papers and some government information were also collected as secondary data. Related data were also collected from the available traditional healers and village elders of the above-mentioned blocks which were key informants of my study. I conducted the interview with the help of a local enumerator in vernacular or in Bengali. Information on local names of ethnomedicinal plants with their parts used along with their therapy for different ailments were documented.

RESULTS AND DISCUSSION

The present study documented folk therapeutic knowledge of 27 ethnomedicinal plant species of 16 ethnic communities of Alipurduar and Cooch Behar districts (Table 1). The data obtained from the evaluation of the anthropological aspects of the collected medicinal plants reveal that various plant parts such as roots, root bark, leaves, stems, stem bark, flowers, fruits, and even the whole plant are used for the treatment of various diseases, some of which are special and new to anthropological aspects. Some plants are used for some common problems such as boils, wounds, fever, cough, stomach problems, dysentery, gastric, dandruff, body aches and skin diseases, while some are very special as diabetes, jaundice, kidney stones, heart disease, asthma and blood purifiers.

Table 1. Cross-cultural analysis of ethnomedicinal plants species and their utilization by indigenous communities of Cooch Behar and Alipurduar districts

Sl. No.	Vernacular name (Indigenous community)	Parts Use	Disease	Therapy
1	***Oroxylum indicum*- Bignoniaceae**			
	Kharo khanvai (Mech), Kiring Bijak (Garo), Khardar (Oraon), Jablo fang (Rava), Hatpanjra (Munda, Asur), Surimalai/ Banahata (Santhal), Totla (Limbu), Kanaidinga (Rajbangshi), Koko menda (Tamang)	F, L, SB, Fr, S, R	Jaundice, abdomen pain, indigestion, worm, anorexia	Half-a-cup fresh flower extract consumed in empty stomach (Mech, Munda, Asur, Santhal, Limbu) or consumption of young leaves and 2-3 flowers fried in oil (Mech) or roasted fruits (Munda, Asur, Santhal, Limbu) manage jaundice. Water-soaked dried stem bark @ 1-2 tea spoon three times-a-day (Garo), water-soaked stem bark (Oraon, Rava, Rajbangshi @ half-a-cup) or flower (Oraon, Rava) is consumed in empty stomach to manage jaundice. Boiled leaves/flowers are also eaten at morning to manage jaundice (Garo). Water-soaked stem bark or fruit or seed is consumed to get relief from abdomen pain (Oraon). Water-soaked stem bark consumption also terminates worms (Rajbangshi). Fresh flower extract relieves indigestion (Oraon) and dried flower cooked with black cumin is served against anorexia (Rajbangshi). Flower extract is also topically administered on wound to heal (Tamang).
2	***Terminalia chebula*- Combretaceae**			
	Shithiafitay (Mech), Hartak (Garo), Ksal (Rava), Hara (Toto), Ksal (Rajbangshi)	Fr	Kylonichia, anorexia, acne, constipation, general nutrition, jaundice, toothache	Fresh ripe fruit is consumed for general nutrition (Toto). Fruit paste (dried or fresh) is topically applied on the affected nails to treat Kylonichia (Mech), on acnes (Rava, Rajbangshi) and on aching tooth to get relief from pain (Rajbangshi). Dried fruit pulp (Garo) and raw fruits (Rajbangshi) are consumed to manage anorexia and luke warm solution of dried fruit pulp powder is consumed at night to get relief from constipation (Rava). Water-soaked dried fruits are consumed with jaggery to treat jaundice (Rajbangshi).
3	***Enhydra fluctuance*- Compositae**			
	Henchamaigang (Mech), Muchri (Oraon, Munda, Asur), Muchruara (Samtal), Hincha (Rajbangshi)	S, L	Pruritus, Indigestion, flatulence, hypertension, anemia, anorexia, abdomen pain, thermoregulation, HSDD (hypoactive	Fresh stem and leaf extract is consumed in empty stomach to get relief from pruritus (Mech, Rajbangshi), indigestion, hypertension (Oraon), and anemia (Munda). Boiled leaf and stem extract is eaten to treat flatulence (Asur), and consumption of its extract solution regulate body temperature (Rajbangshi). Fried (Oraon and Munda) and fresh (Asur) stem and leaves are eaten to manage anorexia. Fresh stem and leaves are also eaten to get relief from

			Sexual desire disorder)	abdomen pain (Samtal) and cure HSDD (Rajbangshi).
4	***Ocimum sanctum*- Labiateae**			
	Tursi bilai (Mech); Tulsi (Garo, Oraon, Munda, Asur, Samtal, Toto, Rajbangshi, Khariya, Lohar, Kharoyar)	L	Common cold, sore throat, fever, flatulence, ringworm	Fresh extracts of tulsi leaf, *Adhatoda vasica* mixed with honey taken orally relieves common cold (Mech). Consuming either fresh leaf extract treats cough and cold, sore throat and fever (Garo, Asur, Toto, Samtal, Khariya, Lohar, and Kharoyar) and flatulence (Asur) or mixing leaf extract with sunned rice treat common cold (Samtal) and with honey treats fever, and ginger treat cough Rajbangshi, and. Topically applying leaf extract with black pepper relieve dental pain (Rajbangshi). Mixing this extract with salt (Oraon) and ginger and black pepper (Munda) treat cough and cold while, salt-mixed extract applied topically soothe itching (Oraon). Consuming tulsi leaves, *Adhatoda vasica*, ginger and black pepper in empty stomach give relief against sore throat (Munda). Topically applying crushed leaves on cuts and wound stop bleeding (Rava), and control ringworm (Asur, Samtal, Rajbangshi).
5	***Cyndon dactylon*- Gramineae**			
	Dubrigangsi—(Mech); Dublajen (Garo), Dubba (Oraon, Asur, Rajbangshi), Durba Harchak (Rabha), Dubighas (Santhal), Durba (Toto)	WP	Injury bleeding, body pain/ache, diarrhoea, nausea, diarrhoea (young), hair fall, amoebiasis, Leucorrhoea, dysuria (burning sensation during urination/ micturition)	Topical application of crushed whole plant on cuts and wounds (Mech, Oraon, Rabha, Asur, Santhal, Toto, Rajbangshi and Garo), and ash of whole plant mixed with kerosene relieve body pain (Garo). Consuming the whole plant after boiling with sunned rice control diarrhoea (Oraon). Consuming fresh whole plant extract with sugar control nausea (Rabha). Whole plant and turmeric fresh extract mix oral administration relieve Piles (Rajbangshi). Eating boiled whole plant with sunned rice treat diarrhoea in children, topical application of boiled whole plant in coconut oil stops hair fall, and eating whole plant fresh extract treat amoebiasis and leucorrhoea (Rajbangshi). Eating filtrate of boiled meshed *Streblus asper* leaves, whole plant of Cynodon and sunned rice mixing with candies for 2-3 days and whole plant with water then filtered and eat with mixing of candy 2-3 days give relief against dysuria (Rajbangshi).
6	***Centella asiatica,* Umbelliferae**			
	Manamunibilai (Mech), Mishinachil (Garo), Bang shak (Oraon, Munda, Asur, Kharya, Chikbaraik), Khudamanamani	L, WP	Fever and Weakness, abdomen pain, anorexia, diarrhoea, flatulence,	Solution of boiled fresh leaves and zinger boiled with salt is consumed to treat fever and weakness (Mech and Oraon) while, Oraons treat fever by orally administering fresh leaf extract mix of *Centella asiatica* and *Nyctanthes sarbortristris*.

	(Rava), Rateyara (Samtal), Beguteshak (Limbu), Dholmani (Rajbangshi), Eumathegm (Dupka)		amoebiasis, bloating, burning sensation during micturition, sore throat,	Fresh leaf extract mixed with common salt is administered orally against abdomen pain by both Mech and Oraons. The whole plant is cooked and served to treat anorexia (Mech), Amoebiosis, flatulence (Asur) and abdomen pain Chikbaraik. Fresh leaf extract is used as therapy against diarrhoea, amoebiasis, and flatulence by Kharyas, Garos and Oraons while the fresh leaf extract is consumed in empty stomach to get relief from bloating (Rava), flatulence and anorexia by the Mundas, and twice-a-day (morning, evening) to treat amoebiasis and burning sensation during micturition by Rajbangshis. Indigestion (Samtal) and acidity (Limbu), is controlled by eating fresh leaves in empty stomach. Eating raw leaves alleviates sore throat (Dupka).
7	***Cyperus rotundus*, Cyperaceae**			
	Khila dakini gantos (Mech), Kahia (Garo), Mutha ghas (Oraon), Kella harchak (Rava), Kelana (Samtal), Kella (Rajbangshi)	T	Constipation, abdomen pain, Dhat syndrome, fever, nausea, diarrhoea, worm, indigestion	Extract of 2-3 tubers orally twice-a-day consumed to release constipation (Mech) a day while, abdomen pain is relieved with eating either seven tubers with salt (Garo) or its fresh extract to treat fever, abdomen pain (Oraons, Asur, Samtal, Rava). Similarly, fresh tuber extract is also used to treat Dhat syndrome (Samtal) while, Rajbangshis also treat abdomen pain, nausea, diarrhoea, fever, worm, and indigestion with fresh tuber extract.
8	***Azadirachta indica*, Meliaceae**			
	Neem bilai (Mech), neem (Garo, Oraon, Munda, Asur, Khariya, Chikbaraik, Rajbangshi), neem chak (Rava), neem sakam (Samtal)	L, SB, SO	Worm, diabetes, allergy, pruritus, acnes, scabies, anorexia, worm,	Mech chew leaves to treat worm, diabetes, and allergy while Garos and Oraons chews leaves to get relief from pruritus and piles. But Ravas chew neem leaves in empty stomach to treat diabetes while, Khariyas treat diabetes by consuming fresh leaf extract. Acnes are treated by topical application of leaf paste by Mech while, Oraons apply mix of neem leaf and turmeric paste on acnes but Samtals chew leaves to treat acnes. Scabies is treated by Garos by topical application of water boiled with neem leaves while Rajbangshis treat it with topical application of neem leaves pasted with raw turmeric to control scabies. Topical application of leaf pastes also controls ring worm and pruritus (Chikbaraik). Fresh leaf extract is used to treat anorexia, and scabies (Oraon). Similarly, worms are also controlled by consuming leaf extract by Oraons and Ravas and chewing raw leaves by Chikbaraik while, Ravas additionally use bark

				extract to treat worms. Allergy is treated by eating fried leaves (Munda). Mundas and Asur control itching taking bath with neem leaf-boiled water and Santhals treat it with topical application of neem seed oil. Allergy is treated by eating fried leaves (Munda).
9	***Cajanus cajan,* Papilionaceae**			
	Thakleng (Mech), Taru kalai (Garo, Rava), Raher (Oraon), Tauri kalai Rajbangshi, Tauriling (Asur), Rahel dal (Samtal), Rahir (Khariya)	L	Jaundice, canker sore	Fresh leaf extract in empty stomach to treat jaundice (Mech, Garo, Rava, Raher, Samtal, Rajbangshi, Oraon, Khariya). However, Asurs treat jaundice with leaf extract mixture of Cajanus *cajan* and *Azadirachta indica*. Additionally, aphthous ulcer or canker sore is also treated by fresh leaf extract by Oraons.
10	***Murraya koenigii,* Rutaceae**			
	Narsing (Garo, Asur, Samtal, Rajbangshi, Kharoar), Narsingchak (Rava), Chhuchhupata (Munda)	L	Hypertension, flatulence, acidity, body ache	Fresh leaf extract is consumed to control hypertension (Rava) and to get relief from flatulence (Rava) while Asurs, Rajbangshi, Kharoar, and Samtals eat cooked leaves with salt to manage flatulence while, Mundas cook it with pulses for consumption to get relief from flatulence. Additionally, acidity is also controlled by consuming the cooked leaves with salt (Kharoar) and body ache by eating fried leaves (Rajbangshi).
11	***Leucas aspera,* Labiatae**			
	Kankisa (Mech), Damkalas (Garo), Ghumashak (Oraon, Asur, Chikbaraik, Kharia), Dhurup (Samtal), Kansisa/Dhulpi (Rajbangshi)	L, S, WP	Migraine, Bleeding nose, body ache, anorexia, cough, flatulence, fever, furuncle (boil)	Migraine (Mech, Rajbangshi), and bleeding nose (Mech, Samtal, and Oraon) is treated by nasal application 1-2 drops of fresh young leaf and stem extract. Eating the fresh leaf and stem treat body ache and anorexia (Garo, Samtal) while eating dried leaves (Oraon) and boiled whole plant (Rajbangshi) also give relief against body ache. Eating boiled leaves and stem control cough (Asur), furuncle and anorexia (Chikbaraik and Kharia). Leaf extract consumption give relief from flatulence and fever (Rajbangshi). Eating cooked leaves and stem treat
12	***Vitex nigundo,* Verbenaceae**			
	Nisinda chak (Rava), Nisindal (Garo), Sinduyar (Oraon), Nishinta (Rajbangshi)	L	Abscess, common cold, fever, headache, arthritis, pain and swelling of joints, hypertension	Ravas topically applies young leaves with ghee to stop abscess formation and consume fresh leaf abstract with honey to get relief from common cold and fever. Arthritis is either managed by chewing raw leaves (Garo) or consuming fresh leaf extract (Oraon). Nasal application of fresh leaf extract mixed with mustard oil give relief from headache (Oraon)

				and topical application of raw leaf paste relieve pain and swelling of joints (Rajbangshi). Hypertension, diabetes, and jaundice are managed by consuming fresh leaf extract by Rajbangshis.
13	***Aegle marmelos,* Rutaceae**			
	Beal (Mech, Limbu, Munda, Kharia, Chikbaraik, Kharoar), Shelfi (Garo), Khotta (Oraon), Bentai (Rava), Sinjadari (Samtal), Byal (Rajbangshi)	Fr, R, L	Stomach heat, diarrhea, amoebiasis, dyspepsia or indigestion, flatulence, nausea, constipation, diabetes, Dhat syndrome, nocturnal emission or wet dream	Drinking sharbet of ripe fruit pulp and manage symptoms of stomach heat (Mech, Garo, Chikbaraik), diarrhoea (Mech, Garo, Limbu, Munda), dyspepsia or indigestion (Oraon, Kharia), piles (Rava), and amoebiasis (Rajbangshi) while, also as liver tonic (Kharoar). Drinking tea made of dry fruit pieces treat diarrhoea (Garo) and flatulence (Rajbangshi). Drinking either solution mixing with candy after soaking the young fruits (Oraon) or eating roasted unripe fruit (Rava) treat amoebiasis and control indigestion. Eating boiled root (Rava), and raw fruits (Rava, Samtal) manage nausea and constipation. Constipation is also relieved by drinking solution after soaking the dried young fruits in water (Rajbangshi). Eating raw fruit manage diabetes, fresh root extract treats Dhat syndrome, and fresh leaf extract manages nocturnal emission (Rajbangshi).
14	***Cissus quadrangularis,* Vitaceae**			
	Har jirghou (Mech), Arang jora (Garo), Kerengbein (Rava), Harjor (Oraon, Asur, Munda, Rajbangshi), Hatjora, (Samtal), Harchur (Toto), Harbhanga (Kharia)	CS	Fracture, arthritis, joint pain	Topical application of stem paste (Mech, Garo, Rava, Asur, Munda, Rajbangshi, Toto, Kharia) mixing with egg (Mech, Munda) or dry fish (Garo) and thereafter either bandaging with bamboo lath for 4-5 days (Mech and Garo) or banana leaves (Rava) and cloth (Asur, Munda, Rajbangshi, Toto, Kharia) heal fracture. Arthritis (Oraon, Samtal), joint pain and burns (Kharia) are also treated with fresh stem and leaf extract.
15	***Kalanchoe pinnata,* Crassulaceae**			
	Patharku (Mech), Patharchira (Garo), Patharkuchi (Oraon, Munda, Rajbangshi), Hang kuchi fang (Rava)	L	Headache, flatulence, ringworm, cut and wound, kidney stone, bloating, burning sensation during micturition, oliguria (decreased urination), wound sore or ulcer	Fresh leaf extract relieves headache (Mech), flatulence (Oraon), and drinking it manage kidney stone (Munda) while, topical application of leaf paste heals cut and wound (Garo) and control ringworm (Oraon). Chewing 3-4 fresh leaves empty stomach during morning also manages kidney stone (Rajbangshi) Drinking leaf extract solution with sugar manage bloating (and mixing the extract with cucumber seeds cures burning sensation during micturition (Rava). Bandaging warm leaf on affected region heal wound sore while, topical application of leaf paste on affected area and leaf extract on lower

				abdomen manages oliguria and heals burn, respectively (Rajbangshi).
16	***Catharanthus roseus,* Apocynaceae**			
	Nayantara (Garo), Chepti par (Rava), Bostumiful (Rajbangshi)	F, L, R	Hypertension, diabetes, hypertension, cut and wound	Fresh leaf extract (Garo), root extract (Rava, Rajbangshi) manages hypertension and topical application of flower extract (Garo) and leaves (Rava, Rajbangshi) manages hyperpigmentation (Garo), and heals cut and wound, respectively. Chewing two flowers empty stomach during morning manages diabetes (Rava, Rajbangshi)
17	***Dillenia indica,* Dilleniaceae**			
	Thaidi (Mech), Thibi (Garo), Panchkol (Munda, Asur, Oraon, Rajbangshi)	C, L	Flatulence, bloating, anorexia, hypogeusia, amoebiasis, abdominal cramps	Consumption of fresh calyx extract mixed with salt treat flatulence (Mech) and bloating (Garo) while, with sugar relieve abdominal cramp (Rajbangshi). Eating calyx chutney treats anorexia (Garo), and calyx pickle treats hypogeusia (Munda, Oraon). Calyx pickled is also eaten to treat anorexia (Asur). Young leaf extract mixed with a cup of water is consumed to treat amoebiasis.
18	***Asperagus racemosus,* Asparagaceae**			
	Chanda vanda (Rava), Kaishalgo (Oraon), Shatmuli (Rajbangshi)	R	Blood purifier, abdomen pain, short temper	Boiled root extract twice-a-day is consumed for blood purification (Rava). Fresh root extract is consumed to treat abdomen pain (Oraon) and gonorrhea (Rajbangshi). Topical application of root extract mixed with wax gourd extract and sesame oil manage short temper (Rajbangshi).
19	***Paederia scandens,* Rubiaceae**			
	Mai sundaririda (Mech), Fasunbijak/ gandhapatali (Garo), Padripatai (Oraon), Padripatai (Oraon), ganbhaduri (Rava), Padrishak (Asur), Gandha patali (Samtal), Gan bhadai (Rajbangshi), Padrishak (Chikbaraik)	R, L	Dysentery, amoebiasis, indigestion, anorexia, diarrhoea, flatulence, constipation, abdomen pain, arthritis, leucorrhoea	Consumption of root paste control dysentery (Mech) and leucorrhoea (Rajbangshi). Garos treat amoebiasis consuming leaf extract and indigestion with soup made of leaves. Indigestion is also treated by eating raw leaves and roots (Rajbangshi). Anorexia is treated with consuming chutney made of leaves (Oraon). Diarrhoea (Oraon, Rava, Toto- 2-3 times-a-day), constipation, and abdomen pain (Rajbangshi-mixing with dry ginger and black pepper) is controlled by consuming fresh leaf extract. Eating cooked leaves and roots treat flatulence (Asur) and relieve constipation (Chikbaraik). Root decoction is administered orally to treat arthritis (Rajbangshi).
20	***Terminalia arjuna*, Combretaceae**			
	Arjun (Garo, Oraon, Munda, Asur, Rajbangshi, Kharia), Arjun fangnihalp (Rava), Gutasing (Toto)	SB, F	Heart disease, Dhat syndrome, anorexia, urinary hesitancy, amoebiasis, thermoregulation	Stem bark powder mixed with warm milk (Garo, Rava, Rajbangshi) or its fresh extract is consumed to treat heart disease (Garo, Oraon, Asur). Fresh stem bark extract is also consumed to treat Dhat syndrome (Oraon, Asur), anorexia (Munda), and amoebiasis (Toto).

				Drinking solution of boiled stem bark extract manages urinary hesitancy (Rava, Rajbangshi). Fresh fruit extract is used as anthelminthic (Rajbangshi). Drinking soaked dried stem bark solution regulates body temperature (Kharia)
21	***Ficus racemosa,* Moraceae**			
	Dumair (Oraon), Dumur fang (Rava), Dumrai (Asur), Dumur (Rajbangshi)	Fr, R, La	Amoebiasis, cut and wound, blood tonic	Fresh fruit extract mixed with sugar is consumed to treat amoebiasis and its topical application heal cut and wound (Oraon). Topical application of latex also heals cut and wound (Asur). Consuming root extract manages diabetes (Rava). Eating cooked fruits increases blood (Rajbangshi)
22	***Emblica officinalis,* Euphorbiaceae**			
	Amlai (Mech), Ambri (Garo), Aunra (Oraon), Aonra (Asur), Anra (Munda), Amloki (Rajbangshi), Maisi (Toto), Moral (Samtal), Anora (Kharia, Chikbaraik), Kirula (Tamang), ghmrek (Limbu)	Fr	Allergy, conjunctivitis, burning sensation during micturition, anorexia, jaundice, flatulence, diabetes, constipation, hair care, digestive tonic, indigestion, cough and cold	Consuming extract of amla fruit either mixed with turmeric and leaves of *Azadirachta indica* give relief from allergy (Mech) or with candy/sugar manage burning sensation during micturition (Garo, Limbu) and jaundice (Oraon). Topical application of raw fruit extract treats conjunctivitis (Garo). Eating raw fruit with or without salt manages anorexia (Garo, Asur, Rajbangshi) and general nutrition (Munda) and increases digestion (Kharia). Consumption of fresh fruit extract manages flatulence (Asur), anorexia (Samtal), diabetes (Rajbangshi), increases digestion (Toto), and treat indigestion (Chikbaraik). Topical application of fresh fruit extract (Kharia) or boiled fresh fruit extract with mustard oil (Munda) maintains black hair. Consumption of overnight water-soaked dried fruit solution alleviates constipation (Rajbangshi) and water-soaked fresh fruit treats cough and cold (Tamang).
23	***Moringa oleifera*, Moringaceae**			
	Sajna jadel (Garo), Munga (Oraon, Munda, Kharia, Chikbaraik), Mugga (Asur), Sajne (Rajbangshi)	SB, L, Fr, F, S	Headache, hypertension, chickenpox, diabetes, anaemia, arthritis, general tonic, jaundice	Topical application of stem bark paste relieves headache (Garo). Consumption of fresh leaf extract manages hypertension (Oraon, Munda, Asur) and diabetes (Chikbaraik). Eating fried leaves with rice gruel also manages hypertension (Kharia) Eating fried fruit and flower prevent chicken pox, fried leaves manage diabetes, cooked fruit cure anaemia, and cooked seeds relieve arthritis (Rajbangshi). Rajbangshi's also treat arthritis through topical application of hot stem bark paste. Leaves cooked with cereals are consumed for general nutrition (Kharia)

24	***Mentha spicta,* Labiate**			
	Pudina rida (Mech), Pudina bijak (Garo), Pachcha tentali/Fudna (Oraon), Pudina chak Rava), Pudina (Munda, Rajbangshi, Kharia), Pudinara (Samtal)	L	Diarrhea, anorexia, earache, loss of appetite, digestive tonic, nausea, vomiting, bloating, toothache, hyperacidity, flatulence, constipation	Consuming extract-mix of fresh mint, *Psidium guajava*, and *Citrus limon* leaves, and *Paederia scandens* roots control diarrhoea (Garo). Eating salted leaf paste with rice manages anorexia (Garo), fresh leaf extract with candy stops vomiting (Oraon), fresh leaf extract manages anorexia (Munda), hyperacidity (Kharia, Samtal, Rajbangshi), boost digestion, nausea, flatulence, and constipation (Samtal, Rajbangshi) and mint chutney gains appetite (Oraon), and control hyperacidity, nausea, flatulence, boost digestion, and constipation (Samtal, Rajbangshi). Drinking solution after soaking dried leaves manages bloating (Rava). Topical application of fresh leaf extract relieves earache (Garo). Dental wash by dried leaves twice-a-day give relief from tooth ache (Rava).
25	***Nyctenthes arbor-tristris*, Oleaceae**			
	Shefali (Mech, Garo, Oraon, Rajbangshi, Limbu), Hardi (Asur)	F, L, Tw	Conjunctivitis, fever, cut and wound, pitta jawr (fever), arthritis, anorexia, toothache	Topical application of flower extract cure conjunctivitis (Mech) and leaf paste mixed with turmeric and mustard oil heals cut and wound (Asur). Consumption of fresh leaf extract (Mech), fried flower (Mech, Oraon), and fresh leaf paste (Asur) control fever. Consumption of fresh leaf extract also cures pitta jawr and manages worm, while dry leaf decoction relieves arthritis and fried leaves manages anorexia (Rajbangshi). Dental care by brushing with twigs alleviates pain (Limbu).
26	***Clerodendrum viscosum,* Verbenaceae**			
	Bhati/Lakhna bilai (Mech, Rajbangshi), Bhatiya (Garo), Khato/Bhato (Oraon), Bhati (Rava), Ghat (Munda), Ghato (Asur), Bandari (Samtal), Ambarasi (Toto), Bhant (Kharia)	L, F, S, RB, R	Pruritus, worm, lice, skin disease, heat rash, arthritis, amoebiasis, diabetes, fever, dental care, toothache, diarrhoea, constipation	Taking shower after boiling the water with leaves (Mech). Worms and lice are controlled by eating flower buds and topical application of leaf extract on scalp (Garo). Worms are also managed by chewing roots of about 2-inch size in the morning (Kharia). Topical application of leaf pastes and extract manages skin disease and heat rash, respectively while, consumption of root extract and tender leaf extract cures arthritis and amoebiasis, respectively (Oraon). Oral administration of leaf extract mixture of *Clerodendrum viscosum* and *Andrographis paniculata* manages diabetes (Rava), and kills worm (Rajbangshi). Topical application of extract mixture of *Clerodendrum viscosum* and *Azadirachta indica* cures skin disease (Rava).

				Dental care is done by brushing with twigs (Munda, Samtal, Rajbangshi) and dermal diseases by taking shower after boiling the water with leaves (Munda, Samtal). Consumption of fresh leaf extract manages diabetes and worms and mixing it with salt cures fever (Asur). Drinking water after boiling with root (Toto) or consumption of leaf extract with betel nut also cures fever (Rava). Topical application of leaf extract mixed with black pepper on scalp terminates lice Rajbangshi). Consumption of leaf extract mixed with black pepper and salt relieves constipation (Rajbangshi). Consumption of either root bark extract alone (Toto) or mixed with sugar and salt manages diarrhoea (Rajbangshi).
27	***Adhatoda vasica,* Acanthaceae**			
	Baksa (Mech, Asur, Lohar, Chikbaraik), Machaks (Garo), Bakso (Oraon), Basak fang (Rava), Baksa vata (Munda), Bakshasakam (Samtal), Harbaksha (Rajbangshi), Kasai (Toto), Baksha (Kharoar), Asura (Tamang)	L, F	Cough, common cold, constipation, asthma, sore throat, asthma, fever, worm, ringworm	Drinking water boiled with leaves is remedy of cough (Mech) and asthma (Oraon- 5-10 leaves). Consumption of warm leaf extract with *Ocimum sanctum* give relief against common cold (Mech, Rava), and leaf extract mixed with ginger and *Ocimum sanctum* alleviate sore throat (Munda). Fresh leaf extract is consumed to get relief from cough (Garo, Asur, Samtal, Rajbangshi, Kharoar), constipation (Garo, Asur), asthma (Asur), and worms (Lohar, Tamang). Hot leaf extract is also administered against cough (Oraon), while fresh leaf extract with ginger is consumed to get relief from asthma (Rajbangshi). Fever is cured by drinking water boiled with flower (Toto). Topical application of leaf extract control ringworm (Chikbaraik)

C: Calyx**; CS:** Creeping stem**; F:** Flower**; Fr:** Fruit**; L:** Leaves**; La:** Latex**; R:** Root**; RB:** Root bark**; S:** Stem**; SB:** Stem bark**; SO:** Seed oil**; T:** Tuber**; Tg:** Twig**; WP:** Whole plant

These 16 ethnic groups of people have developed this traditional knowledge experimentally and developed their own diagnosis and treatment methods for various diseases. Regarding the method of application, decoctions, pastes, raw materials, juices of fresh plant parts and products derived from them are applied orally or topically depending on the nature of the disease. However, the dosage of application per day and the duration of treatment vary depending on the nature and history of the disease. Due to awareness about use of medicinal plants, respondents who are living in Cooch Behar have informed that they have increased the traditional use of medicinal plants. These types of results have been also observed in the study of others (Shukla and Chakravarty, 2012; Dey *et al*., 2015; Mandal *et al*., 2020$_{a, b}$, 2021; Rakshit, 2022; Adhikari *et al*., 2023; Dinda, 2025).

CONCLUSION

The present documentation on the cross-cultural analysis of ethno medicinal plants among the sixteen ethnic community Cooch Behar and Alipurduar district of West Bengal, India listed 27 plant species used as folk therapy by 16 ethnic groups. Maximum community used Oroxylum indicum, Ocimum sanctum, Centella asiatica, Emblica officinalis, Clerodendrum viscosum, these species. Leaves and fruits are used maximum by these ethnic groups. They used the plants in case of fever, cough, indigestion, worm infestation. The forested, humid climate and lack of vehicular access are major barriers to limited access to healthcare facilities in these areas. The ethnic communities have developed traditional medical systems using locally available medicinal plant resources for their healthcare needs. Almost half of the informants in this study were women, indicating that women have equal participation in all aspects of life and are important negotiators within the families and communities of Terai region of West Bengal.

REFERENCES

Adhikary P, Sharma C, Roy P, Chettri S, Das R, Ghosh P, Mohanty JP. 2023. Study of medicinal plants utilized by Rajbangsi's: against fever in Cooch Behar, West Bengal, India from an ethno botanical perspective. International Journal of Pharmacognosy and Life Science 4(1): 109-115. http://doi.org/10.33545/27072827.2023.v4.i1b.81.

Dey AN, Datta S, Sharma B. 2015. Documentation of ethno-medicinal practices: A case study on tribal forest fringe dwellers of Terai West Bengal in India. Journal of Applied and Natural Science 7(2): 822-827.

Dinda BK. 2025. Improvement of health and socio-economic status of women self-help groups after development of bhesaj gram (herbal village) through home herbal gardens: a case study. Journal of Agriculture and Technology 12(1): 1-13.

Dutta T, Patra AK, Dastidar SG 2014. Medicinal plants used by tribal population of Cooch Behar district, West Bengal, India- an ethnobotanical survey. Asian Pacific Journal of Tropical Biomedicine 4(Suppl 1): S478-S482. http://doi.org/10.12980/APJTB.4.2014C1122.

Mandal A, Adhikary T, Chakraborty D, Roy P, Saha J, Barman A, Saha P. 2020b. Ethnomedicinal uses of plants by Santal tribe of Alipurduar district, West Bengal, India. Indian Journal of Science and Technology 13(20): 2021-2029. http://doi.org/10.17485/IJST/v13i20.565.

Mandal A, Roy R, Roy K, Choudhury A, Islam J, Thakur S, Barman S, Dutta A, Sarkar M, Debnath A, Alam R. 2021. Ethnobotanical study of medicinal plants used by the ethnic communities of Alipurduar district of West Bengal, India. Plant Archives 21(1): 229-238. https://doi.org/10.51470/PLANTARCHIVES.2021.v21.no 1.032.

Mandal A, Saha P, Begum A, Saha A, Chakraborty B, Dutta S, Roy KK. 2020a. Ethnomedicinal plants used by the ethnic people living in fringe villages of Rasikbil of Cooch Behar District, West Bengal, India. Indian Journal of Science and Technology 13(16): 1676-1685. http://doi.org/10.7485/IJST/v13i16.380.

Prajapati ND, Purohit SS, Sharma AK, Kumar T. 2003. A Hand book of Medicinal Plants. Agrobios, Jodhpur, India. 553p.

Rakshit S. 2022. Use of herbal plants as medicines by Rajbanshi people of Cooch Behar and Jalpaiguri districts of West Bengal: A cultural and socio-economic analysis. Journal of Engineering Technologies and Innovative Research 9(10): a415-a426.

Sen S, Chakraborty R. 2017. Revival, modernization and integration of Indian traditional herbal medicine in clinical practice: Importance, challenges and future. Journal of Traditional and Complementary Medicine 7 (2): 234-244. https://doi.org/10.1016/j.jtcme.2016.05.006.

Shukla G, Chakravarty S. 2012. Ethnobotanical plant use of Chilapatta Reserve Forest in West Bengal. Indian Forester 138(12): 1116-1124.

WHO. 2019. WHO global report on traditional and complementary medicine 2019. World Health Organization. Available at https://apps.who.int/iris/handle/10665/ 312342.25February 2023.

J. Agric. Technol., 12(2): 49-67 (2025)
Print: ISSN: 2348-4721; Online: ISSN: 2349-610X

Ethnomedicinal Uses of Plants by the Rajbanshi Community in Cooch Behar District, West Bengal, India

Jayita Debnath[1], Jayanwita Sarkar[2*], Jyotsna Das[3]

[1]*Department of Botany, ABN Seal College, Cooch Behar, West Bengal, India*
[2]*Department of Botany, Cooch Behar Panchanan Barma University, Cooch Behar, West Bengal, India*
[3]*Department of Botany, Alipurduar University, Alipurduar, West Bengal, India*

***E-mail**: sarkar.jayanwita@gmail.com*

Received: 03-09-2025; **Revised:** 21-09-2025; **Accepted:** 24-09-2025

Citation: Debnath J, Sarkar J, Das J. 2025. Ethnomedicinal Uses of Plants by the Rajbanshi Community in Cooch Behar District, West Bengal, India. J Agric Technol. 12(2): 49-67.

The present survey was conducted among the Rajbangshi community of Khapaidanga village, Cooch Behar district, West Bengal to document ethnomedicinal plant species used and their therapeutic applications against common ailments. A total of 33 species represented by 32 genera and 28 families were documented. Leaves are the most commonly used plant part, with extract, decoction and diverse paste formulations being the main application methods. The community generally rely on plant-based folk medicines for common ailments and diseases. Therefore, proper documentation of such traditional knowledge not only preserves indigenous usage but also offers a valuable foundation for future pharmacological studies and sustainable management of these plant resources.

Keywords: Ethnomedicine, Traditional knowledge, Rajbangshi community, Phytotherapy

INTRODUCTION

Herbal medicine plays a significant role in the lives of ethnic communities across India, serving not only as a primary healthcare resource but also as a foundation of cultural identity and responsible management of natural resources and ecosystems (Bisht and Badoni, 2009). Indigenous people always generated, refined and passed on traditional knowledge from generation to generation. This knowledge is based on their needs, instinct, observation, trial and error and long experience. In remote villages, where access to modern medical facilities is limited, herbal remedies are often the first and only line of treatment (Dhar *et al.*, 1999). Traditionally, ethnic communities use plants to treat common ailments like fever, digestive disorders, skin infections, respiratory issues, arthritis, jaundice and even bone fractures. The use of medicinal plants for the treatments of diverse types of ailments has been documented since long and such traditional knowledge on ethnomedicines has led to develop many modern medicines (Dinda, 2025$_{a,\,b}$).

Terai–Duars region of West Bengal is covered with lush green diverse vegetation, mainly forests and has long been a mosaic of several ethnicity. Rajbangshi community - also known as 'Koch-Rajbangshi' is one of the predominant inhabitants of this region and culturally rich and historically significant indigenous group (Roy *et al*., 2016). Historical and ethnographic documents trace Rajbanshi settlements in North Bengal, Western Assam, and northern Bangladesh effectively spanning in Brahmaputra-Teesta valley and even in parts of Nepal and Bihar. The traditional knowledge of Rajbagnshi community regarding ethnomedicinal value of indigenous plants is very rich and they use plants in almost all aspects of their life (Debnath *et al.*, 2019; Roy, 2015). The present survey was conducted on Rajbangshi community at Khapaidanga village, district Cooch Behar where they are the predominant community inhabiting there since long and carrying out their livelihoods with their rich cultural heritage and traditional belief. The study aims to systematically document the plant-based medicinal practices of the Koch Rajbangshi community of this area, including the identification of locally used species, their preparation methods, dosage and medicinal properties. We have tried to explore the proposition that despite the study's restricted geographical scope, the Rajbangshi community in this locality holds a robust and dynamic repository of traditional knowledge, using locally available flora in a purposeful manner as a remedy of recurrent local health concerns.

MATERIALS AND METHOD

The study area is Khapaidanga, a village in Cooch Behar-II block of district Cooch Behar, West Bengal, India which occupies an area of 1291.89 sq. km and lies between 26.34° N latitude and 89.51° E longitude (Figure 1). Khapaidanga has a population of 9839 as recorded in the 2011 Census where the male population is 5116 and the female population is 4723. The village has approximately 2445 households and the average household size in the village is about 4 persons per house. Khapaidanga has a large Rajbangshi population (5796 out of 9,839 as per 2011census data) representing schedule caste community. Among the Rajbangshi population 2976 (51.35%) were males and 2820 (48.65%) females. The nearest town to Khapaidanga is Cooch Behar, the district headquarters. As per the 2011 Census, the literacy rate of Khapaidanga village was 74%. The predominant language spoken Bengali which includes local dialects like Kamtapuri.

The study design used in this study is a cross-sectional descriptive method. The population comprises male and female people of Rajbangshi community residing in Khapaidanga village. This study enrolled 120 respondents (sampling intensity about 2 %) with age varying from younger than 30 years to 75 years of age. The respondents were selected randomly and then interviewed using pre-tested semi-structured questionaries (Uzun and Koca, 2020). The questionary composed of information on demographic information and about folk therapy using ethnomedicinal plants. A total of four field trips were conducted from June 2025 to July 2025 for the documentation of ethnomedicinal knowledge of target group. Three Rajbangshi traditional healers and other knowledgeable persons were also interviewed. Prior Informed Consent (PIC) was taken from each informant before interview. Information about the plants were recorded with regards to their vernacular/local names, plant parts used, usefulness, method of preparation either individually or in combination with other plant parts, mode of application and dosages.

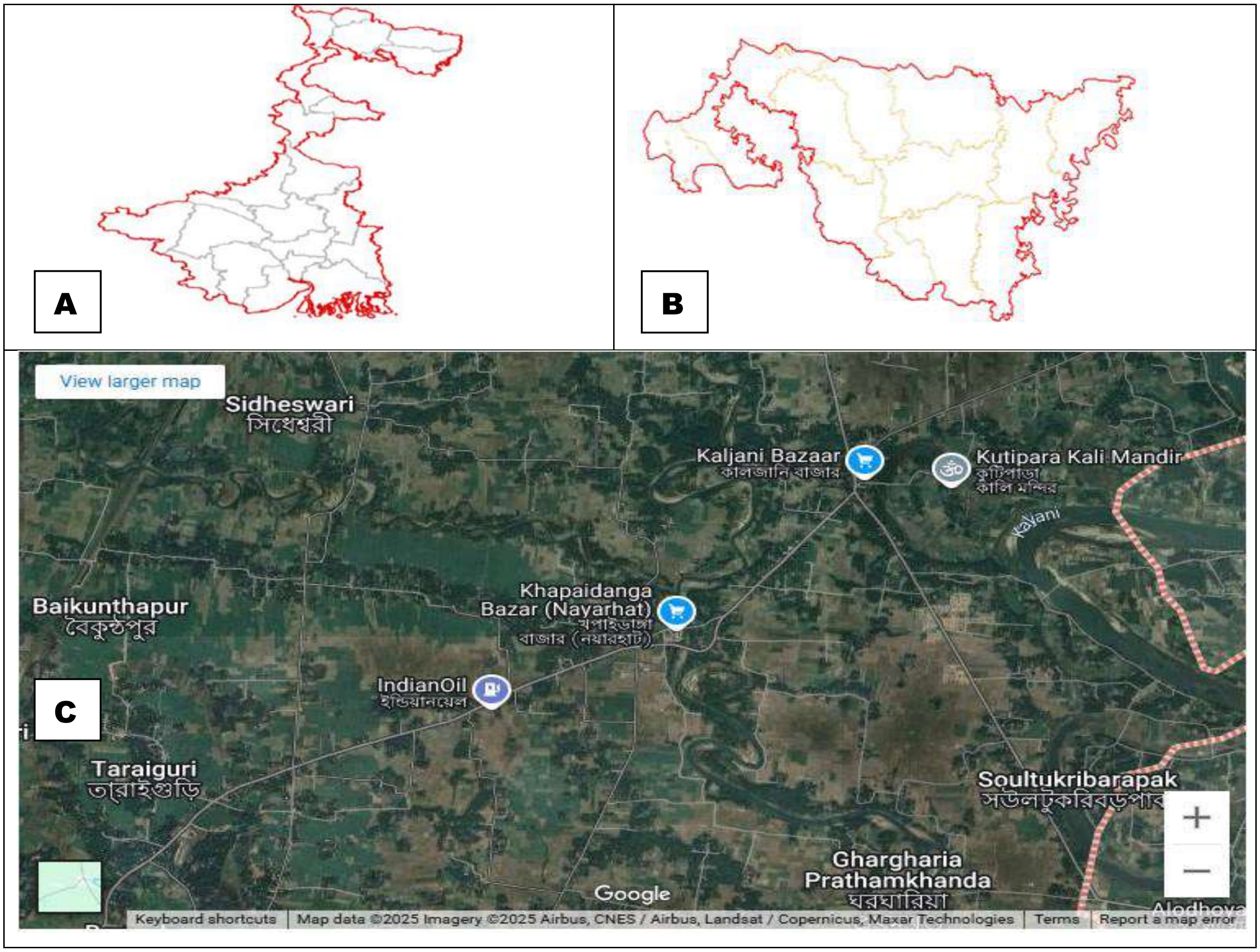


Figure 1. Map of the study area, A. West Bengal, B. Cooch Behar district, C. Khapaidanga village (Source: Internet)

RESULTS AND DISCUSSION

The knowledge on ethnomedicinal plants and their therapy in Rajbanshi community is a dynamic continuity of oral tradition and practice through transgenerational transmission. During our survey in Khapaidanga, interestingly we observed that local Rajbanshi community relies on locally available plants as folk medicine to cure ailments. The complete list of the ethnomedicinal plants found during survey is given in Table 1. In most cases, precise method of the preparation of medicine and dosage of administration were not exactly disclosed, as the community healers were hesitant due to their belief that sharing such information outside the community will under-value their traditional knowledge. Similar belief was also earlier reported by many workers (Mandal *et al*., 2020; Mitra and Mukherjee, 2022).

Table 1. Ethnomedicinal plants and therapy used by Rajbangshi community

SN	Scientific name, family, vernacular name	PP	Therapy
Climbers			
1	*Asparagus racemosus*, Liliaceae, Shatamuli	R	Root decoction treats jaundice.
2	*Cissus quadrangularis* (L.), Vitaceae	S	Heal broken bones, injured ligaments and tendons.
3	*Cissampelos pareira* (L.), Menispermaceae, Niltat	R	Root decoction treats rheumatism.
4	*Cuscuta reflexa Roxb.,* Convolvulaceae*,* Swarnalata	S	It is useful against arthritis.
5	*Dioscorea bulbifera (L.)*, Dioscoreaceae*,* Chuprialu	Bu, Tu	Treats stomach ache and rheumatism.
6	*Paederia foetida*, Rubiaceae*,* Gandalpata	L, R	Fresh leaf juice treats stomach problem; root decoction treats rheumatism.
7	*Tinospora cordifolia*, Menispermaceae*,* Gulancha/Giloe	L	Cures fever, arthritis, diabetes, high cholesterol, and stomach upset.
Herbs			
8	*Achyranthes aspera* (L.), Amaranthaceae, Apang	L, Sd	Seeds treats hydrophobia and snake-bites. Fresh pulp made from leaves is topically applied to against scorpion bite.
9	*Allium cepa* (L.), Amaryllidaceae, Peaj	Bb	Extract used against joint pain.
10	*Allium sativum* L*,* Amaryllidaceae Rasun	Bb	Extract used against rheumatism.
11	*Andrographis paniculata* (Brum. f.), Acanthaceae, Chiretta	L, R	Leaf extract or root decoction is taken orally to treat stomach problems and jaundice.
12	*Centella asiatica* (L.), Apiaceae, Gotu kola	L	Neuro-protective, heals wound, anti-inflammatory, hepatoprotective, sedative, cardioprotective, antidiabetic and treat skin disorders like acne, ulcer and boils.
13	*Coccinia cordifolia* (L.), Cucurbitaceae, Telakucha	L	Decoction treat diabetes and jaundice.
14	*Curcuma longa* (L.), Zingiberaceae, Holud	Rh	Natural detoxifier, anti-inflammatory, pain killer, treats anaemia, liver disorder, gout, fractured bones, diabetes and urinary tract infection.
15	*Cynodon dactylon* (L.), Poaceae, Durba	Wp	Antibacterial, antimicrobial, antiviral, heals wound, treat cough, headache, diarrhoea, epilepsy, dropsy, dysentery, snakebite,

			sores and tumours.
16	*Heliotropium indicum* (L.), Boraginaceae, Hatisur	L	Topical paste application treats joint pain and swelling.
17	*Oxalis corniculata* L., Oxalidaceae, Tok pata	L	Fresh leaf decoction treats jaundice.
18	*Piper chaba* (L.), Piperaceae, Chuijhal	F	Treats arthritis.
19	*Zingiber officinale*, Zingiberaceae, Aada	Rh	Cures abdominal pain.
Shrub			
20	*Cajanus cajan* (L.), Fabaceae, Aarahar	L	Decoction treats jaundice.
21	*Calotropis gigantea* (L.), Apocynaceae, Akondo	L, R, B	Root and leaf extract treats asthma, bacterial infection, shortness of breath and bark treat liver and spleen diseases.
22	*Cannabis sativa* (L.), Cannabinaceae, Bhang	L, I	Hallucinogenic, hypnotic, sedative, analgesic, and anti-inflammatory.
23	*Datura metel* (L.), Solanaceae, Dhutura	L, Fl, Sd	Powder treats rheumatic pain.
24	*Ricinus communis* (L.) Euphorbiaceae, Eradom	Sd	Oil applied topically treat rheumatic pain.
25	*Vitex negundo* (L.) Lamiaceae, Nisinda	L	Decoction treats arthritis.
Trees			
26	*Aegle marmelos* (L.), Rutaceae, Bel	F, L	Leaf extract cures ulcer and intestinal worms, ripe fruit promotes digestion and treats rectum inflammation, fine powder of unripe fruit treats intestinal parasites.
27	*Alstonia scholaris* (L.), Apocynaceae, Chhatim	S	Latex topically applied to heal fractured bone.
28	*Carica papaya* (L.), Caricaceae, Paypay	F, L	Leaves treat malaria, purgative, smoked to get relieve from asthma; ripe and unripe fruits treat gastrointestinal problems.
29	*Dillenia indica* (L.), Dilleniaceae, Chalta	B, L, F	Fruit pulp treats stomach problems.
30	*Moringa oleifera* Lam., Moringaceae, Sojna	F, L, R	Treat arthritis and diabetes.
31	*Murraya koenigii* (L.), Rutaceae, Karipata	L	Culinary, treat rheumatic pain.
32	*Nyctanthes arbortristis* (L.), Oleaceae, Siuli	L	Fresh decoction treats arthritis.
33	*Syzygium cumini* (L.), Myrtaceae, Jamun	B, L, Sd	Treats malaria, gastro-intestinal disorder and arthritis.

SN: Serial number**; PP:** Plant part (**B:** Bark**; Bu:** Bulbil**; Bb:** Bulb**; F:** Fruit**; Fl:** Flower**; I:** Inflorescence**; L:** Leaf**; R:** Root**; Rh:** Rhizome**; S:** Stem**; Sd:** Seed**; Tu:** Tuber**; Wp:** Whole plant)

Botanical Classification of Medicinal Plants

Rajbangshi community used a total of 33 ethnomedicinal plant species represented by 32 genera and 28 families (Table 1; Plate 1). Families Amaryllidaceae, Apocynaceae, Menispermaceae, Rutaceae and Zingiberaceae each were represented by two species and rest 23 families were each represented by single species (Figure 2). There are many studies validating similar ethnomedicinal plant species use by indigenous communities across the world (Dharmasiri *et al*., 2003; Ahmad *et al*., 2016; Janghel *et al*., 2019; Prasad *et al*., 2019; Kaloni *et al*., 2020; Saleem *et al*., 2020; Singh *et al*., 2020, 2021; Cheruku *et al*., 2021; Manica *et al*., 2021; Mehta *et al*., 2021; Ojetunde *et al*., 2021; Chakraborty *et al*., 2022; Kunjumon *et al*., 2022; Emeka *et al*., 2023; Islam *et al*., 2023; Sharma *et al*., 2023$_{a, b}$; Sivapalan *et al*., 2023; Hossain *et al*., 2024; Joshi *et al*., 2024; Meher *et al*., 2024; Dinakarkumar *et al*., 2025; Verma *et al*., 2025; Zhang *et al*., 2025).

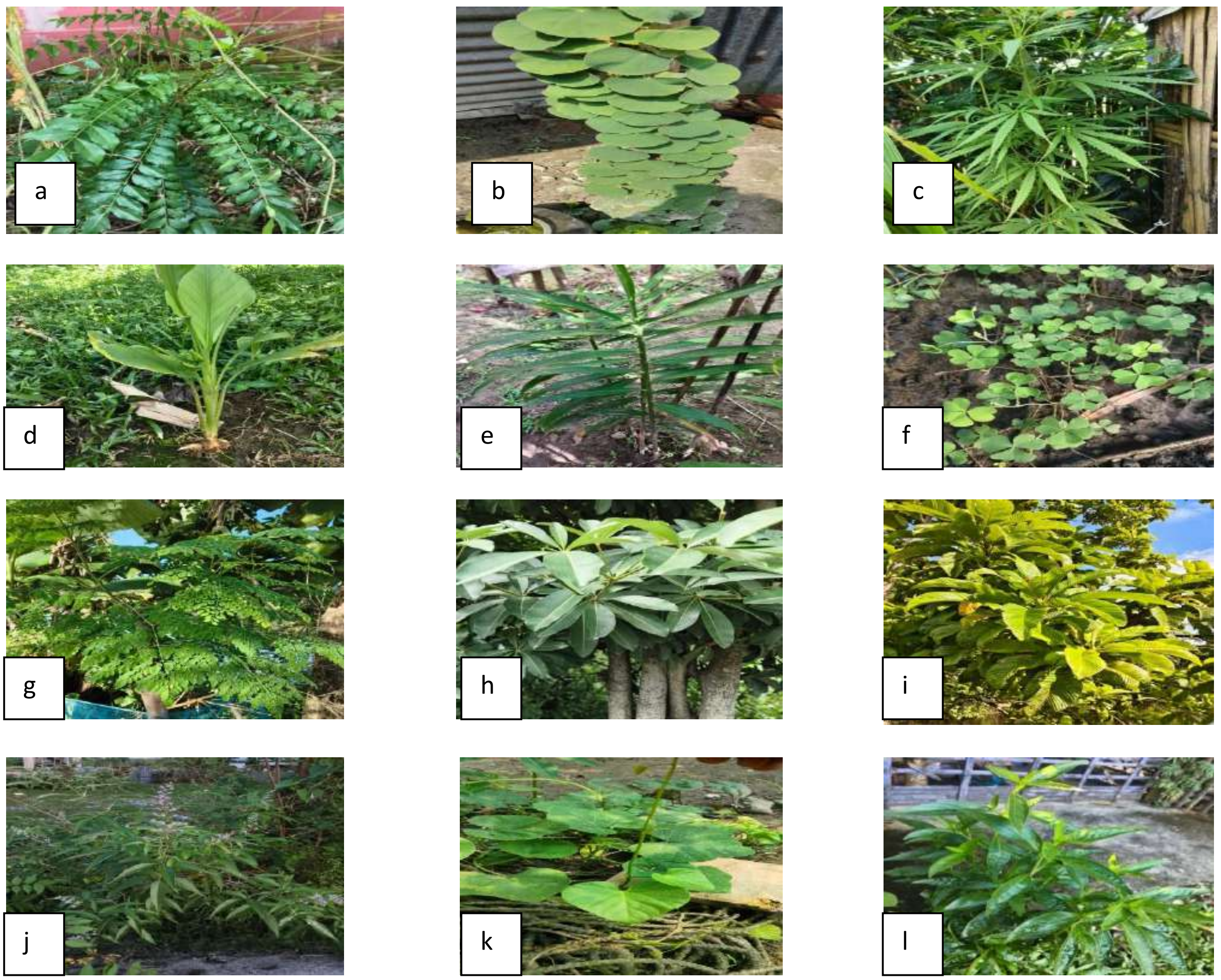


Plate 1. Some documented ethnomedicinal plants **a.** *Murraya koenigii*, **b.** *Cissampelos pareira*, **c.** *Cannabis sativa*, **d.** *Curcuma longa*, **e.** *Zingiber officinale*, **f.** *Oxalis corniculata*, **g.** *Moringa oleifera*, **h.** *Alstonia scholaris*, **i.** *Dillenia indica*, **j.** *Vitex negundo*, **k.** *Tinospora cordifolia*, **l.** *Andrographis paniculata*

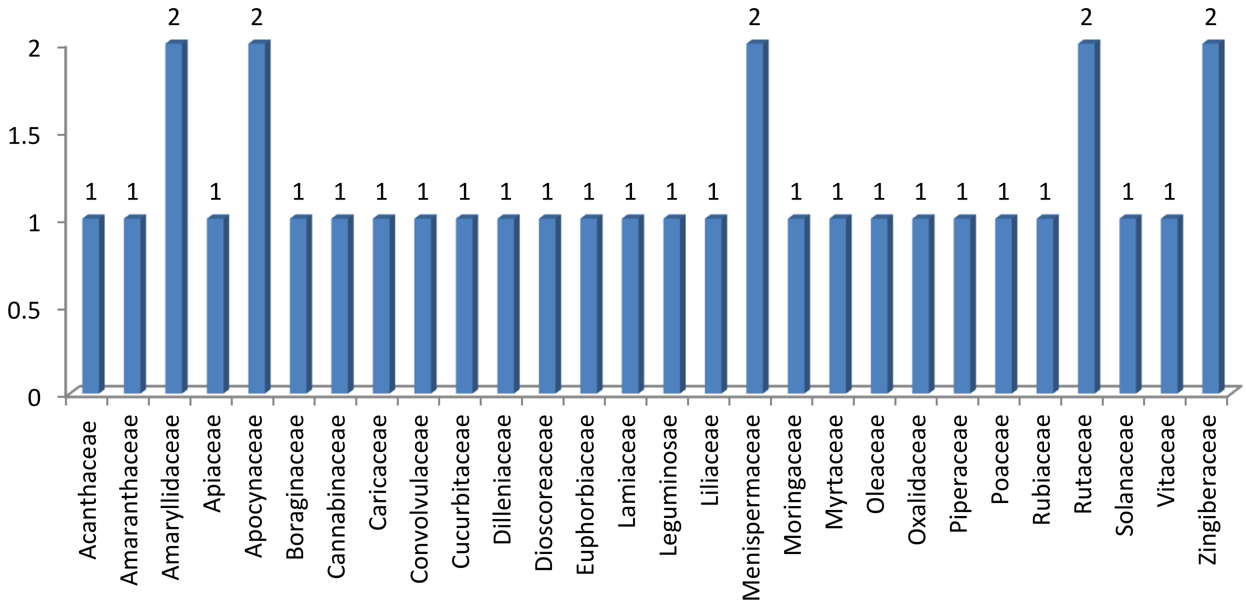


Figure 2. Ethnomedicinal plant families documented

Growth Habit

The growth habit of the documented plants showed that herbs (12 species, 36.36%) and trees (8 species, 24.24%) were the predominant group followed by climbers (7 species and 21.21%) and shrubs (6 species, 18.18%) (Figure 3). All the plants were collected either from natural vegetation or home garden which indicated their dependency on these plants to overcome common ailments.

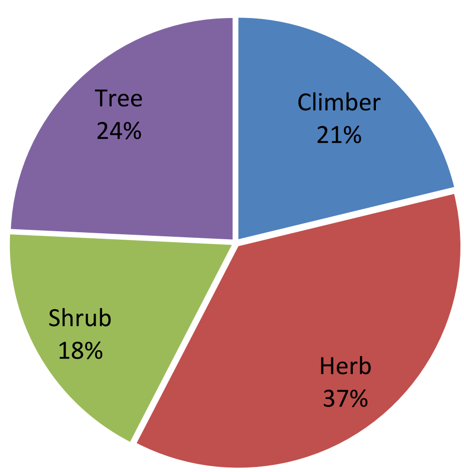


Figure 3. Growth habit of the ethnomedicinal plant species

Plant Parts Used as for Medicinal Purpose

Different plant parts (Table 1; Figure 4) were found to be useful in ethnomedicinal practices by the Rajbangshi community. Leaves (51.5%) were mostly used as ethno medicinal therapy followed by root (18.18%), fruits (12.12%), stem and bark (9.09%) and seed (9.09 %). Other parts used as medicine includes bulb, inflorescence and rhizome (6.06% each) along with tuber (3.03%). Earlier ethnomedicinal studies also reported leaves mostly used in therapy along with other plant parts similarly found in this study (Rahman and Asha, 2021; Vineeta *et al*., 2022). A common belief behind such practices as mentioned by earlier workers was that the plant parts other than leaves may harm the mother plant and thus destroy its existence in future (Mandal *et al*., 2020). The present survey also indicated similar consciousness among the Rajbangshi people to conserve their ethnomedicinal plant resources.

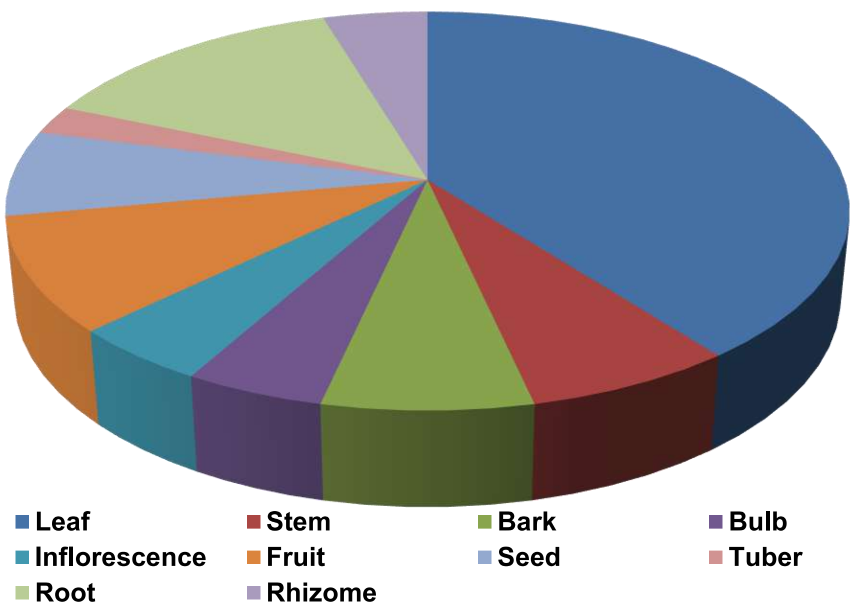


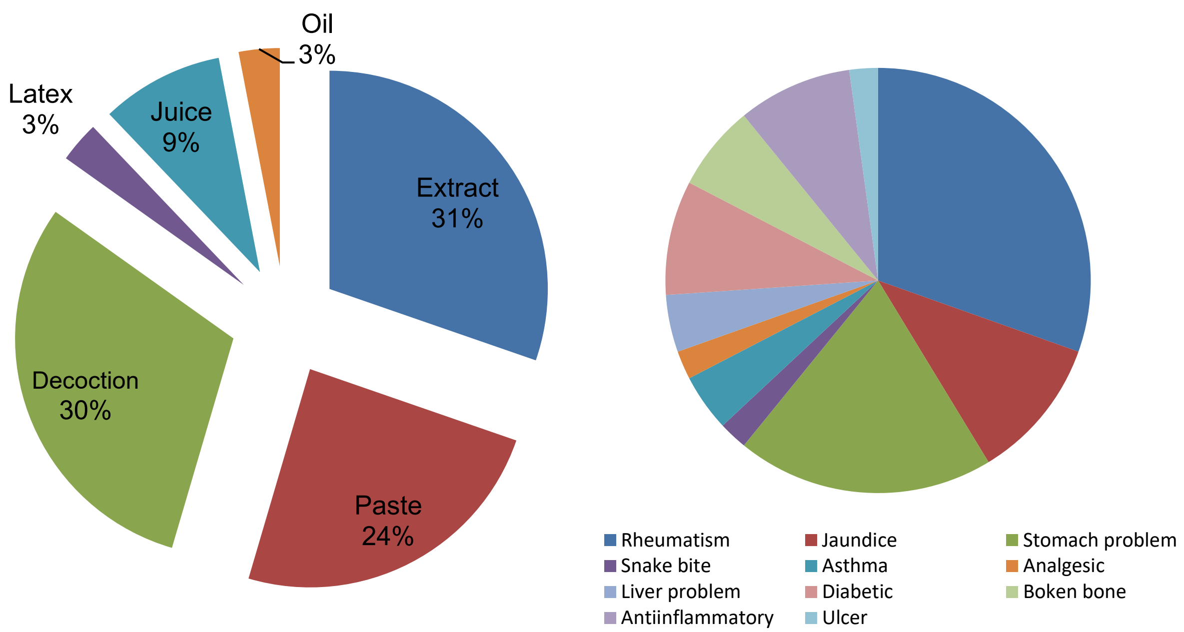
Figure 4. Plant parts of ethnomedicinal plant species used

Mode of Preparation

Mode of preparation of the medicine encompasses extract (31%), decoction (30.0%), paste (24%), juice (9.0%), latex (3.0 %) and oil (3%), and most of the time fresh plant parts were used for medicine preparation (Table 5a). The role of folk healers was found crucial in this regard to prepare fresh medicines for various ailments (Roy *et al*., 2017).

Diseases Treated

The community used the ethnomedicinal plant species to treat and manage 11 common diseases and ailments (Table 5b). The most common disease/ailments found was rheumatism (30.4%) followed by stomach problems (19.6%), diabetes (8.7%), and inflammation (8.7%). Others like fracture, asthma, liver problems, and ulcer were also treated using plant-based ethnomedicinal therapy. Similar plant-based ethnomedicinal therapy by the indigenous communities of North Bengal was also documented for diseases/ailments like stomach problem (Mandal *et al*., 2020; Singh *et al*., 2021; Joshi *et al*., 2024), skin diseases (Rahman and Asha, 2021; Kunjumon *et al*., 2022), rheumatism (Chakraborty *et al*., 2022; Sivapalan *et al*., 2023; Verma *et al*., 2025; Zhang *et al*., 2025), female disorders like dysmenorrhea (Roy *et al*., 2017; Vineeta *et al*., 2022), cough and cold, and diarrhoea were being treated by these indigenous plants by different ethnic community of North Bengal.



a. Mode of dosage preparation **b. Diseases treated**

Figure 5. Mode of dosage preparation and disease treated

Phytochemical Compounds Responsible in Ethnomedicines

Studies of folk medicinal florals across the spectrum of indigenous communities globally has led to discovery of an array of medically important phytochemicals, reiterate the epistemic depth of indigenous medical traditions. Likewise, plants documented used by Rajbanshi community also have bioactive compounds of therapeutic significance. *Aegle marmelos* contains coumarins, quinoline alkaloids, phenolic acids and flavonoids which are useful for ulcers, intestinal worms and GI inflammation (Sharma *et al*., 2018; Manandhar *et al*., 2019). The effects are due to inhibition of *Helicobacter pylori* growth and modulating prostaglandin synthesis (Singh *et al*., 2022; Patel *et al*., 2023). *Achyranthes aspera* has saponins, oleanolic-acid glycosides, steroids (stigmasterol), and betaine and achyranthine alkaloids which acts as external antidote for stings and also has antirheumatic uses (Gupta *et al*., 2013; Reddy *et al*., 2024) by inhibiting phospholipase A2 and cyclooxygenase pathways (Verma *et al*., 2021). *Allium cepa* bulbs accumulate quercetin, quercetin-glucosides, cysteine-sulfoxides and S-alkenyl-L-cysteine sulfoxides which are anti-inflammatory for joint inflammation (Griffiths *et al*., 2002). *Allium sativum* bulbs release allicin/alliin, ajoene, and organosulfur polysulfides that underpin anti-rheumatic, antimicrobial effects (Bayan *et al*., 2014). *Allium cepa* and *Allium sativum* are rich in organosulfur compounds including allicin and quercetin, which exert antioxidant, NF-κB modulatory, and pro-inflammatory cytokine-reducing effects with consequent cardioprotective and anti-arthritic actions (Choudhury *et al*., 2023). *Alstonia scholaris* bark and latex contain indole alkaloids- echitamine, alstonine, picrinine, scholarisines which are chemotaxonomic markers that facilitate bone healing through osteoblastic activation (Rahman and Khan, 2012; Das *et al.,* 2022; Jeyaraman *et al.,* 2022).

Andrographis paniculata is characterized by the diterpenoid lactone andrographolide which are used as decoctions for dyspepsia and jaundice and it acts through Nrf2 and MAPK signaling pathway activation and inhibition (Jarukamjorn and Nemoto, 2008; Kumar *et al.*, 2021). *Asparagus racemosus* roots contain steroidal saponins, isoflavones and racemosol substantiating hepatoprotective, anti-jaundice actions through estrogenic receptor modulation (Goyal *et al*., 2003; Sharma *et al.,* 2022). *Cajanus cajan* leaves exhibit cajaninstilbene acid, pinostrobin, genistein and flavanones which are anti-inflammatory and anti-jaundice compounds (Luo *et al*., 2014). *Calotropis gigantea* contains cardenolides (calotropin, uscharin), triterpenes and flavonoids that are associated with breathlessness, bacterial infection, and hepatosplenic disorders (Srinivasan *et al.,* 2018). *Cannabis sativa* contains phytocannabinoids Δ9-THC, CBD, CBN, along with terpenes, indicative of sedative, analgesic and anti-inflammatory properties (ElSohly and Gul, 2014). *Carica papaya* contains proteolytic enzymes (papain, chymopapain), phenolics in the leaf which modulate immune function, and increase platelet activity in dengue fever (Aravind *et al.*, 2013; Singh *et al.,* 2022). *Centella asiatica* triterpenoid, aglycones are associated with neuroprotective, wound-healing, hepatoprotective and dermatologic applications which induce collagen synthesis and have neuroprotective roles by modulating PI3K/Akt signaling (James and Dubery, 2009; Khan *et al.,* 2023). *Cissus quadrangularis* includes ketosteroids, triterpenes (β-sitosterol), flavonoids (quercetin), and resveratrol-type stilbenes—a group commonly referenced for bone repair/healing of ligaments and acts by modulating TNF-α and IL-6 pathways (Bose *et al*., 2021).

Bisbenzyl-isoquinoline alkaloids (hayatinine, cissamine, pareirine) in *Cissampelos pareira* roots favour antirheumatic decoctions (Breeveld *et al*., 2010). *Coccinia cordifolia* leaves contain cucurbitacins, triterpenoids (lupeol), β-sitosterol and flavonoids which has antidiabetic and anti-jaundice uses and acts by regulating blood glucose by modulating PPARγ (Grover *et al*., 2002; Rahman *et al*., 2023). *Curcuma longa* rhizomes contain curcuminoids (curcumin, dimethoxy-, bis-demethoxycurcumin) and sesquiterpene turmerones, which are used as detoxifying, anti-arthritic and fracture-supportive poultices through NF-κB inhibition and Nrf2 activation (Hewlings and Kalman 2017; Sharma *et al*., 2023$_b$; Wang *et al*., 2024). *Cuscuta reflexa* stems are found to contain flavonoids (quercetin, kaempferol, myricetin), lignans and triterpenes (oleanolic acid) which have anti-arthritic traditional use (Sharma *et al.,* 2012). *Cynodon dactylon* displays flavones, triterpenes, phenolic acids and are used for antimicrobial/antiviral activity in conformity with wound healing through the promotion of angiogenesis and fibroblast proliferation (Mishra *et al.,* 2001; Roy *et al*., 2022). *Datura metel* contains tropane alkaloids—atropine, hyoscyamine, scopolamine which inhibit muscarinic receptors to inhibit pain (Li *et al*., 2011; Alam *et al.,* 2021). *Dillenia indica* leaves/fruits contain triterpenoids (betulinic/ursolic acids), tannins and flavonoids corresponding to stomachic uses (Rai *et al.,* 2013). *Dioscorea bulbifera* tubers/bulbils contain steroidal saponins (diosgenin, diosbulbins) corresponding to anti-rheumatic and GI uses by suppressing COX enzymes (Kumar *et al*., 2017; Mehta *et al*., 2022). *Heliotropium indicum* has pyrrolizidine alkaloids (heliotrine, lasiocarpine) along with phenolics which inhibit inflammation by regulating nitric oxide synthase activity (Das *et al.,* 2021). *Moringa oleifera* leaves/roots/flowers contain glucosinolates (glucomoringin) and isothiocyanates, quercetin/kaempferol glycosides and phenolic acids which modulate glucose metabolism, alleviate oxidative stress, and guard against cartilage damage in arthritis (Leone *et al.,* 2015; Iqbal *et al*., 2023).

Murraya koenigii leaves yield carbazole alkaloids (mahanimbine, girinimbine, murrayazoline) corresponding to food use and anti-rheumatic purposes (Basu and Bandyopadhyay, 2013; Khatri *et al*., 2015). *Nyctanthes arbortristis* seeds/leaves have iridoid glycosides (arbortristoside A/B), nyctanthoside and flavonoids that affect IL-1β and TNF-α signaling pathways in arthritis (Chopra *et al*., 1992; Ahmed *et al*., 2023; Mondal *et al*., 2023). *Oxalis corniculata* leaves contain oxalic acid, flavonoids (apigenin/luteolin glycosides) and phenolics consistent with anti-jaundice use in traditional practice (Dhananjayan *et al.,* 2015). *Paederia foetida* leaves/roots contain iridoid glycosides (paederoside, asperuloside) and volatile sulfur compounds accounting for GI carminative and antirheumatic uses through antioxidant mechanisms (Dutta *et al.,* 2013; Roy *et al*., 2023). *Piper chaba* fruits have piperamides (piperine, chavicine, retrofractamides) which suppress joint inflammation by inhibiting NF-κB (Rukachaisirikul *et al.,* 2006; Islam *et al*., 2022). *Ricinus communis* seeds provide ricinoleic-acid–rich castor oil (and the ribosome-inactivating protein ricin), supporting counter-irritant rheumatic massage applications (Severino *et al*., 2012). *Syzygium cumini* bark/leaves/seeds are ellagitannin-, anthocyanin-, jambosine-type alkaloid- and flavonoid-rich, substantiating antidiabetic, anti-arthritic and anti-diarrheal use (Baliga *et al*., 2013). *Tinospora cordifolia* contains clerodane/diterpenoid lactones (tinosporide, cordifolide), alkaloids (magnoflorine), and polysaccharides in line with antipyretic, anti-arthritic, antidiabetic activity through TLR4-NF-κB regulation (Saha and Ghosh, 2012; Shah *et al.,* 2021). *Vitex negundo* leaf flavonoids, iridoids (negundoside) and volatile monoterpenes validate anti-arthritic leaf decoctions through the inhibition of COX-2 pathway (Tandon *et al*., 2008; Khan *et al*., 2022). *Zingiber officinale* rhizome gingerols/shogaols and paradols modulate gastrointestinal motility and suppress prostaglandin formation, thus lessening pain and inflammation (Mashhadi *et al*., 2013; Mishra *et al.,* 2023).

Conservation Prospect

Herbal medicine practices spread widely for wellbeing of people not only in remote area but also in urban area as natural plant product is compatible with human system and comparatively less side effect than synthetic drug. As a result, herbal medicine becomes popular which enhance research towards ethnomedicinal studies, consequently medicinal plants are in great pressure due to high demand. Among the listed plants of this study *Asparagaus racemosus* are reported as endangered in India (Kumar *et al.,* 2016). Due to overexploitation or extensive use *Aegle marmelos* is nearly endangered (Plummer, 2020) and *Dioscorea bulbifera* is reported as threatened. No plants are endemic from the list except *Tinospora cordifolia* which is reported as endemic in India (Vikaspedia, Govt of India). Therefore, collection of wild plants from forest is a great threat for extinction of biodiversity. To combat these a great concern over conservation thorough out the globe is our compulsion.

Therefore, sustainable herbal practices are required which is encouraged by Ministry of AYUSH through NMPB (National Plant Diversity Board), West Bengal Biodiversity Board and many other organizations along with the individual endeavour. Establishment of Medicinal plant garden in school, college, Universities, in block level health centre, home garden concept, herbal village (Pala *et al*., 2019; Dinda, 2025_b) all are reflection of conservation concern with elevated ethnomedicinal practices to boost up our immunity and good health. Without proper cultivation or propagation, conservation of medicinal plants will become useless.

CONCLUSION

Even though this ethnomedicinal survey was done taking in a comparatively small geographical area, the documentation reveals a substantial corpus of traditional knowledge. Within a single village, respondents are familiar with 33 plant species across 28 families, all are readily accessible in their local landscape indicating part of community's healthcare is pragmatically shaped by what is locally accessible and abundant. Mostly leaves (51.5%) and herbs (36.36%) are being used, as decoctions (30%) and extracts (31%) with nominal dispensation, reiterating both their accessibility and ease of preparation, while herbs predominate in growth habit, consistent with their profusion in home gardens and field margins. The recurrent usage of locally available floras for common illnesses like rheumatism (30.4%), stomach disorders (19.6%), and diabetes (8.7%) shows that, even in the presence of modern primary healthcare amenities, the Rajbangshi people in this area continues to rely on traditional remedies for immediate relief. This outlines a healthcare approach where traditional knowledge complements formal medical amenities, providing culturally familiar, accessible, and rapid solutions. This survey covering a small area, highlights the pliability of oral traditions and highlights the enduring role of common local plants in sustaining community health and cultural therapeutics. The phytochemical and pharmacochemical properties of these plants require a deeper evaluation to discover their potentiality in developing drugs by further comprehensive scientific studies. Finally, it can be concluded that availability of ethnomedicinal plant species can be ensured through management of areas that are rich in biodiversity of such plants with the development of rural and community based medicinal plant gardens.

REFERENCES

Ahmad F., Tabassum N, Rasool S, Ahmad A, Khan R. 2016. Pharmacological potential of Nyctanthes arbor-tristis Linn. (Night jasmine): A comprehensive review. Journal of Pharmacy Research 10(3): 148–156.

Ahmed S, Rahman MA, Alam MT, Hasan M. 2023. Gastroprotective potential of *Dillenia indica* fruit extract via antioxidant and cytoprotective mechanisms. Journal of Ethnopharmacology 305: 116047. https://doi.org/10.1016/j.jep.2022.116047

Alam M, Khan MA, Rahman S, Azad AK. 2021. Phytochemistry, pharmacology, and toxicology of *Datura metel* L.: An updated review. Journal of Ethnopharmacology 271: 113877. https://doi.org/10.1016/j.jep.2021.113877.

Aravind G, Debjit B, Duraivel S, Harish G. 2013. Traditional and medicinal uses of *Carica papaya*. Journal of Medicinal Plants Studies 1(1): 7–15.

Baliga MS, Bhat HP, Baliga BRV, Wilson R, Palatty PL. 2013. Phytochemistry, traditional uses, and pharmacology of *Syzygium cumini* (L.) Skeels. Food Research International 50(2): 597–605. https://doi.org/10.1016/j.foodres.2011.09.025.

Basu A, Bandyopadhyay A. 2013. Pharmacological activities of *Murraya koenigii* (Linn.) Spreng and its bioactive constituents: A review. Journal of Complementary and Integrative Medicine 10(1): 1–14. https://doi.org/10.1515/jcim-2012-0001.

Bayan L, Koulivand PH, Goji A. 2014. Garlic: A review of potential therapeutic effects. Avicenna Journal of Phytomedicine 4(1): 1–14.

Bisht C, Badoni A. 2009. Medicinal strength of some alpine and sub-alpine zones of Western Himalaya, India. New York Science Journal 2(5): 41-46.

Bose A, Roy S, Chatterjee P. 2021. Isoquinoline alkaloids of *Cissampelos pareira* and their anti-rheumatic action through cytokine modulation. Phytomedicine 87: 153590. https://doi.org/10.1016/j.phymed.2021.153590

Breeveld FJ, Vreden SG, Grobusch MP. 2010. History of *Cissampelos pareira* in tropical medicine. Tropical Medicine & International Health 15(11): 1321–1326. https://doi.org/10.1111/j.1365-3156.2010.02633.x.

Chakraborty AJ, Uddin TM, Matin Zidan BMR, Mitra S, Das R, Nainu F, Dhama K, Roy A, Hossain MJ, Khusro A, Emran TB. 2022. *Allium cepa*: a treasure of bioactive phytochemicals with prospective health benefits. Evidence-Based Complementary and Alternative Medicine 18: 4586318. http://doi.org/10.1155/2022/4586318.

Cheruku GR, Anumula P, Jyothi GSVD, Oruganti TSS, Gangi AB. 2021. Phytochemical evaluation and pharmacological screening of *Cuscuta reflexa* Roxburg on anti-arthritic activity. Journal of Phytopharmacology 10(5): 510-513. http://doi.org/10.31254/phyto.2021.10614.

Chopra RN, Nayar SL, Chopra IC. 1992. Glossary of Indian Medicinal Plants (Including the Supplement). Council of Scientific and Industrial Research, New Delhi.

Choudhury P, Singh R, Das A. 2023. Organosulfur compounds of Allium cepa and Allium sativum in inflammatory disorders: Modulation of NF-κB signaling. Food & Function 14(3): 1452–1465. https://doi.org/10.1039/D2FO03451G.

Das S, Pradhan A, Ghosh A. 2021. Anti-inflammatory effects of *Heliotropium indicum* via nitric oxide synthase inhibition. Journal of Traditional and Complementary Medicine 11(5): 435–443.

Das T, Sharma N, Sen S. 2022. Osteogenic potential of Alstonia scholaris latex alkaloids: Role of echitamine and scholaricine. Phytomedicine Plus 2(1): 100153. https://doi.org/10.1016/j.phyplu.2021.100153

Debnath D, Barman BR, Choudhury D, Das AP. 2019. Ethnomedicobotany of Rajbanshi community in the Duars region of Jalpaiguri District, West Bengal, India. Pleione 11(1): 55-64.

Dhananjayan R, Sathish K, Kumar RS. 2015. Phytochemical and pharmacological profile of Oxalis corniculata Linn. International Journal of Pharmacy and Pharmaceutical Sciences 7(2): 1–5.

Dhar U, Rawal RS, Samant SS, Airi S, Upreti J. 1999. People's participation in Himalayan biodiversity conservation: a practical approach. Current Science 76(1): 36–40.

Dharmasiri MG, Jayakody JRAC, Galhena G, Liyanage SSP and Ratnasooriya WD. 2003. Anti-inflammatory and analgesic activities of mature fresh leaves of *Vitex negundo*. Journal of Ethnopharmacology 87(2-3): 199-206. http://doi.org/10.1016/S0378-8741(03)00159-4.

Dinakarkumar Y, Ramakrishnan G, Marimuthu P, Priya SV, Kumar S, Mukkavilli V. 2025. Diverse bioactivity of traditional herb *Achyranthes aspera* in ethnomedicine. Pharmacological Research- Natural Products 7: 100268. https://doi.org/10.1016/j.prenap.2025.100268.

Dinda BK. 2025a. Improvement of Health and Socio-Economic Status of Women Self-Help Groups After Development of Bhesaj Gram (Herbal Village) through Home Herbal Gardens: A Case Study. Journal of Agriculture and Technology 12(1): 1-13.

Dinda BK. 2025b. Nutritional support and promotion of medicinal plants by school herbal gardens through *'Bhesaj Suraksha'* project: a case study. Journal of Agriculture and Technology 12(1): 39-49.

Dutta A, Ray S, Manna A. 2013. Pharmacognostic and phytochemical evaluation of *Paederia foetida* Linn. International Journal of Pharmaceutical Sciences Review and Research 23(1): 36–41.

ElSohly MA, Gul W. 2014. Constituents of *Cannabis sativa*. In: *Handbook of Cannabis*, ed. Pertwee A. Oxford University Press. Pp. 3-22.

Emeka J, Iweala M, Uche E, Emmanuel DD, Lotanna RE, Titilope MD, Oluwapelumi AE, Benedict C, Okoro O, Dania E, Abiodun H, Adebayo E, Ugbogu A. 2023. *Curcuma longa* (Turmeric): ethnomedicinal uses, phytochemistry, pharmacological activities and toxicity profiles—A review. Pharmacological Research-Modern Chinese Medicine 6: 100222. https://doi.org/10.1016/j.prmcm.2023.100222.

Goyal RK, Singh J, Lal H. 2003. *Asparagus racemosus*—An update. Indian Journal of Medical Sciences 57(9): 408–414.

Griffiths G, Trueman L, Crowther T, Thomas B, Smith B. 2002. Onions—A global benefit to health. Phytotherapy Research 16(7): 603–615. https://doi.org/10.1002/ptr.1222.

Grover JK, Yadav S, Vats V. 2002. Medicinal plants of India with anti-diabetic potential. Journal of Ethnopharmacology 81(1): 81–100. https://doi.org/10.1016/S0378-8741(02)00059-4.

Gupta R, Sharma V, Sharma N, Sharma R. 2013. *Achyranthes aspera* Linn.: A review on phytopharmacological aspects. International Journal of Pharmaceutical Sciences Review and Research 21(2): 72–77.

Hewlings SJ, Kalman DS. 2017. Curcumin: A review of its effects on human health. Foods 6(10): 92. https://doi.org/10.3390/foods6100092.

Hossain MS, Jahan, I, Islam M, Nayeem J, Anjum TS, Afrin NA, Mim FK, Hasan MK. 2024. *Coccinia grandis*: Phytochemistry, pharmacology and health benefits. Clinical Traditional Medicine and Pharmacology 5: 200150. http://doi.org/10.1016/j.ctmp.2024.200150.

Iqbal H, Khan S, Ahmad R. 2023. Phytochemicals of *Moringa oleifera* alleviate oxidative stress and inflammation in arthritis. Biomedicine & Pharmacotherapy 161: 114405. https://doi.org/10.1016/j.biopha.2023.114405.

Islam MT, Alam F, Hossen MS. 2022. Anti-arthritic efficacy of Piper chaba constituents via NF-κB pathway inhibition. Journal of Ethnopharmacology 292: 115223. https://doi.org/10.1016/j.jep.2022.115223.

Islam T, Ara I, Islam T, Sah PK, de Almeida RS, Matias EFF, Ramalho CLG, Coutinho HDM, Islam MT. 2023. Ethnobotanical uses and phytochemical, biological, and toxicological profiles of *Datura metel* L.: A review. Current Research in Toxicology 4. 100106.10.1016/j.crtox.2023.100106.

James JT, Dubery IA. 2009. Pentacyclic triterpenoids from the medicinal herb, *Centella asiatica* (L.) Urban. Molecules 14(10), 3922–3941. https://doi.org/10.3390/molecules14103922.

Janghel V, Patel P, Chandel SS. 2019. Plants used for the treatment of icterus (jaundice) in Central India: A review. Annals of Hepatology 18(5): 658-672. http://doi.org/10.1016/j.aohep.2019.05.003.

Jarukamjorn K, Nemoto N. 2008. Pharmacological aspects of *Andrographis paniculata* on health and its major diterpenoid constituent andrographolide. Journal of Health Science 54(4): 370–381. https://doi.org/10.1248/jhs.54.370.

Jeyaraman R, Kumar P, Narasimhan B. 2022. *Alstonia scholaris:* Ethnopharmacological relevance, phytochemistry and pharmacological updates. Phytochemistry Reviews 21(5): 1527–1549. https://doi.org/10.1007/s11101-021-09793-y.

Joshi S, Bhattarai K, Subedi AR, Bhattarai J, Amatya S, Baral B. 2024. Validation of ethnopharmacological findings of *Aegle marmelos* (L.) Correa through phytochemical screening and bioactivity assay. Pharmacological Research- Natural Products 5: 100114. https://doi.org/10.1016/j.prenap.2024.100114.

Kaloni D, Chakraborty D, Tiwari A, Biswas S. 2020. In silico studies on the phytochemical components of *Murraya koenigii* targeting TNF-α in rheumatoid arthritis. Journal of Herbal Medicine 24: 100396. https://doi.org/10.1016/j.hermed.2020.100396.

Khan A, Rahman MA, Hossain M. 2022. Flavonoids of *Vitex negundo* act as COX-2 inhibitors with strong analgesic and anti-arthritic potential. Frontiers in Pharmacology 13: 947152. https://doi.org/10.3389/fphar.2022.947152.

Khan S, Alam T, Singh R. 2023. *Centella asiatica* triterpenoids in wound healing and neuroprotection: Role of PI3K/Akt pathway. Journal of Ethnopharmacology 310: 116381. https://doi.org/10.1016/j.jep.2023.116381.

Khatri S, Singh D, Gupta R. 2015. *Murraya koenigii*: An ethnomedicinal plant with various pharmacological activities—A review. International Journal of Pharmaceutical Sciences and Research 6(10): 4173–4180.

Kumar M, Naik P, Chhokar V. 2016. Genetic variations in Asparagus racemosus, an endangered medicinal herb endemic to India using RAPD markers. British Biotechnology Journal 10(2): 1-11. http://doi.org/10.9734/BBJ/2016/19173.

Kumar S, Dey S, Sharma A. 2017. *Dioscorea bulbifera* L.: A review of its phytochemical constituents and traditional uses. Journal of Ayurveda and Integrative Medicine 8(3): 207–213. https://doi.org/10.1016/j.jaim.2017.02.002

Kumar S, Roy A, Barman S. 2021. Andrographolide-mediated hepatoprotective and immunomodulatory actions via MAPK/Nrf2 modulation. Biomedicine & Pharmacotherapy 141: 111872.

Kunjumon R, Johnson AJ, Baby S. 2022. *Centella asiatica*: secondary metabolites, biological activities and biomass sources. Phytomedicine Plus 2(1). 100176. https://doi.org/10.1016/j.phyplu.2021.100176.

Leone A, Spada A, Battezzati A, Schiraldi A, Aristil J, Bertoli S. 2015. *Moringa oleifera* seeds and leaves: Potential for human health. Nutrients 7(9): 730–754. https://doi.org/10.3390/nu709730.

Li XC, Joshi AS, ElSohly HN, Khan SI, Jacob MR, Zhang Z, Khan IA, Ferreira D, Walker LA. 2011. Pyrrolizidine alkaloids from *Heliotropium indicum*. Journal of Natural Products 74(4): 723–729. https://doi.org/10.1021/np100747g.

Luo Q, Sun L, Si J, Chen C. 2014. Phytochemistry and pharmacological activities of Cajanus cajan. Phytochemistry Reviews 13(3): 653–669. https://doi.org/10.1007/s11101-013-9318-3.

Manandhar S, Luitel S, Dahal RK. 2019. *In vitro* antimicrobial activity of some medicinal plants against human pathogenic bacteria. Journal of Tropical Medicine 2019: 1895340. https://doi.org/ 10.1155/2019/1895340.

Mandal A, Adhikary T, Chakraborty D, Roy P, Saha J, Barman A, Saha P (2020) Ethnomedicinal uses of plants by Santal tribe of Alipurduar district, West Bengal, India. Indian Journal of Science and Technology 13(20): 2021-2029. http://doi.org/10.17485/IJST/v13i20.565.

Manica B, Gras A, Mario R, Joan V, Daniel V and Teresa G. 2021. Traditional uses of *Cannabis*: An analysis of the CANNUSE database. Journal of Ethnopharmacology 279: 114362. http://doi.org/10.1016/j.jep.2021.114362.

Mashhadi NS, Ghiasvand R, Askari G, Hariri M, Darvishi L, Mofid MR. 2013. Anti-oxidative and anti-inflammatory effects of ginger in health and physical activity: Review of current evidence. International Journal of Preventive Medicine 4(Suppl 1): S36–S42.

Meher D, Singh M, Meher, B. 2024. An update on phytoconstituents and pharmacological importance of *Asparagus racemosus*. Journal of Applied Pharmaceutical Research 12(4): 11-20. https://doi.org/10.69857/joapr.v12i4.588.

Mehta P, Sharma R, Das G. 2022. Anti-inflammatory effects of diosgenin-rich *Dioscorea bulbifera* extracts by targeting COx enzymes. Journal of Ethnopharmacology 290: 115095. https://doi.org/10.1016/j.jep.2022.115095

Mehta S, Sharma AK, Singh RK. 2021. Pharmacological activities and molecular mechanisms of pure and crude extract of *Andrographis paniculata*: An update. Phytomedicine Plus 1(4): 100085. https://doi.org/10.1016/j.phyplu.2021.100085.

Mishra P, Mishra S, Singh A. 2001. *Cynodon dactylon* (L.) Pers.: A review. Journal of Medicinal and Aromatic Plant Sciences 23: 414–420.

Mishra S, Saha T, Chatterjee S. 2023. Gastrointestinal protective and anti-inflammatory actions of gingerols and shogaols from *Zingiber officinale*. Food Science & Nutrition 11(2): 745–756. https://doi.org/10.1002/fsn3.3014.

Mitra S, Mukherjee SK. 2022. Observation on traditional treatment methods of furuncle & carbuncle by tribal people of North Bengal plains of West Bengal, India. Plant Archives 22(2): 512-526. http://doi.org/10.51470/PLANTARCHIVES.2022.v22.no2.092.

Mondal A, Paul P, Saha R. 2023. Iridoid glycosides of *Nyctanthes arbortristis* in chronic arthritis: Mechanistic insights. Phytomedicine Plus 3(2): 100251. https://doi.org/10.1016/j.phyplu.2023.100251.

Ojetunde AO, Tongshuwar GT, Oyegoke AF, Oyegoke T. 2021. An ethno-botanical survey of plants used in rheumatoid arthritis treatment: a case study of Gusau in Nigeria. Herbal Medicines Journal 6(4): 135-145. http://doi.org/10.22087/hmj.v6i4.868.

Pala NA, Sarkar BC, Shukla G, Chettri N, Deb S, Bhat JA, Chakravarty S. 2019. Floristic composition and utilization of ethnomedicinal plant in homegardens of the eastern Himalaya. Journal of Ethnobiology and Ethnomedicine 15: 14. http://doi.org/10.1186/s13002-019-0293-4.

Patel R, Singh D, Yadav A. 2023. Cannabinoids of *Cannabis sativa*: molecular mechanisms underlying analgesic and anti-inflammatory effects. Frontiers in Pharmacology 14: 1176139. https://doi.org/10.3389/fphar.2023.1176139.

Plummer, J. 2020. *Aegle marmelos*. The IUCN Red List of Threatened Species 2020: e.T156233789A156238207. https://dx.doi.org/10.2305/IUCN.UK.2020-3.RLTS.T156233789A156238207.en.

Prasad GP, Goli P, Meenakshi V, Pal, PK, Narayanam S. 2019. Ethnomedicinal and dietary uses of *Cissus quadrangularis* L from the tribes, rural people and traditional healers of Andhra Pradesh, India. Journal of Drug Research in Ayurvedic Sciences 3: 96-105. http://doi.org/10.5005/jp-journals-10059-0041.

Rahman A, Khan MA. 2012. Phytochemical and pharmacological studies of *Alstonia scholaris*. International Journal of Pharmaceutical Sciences and Research 3(9): 3185–3190.

Rahman AHM, Asha NA. 2021. A survey of medicinal plants used by folk medicinal practitioners in Daulatpur Upazila of Kushtia District, Bangladesh. Research in Plant Sciences 9(1): 1-6. http://doi.org/10.12691/plant-9-1-1.

Rahman MA, Sultana T, Jahan N. 2023. Antidiabetic effects of *Coccinia cordifolia* phytochemicals via PPARγ modulation. Journal of Ethnopharmacology 305: 116105. https://doi.org/10.1016/j.jep.2022.116105.

Rai PK, Jaiswal D, Singh RK, Gupta RK, Watal G. 2013. Glycemic properties of *Dillenia indica*. International Journal of Pharmaceutical Sciences Review and Research 20(1): 40–45.

Reddy DB, Reddy MR, Reddy KS. 2024. Pharmacological overview of *Achyranthes aspera* L. Journal of Pharmacognosy and Phytochemistry 13(2): 45–52.

Roy P, Mandal P, Panda S. 2017. An Ethnomedicinal survey with the Rajbanshi community of Terai and Duars region in West Bengal part of India for the treatment of Primary Dysmenorrhea. World Scientific News 90: 243-250.

Roy P, Panda S, Mandal P. 2016. Traditional healing practices by some polyherbal formulations of Rajbanshi community. Journal of Chemical and Pharmaceutical Research. 8(10): 146-150.

Roy S, Das T, Alam S. 2022. Wound healing and antimicrobial activity of *Cynodon dactylon* through fibroblast proliferation and angiogenesis. Journal of Ethnopharmacology 285: 114871. https://doi.org/10.1016/j.jep.2021.114871.

Roy S. 2015. An ethnobotanical study on the medicinal plants used by Rajbanshis of Cooch Behar district. Journal of Medicinal Plants Studies 3(5):46–49.

Roy T, Choudhury A, Saha, S. 2023. Gastrointestinal protective and anti-rheumatic roles of *Paederia foetida* phytochemicals. Frontiers in Pharmacology 14: 1125142. https://doi.org/10.3389/fphar.2023.1125142.

Rukachaisirikul V, Sukpondma Y, Phongpaichit, S, Taylor WC. 2006. Chemical constituents and bioactivity of *Piper chaba*. Phytochemistry 67(11): 1095–1101. https://doi.org/10.1016/j.phytochem.2006.03.016.

Saha S, Ghosh S. 2012. *Tinospora cordifolia*: One plant, many roles. Ancient Science of Life 31(4): 151–159. https://doi.org/10.4103/0257-7941.107344.

Saleem A, Mohammad Saleem Md, Akhtar MF. 2020. Antioxidant, anti-inflammatory and antiarthritic potential of *Moringa oleifera* Lam: An ethnomedicinal plant of Moringaceae family. South African Journal of Botany 128: 246-256. https://doi.org/10.1016/j.sajb.2019.11.023.

Severino, LS. Auld DL, Baldanzi M, Cândido MJD, Chen G, Crosby W, He X, Lakshmamma P, Lavanya C, Machado OLT. 2012. A review on the challenges for increased production of castor. Agricultural Sciences 3(1): 29–37. https://doi.org/10.4236/as.2012.31005.

Shah S, Iqbal M, Alam R. 2021. Immunomodulatory effects of *Tinospora cordifolia* via TLR4-NF-κB regulation. Frontiers in Immunology 12: 671335. https://doi.org/10.3389/fimmu.2021.671335.

Sharma A, Goel A, Lin Z. 2023$_a$. Analysis of anti-rheumatic activity of *Nyctanthes arbor-tristis* via in vivo and pharmacovigilance approaches. Frontiers in Pharmacology 14:1307799. http://doi.org/10.3389/fphar.2023.1307799.

Sharma P, Gupta N, Kumar V. 2023$_b$. *Curcuma longa* and curcumin in oxidative stress-related disorders: NF-κB and Nrf2 mechanisms. Food & Function 14(1): 312–325. https://doi.org/10.1039/D2FO03011A.

Sharma R, Verma P, Singh S. 2022. Phytochemical constituents of *Asparagus racemosus* and their adaptogenic potential. Journal of Ayurveda and Integrative Medicine 13(4): 100620. https://doi.org/10.1016/j.jaim.2022.100620.

Sharma R., Manhas RK, Magotra R. 2018. Ethnoveterinary remedies of diseases among milk yielding animals in Kathua, Jammu and Kashmir, India. Journal of Ethnopharmacology 207: 8–32. https://doi.org/10.1016/j.jep.2017.06.023.

Sharma S, Rathi N, Sharma D. 2012. Phytochemical investigations and evaluation of antioxidant activity of *Cuscuta reflexa*. International Journal of Pharmacy and Pharmaceutical Sciences 4(4): 494–496.

Singh A, Patel R, Kumar P. 2022. *Aegle marmelos* phytochemicals in gastrointestinal protection and anti-parasitic therapy. Journal of Ethnopharmacology 289: 115078. https://doi.org/10.1016/j.jep.2022.15078.

Singh SP, Kumar S, Mathan SV, Tomar MS, Singh RK, Verma PK, Kumar A, Kumar S, Singh RP, Acharya A. 2020. Therapeutic application of *Carica papaya* leaf extract in the management of human diseases. Daru. 28(2): 735-744. http://doi.org/10.1007/s40199-020-00348-7.

Singh V, Singh A, Singh IP, Kumar BD. 2021. Phytomedicinal properties of *Cynodon dactylon* (L.) pers. (Durva) in its traditional preparation and extracts. Phytomedicine Plus 1(1): 100020. https://doi.org/10.1016/j.phyplu.2021.100020.

Sivapalan S, Dharmalingam S, Venkatesan V, Mangalagowri Angappan M, Veeramuthu AK. 2023. Phytochemical analysis, anti-inflammatory, antioxidant activity of *Calotropis gigantea* and its therapeutic applications. Journal of Ethnopharmacology 303: 115963. https://doi.org/10.1016/j.jep.2022.115963.

Srinivasan S, Prakash A, Nalini N. 2018. Chemo-preventive potential of *Calotropis gigantea* against colon carcinogenesis. Biomedicine & Pharmacotherapy 105: 1068–1078. https://doi.org/10.1016/j.biopha.2018.06.061.

Tandon VR, Khajuria V, Kapoor B, Kour D, Gupta S, Gillani Z. 2008. Hepatoprotective activity of *Vitex negundo* leaf extract against anti-tubercular drugs induced hepatotoxicity. Fitoterapia 79(7–8): 533–538. https://doi.org/10.1016/j.fitote.2008.06.005.

Uzun SP, Koca C. 2020. Ethnobotanical survey of medicinal plants traded in herbal markets of Kahramanmaraş. Plant Diversity 42(6): 443-454. https://doi.org/10.1016/j.pld.2020.12.003.

Verma N, Singh M, Rai R. 2021. Anti-snake venom and anti-inflammatory activities of *Achyranthes aspera* via phospholipase A2 inhibition. Biomedicine & Pharmacotherapy 138: 111439. https://doi.org/10.1016/j.biopha.2021.111439.

Verma PK, Tukra S, Singh B, Sharma P, Abdi G, Bhat ZF. 2025. Unveiling the ethnomedicinal potential of *Alstonia scholaris* (L.) R. Br.: A comprehensive review on phytochemistry, pharmacology and its applications, Food Chemistry Advances, Vol 6, 100866, ISSN 2772-753X, https://doi.org/10.1016/j.focha.2024.100866.

Vineeta, Shukla G, Bhatt JA, Chakravarty S. 2022. Folk therapeutic uses of ethnomedicinal plants to cure gynecological disorders- a meta-analysis of West Bengal State in India. Ethnobotany Research and Applications 24: 17. http://dx.doi.org/10.32859/era.24.17.1-19.

Wang Y, Zhang S, Zhang Y. 2024. Advances in curcumin pharmacology: Focus on its therapeutic potential in chronic diseases. Frontiers in Pharmacology 15: 1309185. https://doi.org/10.3389/fphar.2024.1309185.

Zhang X, Diao Z, Amraii SA, Sillanpää M, Toushmalani R. 2025. Formulation and evaluation of anti-rheumatoid arthritis effects of Ag nanoparticles containing *Allium sativum* L. leaf extract. Inorganic Chemistry Communications 172: 113688. https://doi.org/10.1016/j.inoche.2024.113688.

J. Agric. Technol., 12(2): 68-84 (2025)
Print: ISSN: 2348-4721; Online: ISSN: 2349-610X

Carbon Forestry and Ecosystem Services: Linking Livelihoods with Environmental Security

Soham Roy*, Nistha Sonowal Deori Bhoralee, Sudeepta Singh

Department of Forestry, Uttar Banga Krishi Viswavidyalaya, Pundibari- 736 165, West Bengal, India

E-mail: *soham.ubkv07@gmail.com*

Received: 08-09-2025; **Revised:** 21-09-2025; **Accepted:** 25-09-2025

Citation: Roy S, Bhoralee NSD, Singh S. 2025. Carbon Forestry and Ecosystem Services: Linking Livelihoods with Environmental Security. J Agric Technol. 12(2): 68-84.

Climate change and the degradation of the environment have emerged as the biggest threats to ecosystem stability and human civilization. Forests, as the biggest carbon pools, give the most effective strategies in climate change mitigation through carbon sequestration and various ecosystem services. Carbon forestry is defined as the overall management of the forests, plantations, and agroforestry systems for carbon storage and beneficial services for the ecosystem. It has gained global attention through frameworks like REDD+, CDM, and Payment for Ecosystem Services. This article focuses on finding the basic aspects of the linkage between carbon forestry, environmental security, and sustainable development of the livelihood. Case studies from different regions also shows the developmental works through carbon forestry. The article also highlights the key challenges, like insecurity of the grassroot people, unequal benefit sharing, and unorganized governance practices in the works, but emphasizes the overcoming of the challenges to fulfil the sustainable development goals. The main motive is to provide a viable pathway towards the success of carbon forestry in the welfare of humans as well as the nature.

Keywords: Carbon Forestry, Agroforestry, REDD+, Environmental Security, Sustainable development

INTRODUCTION

The 21st century is facing huge challenges of global climate change, degradation of forest land and biodiversity loss. Emission of greenhouse gasses- especially CO_2 and methane are creating greenhouse effect, damaging the Earth's atmospheric balance, increasing temperature and unbalancing the climatic conditions. Forests act as the biggest defence against these changes by its ability of storing huge amount of carbon. According to the Intergovernmental Panel on Climate Change (IPCC) assessment reports deforestation is causing about 10-12% global emission, making it one of the main concerns (Anon., 2022). However, the damages are not only limited to carbon concerns but also threatening hydrological cycle, soil fertility, ecosystem balance and a huge human population dependent on it (Anon., 2020).

In this situation, carbon forestry emerges as one of the most effective strategies, which integrates carbon storage with sustainable developmental goals. The practice goes beyond the conventional forestry practices (solely emphasising on production of timber, and NTFPs), provides more space for the ecosystem and carbon storage by afforestation, reforestation and agroforestry leading to an improved forest management (Nair *et al.,* 2010). It is also associated with the international structures like REDD+ which aims to decrease the emissions by deforestations and also rewards the associated communities for their contribution towards the protections and management of the forests (Angelsen, 2017). Although carbon sequestration is the main basis of carbon forestry, but its importance extends to the multiple ecosystem services that forests provide. Forests provide habitat to about 80% of the land biodiversity who maintains the ecosystem balance (Anon., 2005). Forest and its biodiversity contribute in regulation of climatic, edaphic and hydrological factors in huge scale as well as they have cultural, spiritual and social significance for many communities, emphasising the integrated participatory approaches in carbon forestry (Chhatre and Agarwal, 2009). The linkages between carbon forestry, livelihoods and environmental security are particularly relevant to the developing countries, where a large number of rural populations is highly dependent on forests for fodder, fuel and livelihood. Degradation of forests directly reduces their benefits. So, this paper is therefore suggesting the broader aspects of carbon forestry initiatives, alongside with the basics, towards the mitigation of climate change, ecosystem balance and securing livelihoods through employment generation.

APPROACHES EMPLOYED IN CARBON FORESTRY

Carbon forestry practice requires scientific as well as socio-political approaches to be impactful to the context of reality. Environmental susceptibility, government rules, forest management practices & local acceptance to the specific approach plays a vital role in the selection of method in carbon forestry.

Measurement Approach

The approach is totally dependent upon scientific calculations and basic forest measurements such as diametre at breast height, height and species specific allometric equations for biomass carbon (Masera *et al*., 2003). In recent times, development of remote sensing, LiDAR and UAV technologies have been adopted in place of conventional methods for high resolution biomass mapping. (Dubayah *et al.*, 2020). The approach is useful for only serving the carbon sequestration purposes.

Modelling Approaches

Process based models like CENTURY, CO2FIX and InVEST are widely used for simulating the carbon sequestration pattern in different forest management practices (Smith *et al*., 2014). The models integrate ecological processes with land use pattern to simulate the carbon sequestration. Useful for long time planning for afforestation patterns keeping in mind both the environment and biodiversity.

Socio-Economic Approaches

For evaluating the impacts of carbon forestry in social scale, it is an important path. Conduction of participatory rural appraisal and household surveys, gives the concept of local aspects to carbon forestry and their demands. Institutional analysis framework depending on those, helps in setting up the governance structure, tenure security and local participation (Agrawal *et al*., 2011).

Integrated Monitoring, Reporting and Verification (MRV) Approach

International carbon forestry projects, particularly under REDD+, emphasises on MRV approaches, which combines field inventory, remote sensing and modelling approaches to provide the carbon sequestration data, which aligns with IPCC good practice guidelines (Anon., 2019). MRV is essential not only for global carbon markets, but also ensures the accountability of the local communities (Herold and Johns, 2007).

Emerging Innovations

Recent innovations have pushed carbon forestry towards a multi-objective framework that accounts for climate change mitigation, soil and water regulation, balancing ecosystem and empowering the livelihood. Technology based approaches, nature-based solutions and community-based monitoring highlights this trend (Seddon *et al.*, 2021). When taken together, the all approaches in carbon forestry helps in the sustainability of a specific carbon forestry initiative and maximizing its impact on society and environment.

CARBON FORESTRY AND ECOSYSTEM SERVICES

Carbon forestry is defined as the overall management of the forests, plantations, and agroforestry systems for maximising the carbon storage and beneficial services for the ecosystem. Ecosystem services are the benefits and society gets from the nature, like clean air, water regulation, biodiversity conservation, soil fertility and cultural values. Depending on the aspects, ecosystem services can be classified into four types- provisioning, regulating, supporting, and cultural (Figure 1).

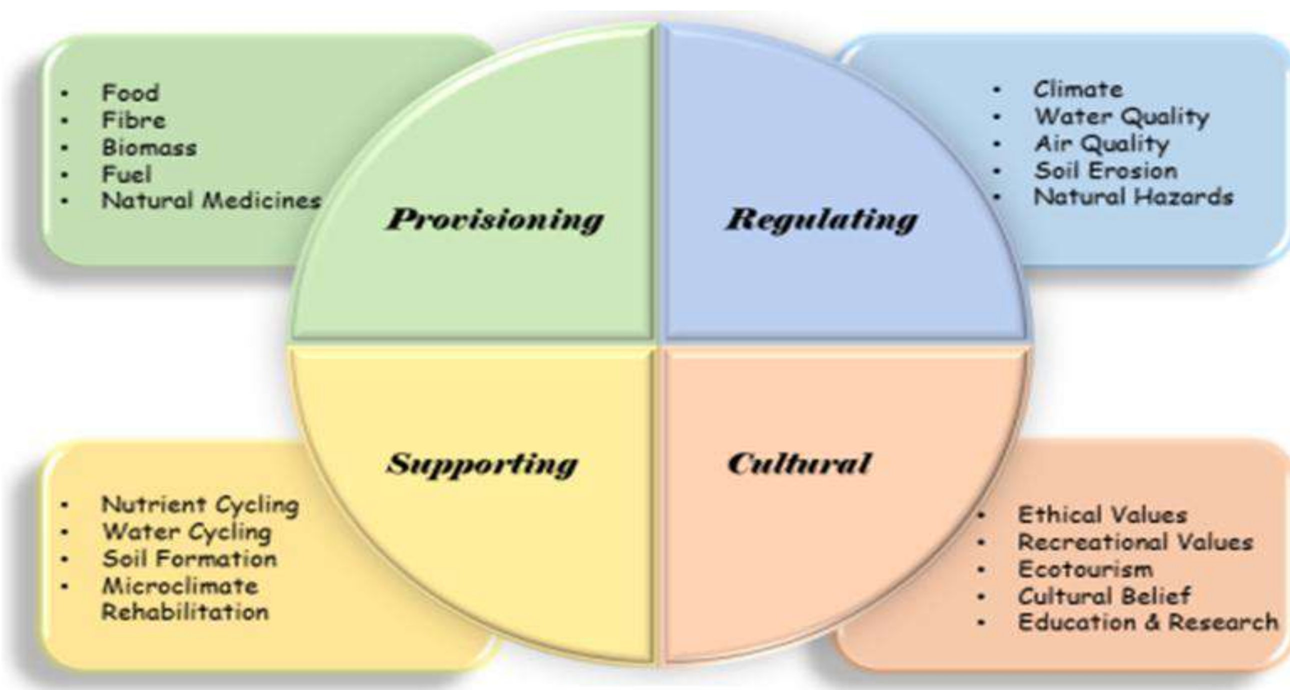


Figure 1. Different types of ecosystem services

Provisioning Services

Provisioning services are the tangible goods that ecosystem supplies, such as food, fuel, timber, water, and genetic resources (Anon., 2005). The conventional methods were solely dependent on these services, now a days provisioning services are giving secondary benefits of carbon forestry. Properly managed carbon forests provide timber products as secondary produce besides the carbon storage. IPCC recognises harvested timber products as a measurable carbon pool, with substitution benefits when wood replaces carbon-intensive materials like cement or steel (Anon., 2019). Carbon forestry also supports the provision of non-timber products like fruits, nuts, resins, fuelwood, medicinal compounds, and fibres, those are also very much important for rural community. Belcher *et al.* (2005) highlighted the importance of NTFPs but its benefit sharing among the local communities is always critical (Phelps *et al.*, 2010_a). Agroforestry integrates trees with crops or livestock, which creates multi-dimensional land use pattern. It gives food, fodder, fuelwood and marketable crops while sequestering carbon. Studies reported carbon storage of 0.3–15 Mg ha^{-1} yr^{-1}, with tropical systems often giving higher yield rates (Nair *et al*., 2010).

Regulating Services

Nature provides important services that keep our environment in balance; like regulating climate, managing water flow, preventing soil erosion, and keeping the air clean (Anon., 2005). Carbon forestry helps in restoring damaged forests, and managing existing ones wisely, supports these services by capturing carbon from the atmosphere, cooling local areas, protecting soil, and ensuring steady water supplies. By capturing carbon dioxide from the atmosphere and storing it in trees, soil, roots, fallen leaves and wood, forests act as natural carbon sinks. It helps in regulating climate change. In fact, scientists estimated that global forests store ~861 ± 66 Pg C in biomass, dead wood, litter and soil pools, which is a significant amount of carbon stored by forests all over the world (Pan *et al.,* 2011). This proves, it is possible to get closer to the global climate goals by reforesting degraded forests as well as planting new ones.

Many soil systems such as reducing soil erosion, stabilizing slopes, and maintaining fertility in soil are also regulated by forests. Tree cover reduces raindrop impact, slows surface runoff, and enhances organic matter input to soils. Lal (2004) underscores the dual function of soil carbon sequestration: it is both a regulating service (climate mitigation, soil fertility) and a foundation for provisioning services (crop yields). Carbon-based forest management also enhances water-related benefits. Even in the dry season, forests help in retention of groundwater, storing rainfall, regulating stream flow by letting more water soak into the soil and reducing runoff, forest cover lowers the risk of floods (Ellison *et al*., 2017). Forests along rivers and streams act like natural filters, trapping sediments and excess nutrients, which not only keeps water cleaner and more secure, but also supports carbon storage (Brauman *et al*., 2007).

Additionally, carbon forestry can improve and enhance wildlife habitats by reinforcing ecological services like pollination, seed distribution, and pest control, but large single-species plantations, while good at capturing carbon, often reduce the benefits linked to biodiversity (Jackson *et al*., 2005). Large-scale monoculture plantations can harm water resources as well as biodiversity, which usually depend on the tree species chosen, local conditions, and management practices. Therefore, balanced approaches- such as mixed-species plantations and community-based forestry; delivers stronger and fairer benefits for both people as well nature.

Supporting Services

Supporting processes are the ecological processes that supports all other ecosystem services, including soil formation, nutrient cycling, biodiversity conservation, and provides habitat (Anon., 2005). Such supporting services form the foundation for long-term carbon sequestration and ecosystem resilience by enhancing ecological processes and sustaining biodiversity in carbon forestry projects, that contribute significantly to well-being of humans as well as climate mitigation (De Groot *et al*., 2010). Practices and techniques used in carbon forestry improves soil fertility by boosting organic inputs through litter fall, root turnover, microbial activity and by stabilizing soils, lowering erosion factor and preserving soil moisture levels, practices such as reforestation improves nutrient cycling as well (Lal, 2004). In particular, practices such as agroforestry systems accelerate nutrient turnover by incorporating nitrogen-fixing species that enrich soil fertility while simultaneously supporting carbon storage (Nair *et al*., 2010).

Forests established through carbon forestry projects act as critical habitats for flora and fauna, supporting species diversity and ecological interactions (Chazdon, 2008). Under climate change scenarios, carbon forestry improves habitat connectivity by re-establishing degraded landscapes, which strengthens ecosystem resilience as well as eases species migration. Biodiversity conservation not only sustains ecosystem functioning but also stabilizes carbon sequestration potential over time (Mori *et al*., 2017). The stability of carbon sinks is ensured by diverse forests, which boost adaptive capacity to pests, diseases, and climate variability, ensuring the stability of carbon sinks, and this gene pool also supports the long-term viability of forest-based livelihoods as well as its ecological resilience (Hooper *et al*., 2005; Thompson *et al*., 2009).

Landscape that includes forests influence hydrological cycles by regulating groundwater recharge, improving water infiltration, and maintaining local microclimates (Jackson *et al*., 2005). Carbon forestry interventions frequently result in better watershed functions that ultimately sustains in provisioning services like agriculture and drinking water supply (Bonan, 2008). Frameworks that include carbon forestry prioritizes countable provisioning or regulating services, but supporting services are frequently overlooked despite their high importance. In recent times of biodiversity loss and land degradation, more effective methods are needed to fully understand how supporting services contribute to the continuation of carbon sequestration practices (Smith *et al*., 2014).

Cultural Services

The non-material advantages of ecosystems, such as spiritual fulfilment, appreciation of art, recreation, education, and cultural identity are referred to as Cultural ecosystem services (CES), but since they are intangible and context-dependent, CES are still relatively understudied in comparison to the provisioning, regulating, and supporting services of forests (Anon., 2005; Chan *et al*., 2012). Recently, practices such as afforestation, reforestation, forest restoration, and sustainable forest management with the goal of absorbing carbon have been recognized as part of carbon forestry, which has the potential to produce important cultural benefits in addition to its role in mitigating climate change (Chazdon and Brancalion, 2019).

Communities in India, West Africa, and Latin America protects forest patches as places of worship and cultural continuity in the form of sacred groves (Ormsby and Bhagwat, 2010). By conserving species essential to rituals and reviving culturally important landscapes, carbon forestry attempts to integrate such native species restoration programs, which may in turn strengthening such values, but by altering such symbolic value of landscapes, the establishment of monoculture plantations under the context of carbon sequestration may risk long-standing ties (Bhagwat *et al*., 2005; Mukul *et al*., 2012). Many people value natural landscapes, such as forests, for their aesthetic appeal as well as healing properties, which helps improve psychological health as well as gives a feeling of familiarity. Restoring degraded lands through carbon forestry practices often results in visually beautiful green places that boost local pride and sense of place (Raymond *et al*., 2009). Afforestation initiatives in urban areas improves the city's aesthetics as well as mitigation of climate change.

Projects and initiatives of reforestation in Costa Rica and Uganda have shown that forest recovery generates revenue for local communities while also attracting tourists (Stem *et al*., 2003; Blignaut *et al*., 2014). Such dual advantages support global goals of climate change mitigation and sustainable development, though scientists warns that if ecotourism connected to carbon forestry is not properly managed, it could result in environmental degradation, cultural commodification, and unequal benefit-sharing (West and Carrier, 2004). Cultural practices such as traditional crafts, music, and storytelling related to particular tree species have been linked to restoration of native forests under carbon forestry schemes which shows that forestry practices are deeply embedded in cultural narratives, folklore as well as identity formation of individuals of community (Pretty *et al*., 2009). Carbon sequestration efforts can improve cultural authority when it is inclusively-designed, which can be seen by indigenous-led carbon forestry projects like Amazonia's REDD+ initiatives, but on the other hand, by limiting access to culturally significant landscapes, exclusionary carbon offset schemes run the risk of weakening community identities (Corbera and Schroeder, 2011; Bayrak and Marafa, 2016).

LINKING LIVELIHOODS WITH ENVIRONMENTAL SECURITY

Carbon forestry which focuses on managing and sequestration of atmospheric carbon, has gained global attention for conserving the nature as well as improve the livelihood. The ability of forest to store carbon along with employment, food and ecosystem services creates a close relation between human and the nature (Figure 2).

Carbon Forestry as a Support for Rural Livelihoods

Carbon forestry offers new opportunities by creating new forms of employment at different stages - such as raising seedlings in nurseries, planting trees, nursery management, caring of young sapling, forest monitoring, and maintaining them over the long term. Such activities provide both seasonal as well as permanent work in places where other jobs are hard to find. For instance, in Nepal, community-managed forests have not only created much-needed employment but also improved people's access to forest resources (Pandit and

Bevilacqua, 2011). Another important side of carbon forestry is the potential to generate income from the carbon credits. By quantifying the amounts of carbon stored in trees and the soil, communities and project developers can make income from the international carbon market. This provides financial support to rural households and forest users, creating a steady income, that rewards long-term management system (Skutsch, 2005; Jindal *et al.,* 2008). Along with employment and carbon market, carbon forestry contributes in production and collection of NTFPs like honey, fruits, and medicinal plants. These parts are also vital for the rural communities. Studies show that NTFPs contributes up to 22% of household income in forest-related communities, with strong benefits for poor families (Belcher *et al.*, 2005; Angelsen *et al*., 2014).

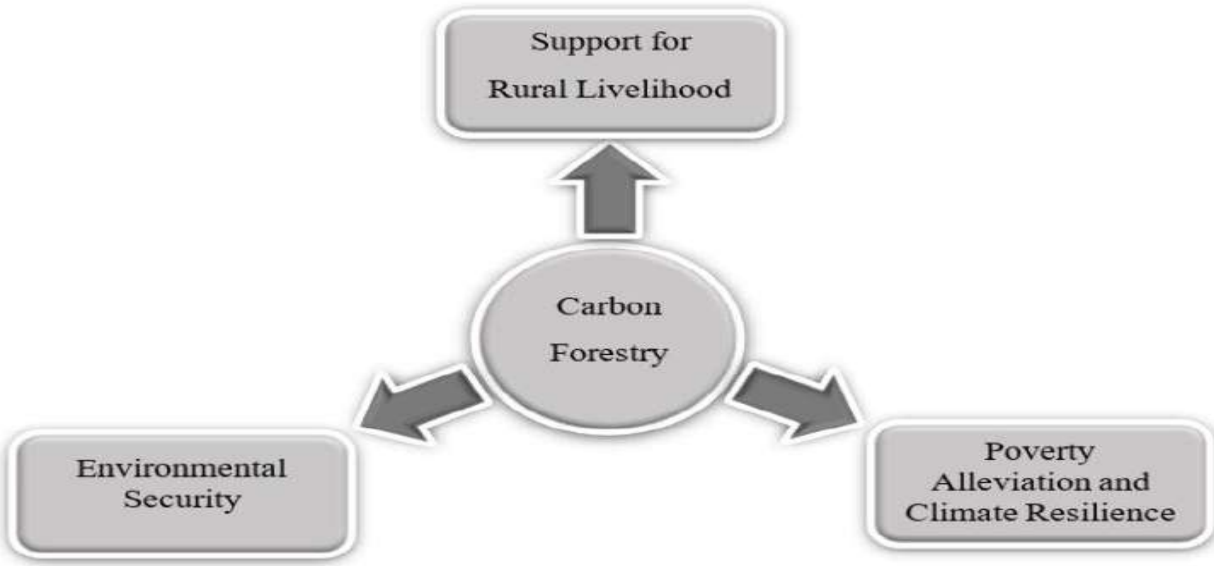


Figure 2. Linkage of carbon forestry and social livelihood

Contribution To Mitigate Poverty and Climate Resilience

Carbon forestry projects are frequently planned keeping in mind the marginal people, by providing them regular employment and additional income facilities. In many cases, community forestry programs have helped many families to fight against poverty by diversifying their sources of income and securing their asset base (Wunder, 2001; Larson *et al.*, 2010).

Environmental Security

While the livelihood benefits are significant, the contributions of carbon forestry towards the are equally important. Forest ecosystems support environmental security, ensuring the continue provision of critical services that sustain life and development. Forests function as major carbon sinks, absorbing carbon dioxide and atmospheric greenhouse gases. Carbon forestry contributes directly to climate change mitigation by increasing the forest cover. By aligning global climate goals with local development, carbon forestry offers dual significance: reduced climate risks globally and improved environmental health locally (Sikor *et al*., 2010).

Tree cover plays an important role in reducing natural disaster risks. Forests reduce floods by intercepting rainfall and slowing runoff, while their root systems stabilize soils against landslides and erosion. In mountain regions of Asia and Latin America, reforestation and forest protection have been shown to mitigate the severity of floods and landslides, providing natural barriers that safeguard rural communities (Locatelli *et al*., 2011). Carbon forestry supports ecosystem stability by maintaining biodiversity, nutrient cycles, and water quality. Planting mixed species and restoring degraded lands enhances soil fertility and promotes pollination services that are essential for agriculture (Tacconi, 2007). In this way, carbon forestry not only helps in carbon sequestration but also maintains the ecological foundations of human security.

SYNERGIES AND TRADE-OFFS BETWEEN LIVELIHOODS AND ENVIRONMENTAL GOALS

Synergies

One of the most valuable things about carbon forestry is that it might help both rural growth and environmental sustainability. Agroforestry systems, which include management of trees along with crops or animals makes the land more fertile, give people more ways to make money, and store carbon all at the same time (Rahut *et al*., 2015). Community-based projects also improve local government and make it easier for people to make decisions, which means that both social and environmental gains are achieved (Larson *et al*., 2010). According to the locals, tropical forests managed by communities produce better quality woods having more carbon storage and also provides employment.

Trade-offs

Trade-offs are also important. It allocates land for carbon forestry can reduce available land for agriculture or grazing. It potentially influences food security for the poorly planned systems (Jindal *et al*., 2008). The time duration between tree planting and carbon credit revenue may challenge poor households who need immediate returns. Also, corruption may take advantage of the system's benefits, which goes against the goals of reducing poverty (Tacconi, 2007). Biologically, monoculture plantations increase the carbon levels which may lower ecosystem benefits and species diversity. Also, the unstable nature of carbon markets can make things unclear for the people who count on carbon income (Wunder, 2001). Balancing these trade-offs requires proper planning and governmental approach.

Toward Integrated Solutions

For maximizing synergies while minimizing trade-offs requires an integrated approach.

Land-use integration

Instead of replacing cropland, projects should promote agroforestry and restore degraded lands, so that it can benefits both food-chain and carbon cycle (Angelsen *et al*., 2014).

Participatory governance

Communities should help each other in terms of planning and benefit sharing (Larson *et al*., 2010).

Phased benefits

Projects should design short, medium, and long-term returns such as early employment, NTFP harvesting, and carbon revenue (Skutsch, 2005).

Ecological integrity

Planting of mixed-species and native trees should be a priority for the protection of biodiversity and ecosystem resilience (Belcher *et al*., 2005).

POLICY PERSPECTIVES AND CHALLENGES

Carbon forestry brings together the key interests of climate policy, environmental management and sustainable development. These policies control the management of a plantation which involves afforestation, reforestation, and REDD+, and how it is financially feasible to the local people and has a positive effect on nature. A Good policy has a good way of linking the global goals such as Paris agreement which was about local land ownership rules and financial support to make sure the people can use the rights for fair use (Angelsen, 2017).

International Frameworks and Global Governance

Carbon forestry has become a key strategy in climate mitigation with the help of international agreements such as the Kyoto Protocol and the Paris Agreement. Under Kyoto Protocol, afforestation and reforestation projects were first introduced through the Clean Development Project (CDM). These projects help industrialized countries to compensate by investing in forestry projects in development of the nations (Schlamadinger *et al.*, 2007). One of the primary initiatives that encourages nations that are developing to cut back on deforestation while encouraging conservation and sustainable forest management is REDD+ (Reducing Emissions from Deforestation and Forest Degradation) (Angelsen, 2017). Although issues with equity, monitoring, and permanence still remain, REDD+ has played a crucial role in establishing forests as hotspots for biodiversity and carbon sinks.

National and Regional Policy Approaches

India presents a unique perspective on carbon forestry by combining its rapid growth alongside its persistent support for climate mitigation. National carbon forestry policies often consider different socioeconomic conditions. For example, India covers forestry in its National Action Plan on Climate Change (NAPCC), which emphasizes afforestation, social forestry, and community-based management as elements of sustainable rural development (Chaturvedi *et al*., 2012).The NAPCC's Green India Mission (GIM) aims to enhance ecosystem services and boost carbon sequestration by replanting 5 million hectares and enhancing the quality of an additional five million hectares of forest (Anon., 2015).To utilize the compensatory afforestation funds which alters the forest land for their projects, India has found a Compensatory Afforestation Fund and Planning Authority, or CAMPA. Although CAMPA's compensatory afforestation programs can be considered as compatible for carbon forestry but new studies shows that they often disagree with the principles of reforestation, ecosystem recovery and socio-ecological sustainability. These rules shows that carbon forestry is centred as a method for reducing climate change, while providing opportunities to build and improve livelihoods, conserve biodiversity, and promote rural sustainability in India.

Market Mechanisms and Carbon Credits

Market-based mechanisms, specifically carbon credit trading under voluntary and compliance markets, have also influenced carbon forestry (Diaz *et al*., 2011). The Verified Carbon Standard (VCS) and Gold Standard provides frameworks for monitoring, and showing carbon benefits. However, critics put their allegations of "greenwashing" and argue that smallholders and indigenous groups may not necessarily get benefits by this (Phelps *et al*., 2010_b).

Equity, Governance, and Policy Challenges

Land tenure, governance, and benefit-sharing are the determinants that provide a structural formulation on carbon forestry strategies. In several domains, uncertainty over property ownership may leads to conflicts and hinder community involvement (Larson *et al*., 2013). Extensive projects often get more emphasis than indigenous technical knowledge which may leads to extinction of traditional cultural expression. Concerns about long-term responsibility have grown because of the uncertainty of long-term carbon forestry projects, since trees can be cut down, infested by diseases, or catch fire due to natural calamities (Schroeder and Lovell, 2012). To solve these problems, we need plans that can combine carbon storage with the protection of environment, employment, and climate change mitigation.

FUTURE DIRECTIONS FOR CARBON FORESTRY

Forests are universally acknowledged as essential carbon sinks, sequestering approximately one-third of anthropogenic carbon dioxide emissions each year (Pan *et al*., 2011). Under the Paris Agreement, carbon forestry has become more important for preparing strategies to combat against climate change. Its main focus has been on carbon, but it has grown to include other benefits as well, such as protecting biodiversity, improving livelihoods, and regulating ecosystems (Nair *et al*., 2009).

Integration with Climate Policy and Carbon Markets

The Paris Agreement's Nationally Determined Contributions (NDCs) which includes carbon forestry, has made it to be a vital part of climate policy. REDD+ (Reducing Emissions from Deforestation and Degradation) and other similar programs encourage people to protect forests and support sustainable development (Angelsen *et al*., 2018). For the future, carbon markets need to be open and trustworthy, with strong systems for monitoring, reporting, and verification (Pistorius, 2012).

Technological Innovations

Remote sensing, GIS, and drones has made it much easier to monitor forest carbon stocks (Avitabile *et al*., 2016). Artificial intelligence and simulation models can predict annual increment, carbon storage, and degradation of land (Reichstein *et al*., 2019). Biotechnological strategies, including the genetic enhancement can introduce tree species which are climate-resilient and produce high-biomass (Neale and Kremer, 2011).

Ecosystem Services Beyond Carbon

Forests offer vital regulating services, such as water purification, soil stabilization, and microclimate regulation (Brauman *et al*., 2007; Bowler *et al*., 2010). Future carbon forestry initiatives ought to embrace a multi-functional strategy involving biodiversity conservation, watershed protection, and agroforestry. Aligning carbon forestry with ecosystem restoration will enhance resilience as well contribute to achieve several sustainable development goals (Chazdon *et al*., 2016).

Climate Adaptation Synergies

Afforestation and reforestation practices through carbon forestry can reduce the impacts of climate change, such as floods, droughts and soil erosion, through restoration of degraded forests. In coastal areas, mangroves and coastal forests act like natural shields, protecting communities from cyclones and rising seas. At a larger scale, creating ecological corridors helps wildlife adapt by providing safe space to species to move as the climate changes (Heller and Zavaleta, 2009).

Urban and Peri-Urban Carbon Forestry

Urban forestry improves local air quality, reduces the “heat-island” effects as well as provides shade and cooler spaces for people in the scorching heat (Bowler *et al*., 2010). By linking carbon forestry with green infrastructure, cities can become more climate-resilience for both people and ecosystems.

Policy, Finance, and Governance

Strong policies and fair governance are essential for carbon forestry to succeed. Communities need secure and clear land rights, and the rules must ensure that the benefits are shared fairly. Additionally, government and private companies should readily invest in carbon forestry projects, where blended finance, such as climate funds, government support, corporate social responsibility (CSR) money, helps scale up such projects to benefit more local communities.

Research and Capacity Building

Future research should focus on ongoing ecological monitoring, carbon sequestration dynamics, and the socio-economic effects of agroforestry (Canadell and Raupach, 2008). It is important to set up local groups and ways for people to share information with each other to help community-driven carbon forestry.

CONCLUSION

Carbon forestry has emerged as a critical factor between ecological balance and human welfare. By contributing to provisioning, regulating, supporting, and cultural services, carbon forestry helps in giving strength to environmental security as well as livelihood opportunities for communities dependent on forest. Provisioning services enhance rural economies through forest produce (like- timber, fuelwood, medicinal parts etc.). Regulating services mitigate climate change by reducing greenhouse gases and maintaining water cycle. Supporting services help in sustaining biodiversity, nutrient cycling and soil fertility. At the same time, cultural services help in maintaining communal identity, cultural knowledge, and eco-tourism opportunities. For the developing countries like India, there are a huge proportion of the population totally dependent on forests for livelihood. Carbon forestry is a huge socio-economic necessity besides its natural factors in these countries. With proper planning, policy making and contribution of the communities it can make a huge impact. However, the effectiveness depends on reducing competition of land, equal benefit-sharing, and integrating cultural knowledge systems into forestry practices. In conclusion, we may say that carbon forestry should be recognized as a multifunctional natural climate solution as it links livelihoods with environmental security. Its success depends on adopting participatory with scientific approaches. That can balance carbon goals, biodiversity conservation and social benefit, making carbon forestry the way toward sustainable development and reducing economic uncertainties.

REFERENCES

Agrawal A, Nepstad D, Chhatre A. 2011. Reducing emissions from deforestation and forest degradation. Annual Review of Environment and Resources 36: 373–396. https://doi.org/10.1146/annurev-environ-042009-094508.

Angelsen A (2017) REDD+ as result-based aid: General lessons and bilateral agreements of Norway. Review of Development Economics 21(2): 237–264. https://doi.org/10.1111/rode.12271

Angelsen A, Jagger P, Babigumira R, Belcher B, Hogarth NJ, Bauch S, Börner J, Smith-Hall C, Wunder S. 2014. Environmental income and rural livelihoods: a global-comparative analysis. World Development 64: S12–S28.

Angelsen A, Martius C, De Sy V, Duchelle AE, Larson AM, Pham TT. 2018. Transforming REDD+: Lessons and new directions. CIFOR. https://doi.org/10.17528/cifor/007045.

Anonymous. 2005. Millennium Ecosystem Assessment. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC.

Anonymous. 2015. India's intended nationally determined contribution: Working towards climate justice. Ministry of Environment, Forest and Climate Change Government of India, New Delhi.

Anonymous. 2019. Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, eds. Calvo Buendia E, Tanabe K, Kranjc A, Baasansuren J, Fukuda M, Ngarize S, Osako A, Pyrozhenko Y, Shermanau P and Federici S. IPCC, Geneva, Switzerland.

Anonymous. 2020. The State of the World's Forests 2020. Food and Agriculture Organization of the United Nations, Rome.

Anonymous. 2022. Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report. IPCC, Cambridge University Press, Cambridge.

Avitabile V, Herold M, Heuvelink GBM, Lewis SL, Phillips OL, Asner GP, Armston J, Ashton P, Banin L, Bayol N, Berry NJ, Boeckx P, de Jong BHJ, De Vries B, Girardin C, Kearsley E, Lindsell J, López-Gonzalez G, Lucas R, Malhi Y, Morel A, Mitchard ETA, Nagy L, Qie L, Quinones M, Ryan CM, Slik F, Sunderland TCH, Vaglio Laurin G, Valentini R, Verbeeck H, Wijaya A, Willcock S. 2016. An integrated pan-tropical biomass map using multiple reference datasets. Global Change Biology 22(4): 1406-1420. http://dx.doi.org/10.1111/gcb.13139.

Bayrak MM, Marafa LM. 2016. Ten years of REDD+: A critical review of the impact of REDD+ on forest-dependent communities. Sustainability 8(7): 620. https://doi.org/1o.3390/su8070620.

Belcher B, Ruiz-Pérez M, Achdiawan R. 2005. Global patterns and trends in the use and management of commercial NTFPs: implications for livelihoods and conservation. World Development 33(9): 1435–1452. https://10.1016/j.worlddev.2004.10.007.

Bhagwat SA, Kushalappa CG, Williams PH, Brown ND. 2005. The role of informal protected areas in maintaining biodiversity in the Western Ghats of India. Ecology and Society 10(1): 8. https://doi.org/10.5751/ES-01285-100108.

Blignaut J, Aronson J, de Wit M. 2014. The economics of restoration: Looking back and leaping forward. Annals of the New York Academy of Sciences 1322(1): 35-47. https://doi.org/10.1111/nyas.12451.

Bonan GB. 2008. Forests and climate change: Forcings, feedbacks, and the climate benefits of forests. Science 320(5882): 1444–1449. https://doi.org/10.1126/science.1155121

Bowler DE, Buyung-Ali L, Knight TM, Pullin AS. 2010. Urban greening to cool towns and cities: A systematic review of the empirical evidence. Landscape and Urban Planning 97(3): 147–155. https://doi.org/10.1016/j.landurbplan.2010.05.006

Brauman K A, Daily G C, Duarte T K and Mooney H A (2007) The nature and value of ecosystem services: An overview highlighting hydrologic services. Annual Review of Environment and Resources 32(1): 67–98. https://doi.org/10.1146/annurev.energy.32.031306.102758.

Canadell JG, Raupach MR. 2008. Managing forests for climate change mitigation. Science 320(5882): 1456–1457. https://doi.org/10.1126/science.1155458

Chan KM, Satterfield T, Goldstein J. 2012. Rethinking ecosystem services to better address and navigate cultural values. Ecological Economics 74: 8-18. https://doi.org/10.1016/j.ecolecon.2011.11.011.

Chaturvedi RK, Joshi J, Jayaraman M, Bala G, Ravindranath NH. 2012. Multi-model climate change projections for India under representative concentration pathways. Current Science 103(7): 791-802.

Chazdon RL, Brancalion PH, Laestadius L, Bennett-Curry A, Buckingham K, Kumar C, Moll-Rocek J, Vieira ICG, Wilson SJ (2016) When is a forest a forest? Forest concepts and definitions in the era of forest and landscape restoration Ambio 45(5): 538–550. https://doi.org/10.1007/s13280-016-0772-y.

Chazdon RL, Brancalion PHS. 2019. Restoring forests as a means to restore biodiversity and ecosystem services. Science 365(6448): 24–25. https://doi.org/10.1126/science.aax9539.

Chazdon RL. 2008. Beyond deforestation: Restoring forests and ecosystem services on degraded lands. Science 320(5882): 1458–1460. https://doi.org/10.1126/science.1155365.

Chhatre A, Agrawal A. 2009. Trade-offs and synergies between carbon storage and livelihood benefits from forest commons. Proceedings of the National Academy of Sciences 106(42): 17667–17670.

Corbera E, Schroeder H. 2011. Governing and implementing REDD+. Environmental Science & Policy 14(2): 89–99. https://doi.org/10.1016/j.envsci.2010.11.002.

De Groot RS, Alkemade R, Braat L, Hein L, Willemen L. 2010. Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. Ecological Complexity 7(3): 260–272. https://doi.org/10.1016/j.ecocom.2009.10.006.

Diaz D, Hamilton K, Johnson E. 2011. *State of the forest carbon markets 2011: From canopy to currency*. Ecosystem Marketplace Report.

Dubayah R, Blair JB, Goetz S, Fatoyinbo L, Hansen M, Healey S, Hofton M, Hurtt G, Kellner J, Luthcke S, Armston J, Tang H, Duncanson L, Hancock S, Jantz P, Marselis S, Patterson PL, Qi W, Silva C. 2020. The global ecosystem dynamics investigation: High-resolution laser ranging of the Earth's forests and topography. Science of Remote Sensing 1: 100002. https://doi.org/10.1016/j.srs.2020.100002

Ellison D, Morris CE, Locatelli B, Sheil D, Cohen J, Murdiyarso D, Gutierrez, van Noordwijk M, Creed IF, Pokorny J, Gaveau D, Spraklen DV, Tobella AB, Ilstedt U, Teuling AJ, Gebrehiwot SG, Sands DC, Muys B, Verbist B, Springgay E, Sugandi Y, Sullivan CA. 2017. Trees, forests and water: Cool insights for a hot world. Global Environmental Change 43: 51–61.

Heller NE, Zavaleta ES. 2009. Biodiversity management in the face of climate change: A review of 22 years of recommendations. Biological Conservation 142(1): 14–32. https://doi.org/10.1016/j.biocon.2008.10.006.

Herold M, Johns T. 2007. Linking requirements with capabilities for deforestation monitoring in the context of the UNFCCC-REDD process. Environmental Research Letters 2(4): 045025. https://doi.org/10.1088/1748-9326/2/4/045025.

Hooper DU, Chapin FS, Ewel JJ, Hector A, Inchausti P, Lavorel S, Lawton JH, Lodge DM, Loreau M, Naeem S, Schmid B, Setälä H, Symstad AJ, Vandermeer J, Wardle DA. 2005. Effects of biodiversity on ecosystem functioning: A consensus of current knowledge. Ecological Monographs 75(1): 3–35. https://doi.org/10.1890/04-0922.

Jackson RB, Jobbágy EG, Avissar R, Roy SB, Barrett DJ, Cook CW, Farley KA, Le Maitre DC, McCarl BA, Murray BC. 2005. Trading water for carbon with biological sequestration. Science 310(5756): 1944–1947. https://doi.org/10.1126/science.1119282

Jindal R, Swallow B, Kerr J. 2008. Forestry-based carbon sequestration projects in Africa: Potential benefits and challenges. Natural Resources Forum 32(2): 116–130.

Lal R. 2004. Soil carbon sequestration impacts on global climate change and food security. Science 304(5677): 1623–1627. https://doi.org/10.1126/science.1097396.

Larson AM, Barry D, Dahal GR, Colfer CJP (Eds.) (2010) *Forests for people: Community rights and forest tenure reform*. Earthscan.

Larson AM, Brockhaus M, Sunderlin WD, Duchelle A, Babon A, Dokken T, Pham TT, Resosudarmo IAP, Selaya G, Awono A, Huynh TB. 2013. Land tenure and REDD+: The good, the bad and the ugly. Global Environmental Change 23(3): 678–689. https://doi.org/10.1016/j.gloenvcha.2013.02.014.

Locatelli B, Evans V, Wardell A, Andrade A, Vignola R. 2011. Forests and climate change in Latin America: Linking adaptation and mitigation. Forest 2(1): 431–450.

Masera OR, Garza-Caligaris JF, Kanninen M, Karjalainen T, Liski J, Nabuurs GJ, Pussinen A, Mohren GMJ. 2003. Modeling carbon sequestration in afforestation, agroforestry and forest management projects: The CO2FIX V. 2 approach. Ecological Modelling 164(2): 177–199. https://doi.org/10.1016/S0304-3800(02)00419-2.

Mori AS, Lertzman KP, Gustafsson L. 2017. Biodiversity and ecosystem services in forest ecosystems: A research agenda for applied forest ecology. Journal of Applied Ecology 54(1): 12–27. https://doi.org/10.1111/1365-2664.12669.

Mukul SA, Uddin MB, Rashid AZMM, Fox J. 2012. Integrating livelihoods and conservation in protected areas: Understanding the role and stakeholder views on prospects for non-timber forest products, a Bangladesh case study. International Journal of Sustainable development & world ecology 17(2): 180-188. https://doi.org/10.1080/13504500903549676.

Nair PKR, Kumar BM, Nair VD. 2009. Agroforestry as a strategy for carbon sequestration. Journal of Plant Nutrition and Soil Science 172(1): 10–23. https://doi.org/10.1002/jpln.200800030.

Nair PKR, Kumar BM, Nair VD. 2010. Carbon sequestration in agroforestry systems. Advances in Agronomy 108: 237–307. https://doi.org/10.1016/S0065-2113(10)08005-3.

Neale DB, Kremer A. 2011. Forest tree genomics: growing resources and applications. Nature Reviews Genetics. 12(2): 111-122. http://doi.org/10.1038/nrg2931.

Ormsby A, Bhagwat S. 2010. Sacred forests of India: A strong tradition of community-based natural resource management. Environmental Conservation 37(3): 320–326. https://doi.org/10.1017/S0376892910000561.

Pan Y, Birdsey RA, Fang J, Houghton R, Kauppi PE, Kurz WA, Phillips OL, Shvidenko A, Lewis SL, Canadell JG, Ciais P, Jackson RB, Pacala SW, McGuire AD, Piao S, Rautiainen A, Sitch S, Hayes D. 2011. A large and persistent carbon sink in the world's forests. *Science* 333(6045): 988–993. https://doi.org/10.1126/science.1201609.

Pandit BH, Bevilacqua E. 2011. Forest users and environmental impacts of community forestry in the hills of Nepal. Forest Policy and Economics 13(5): 345–352.

Phelps J, Guerrero MC, Dalabajan DA, Young B, Webb EL. 2010$_a$. What makes a 'REDD' country? Global drivers of deforestation and the role of governance. Global Environmental Change 20(2): 322–332. https://doi.org/10.1016/j.gloenvcha.2009.11.004.

Phelps J, Webb EL, Agrawal A. 2010b. Does REDD+ threaten to recentralize forest governance? Science 328(5976): 312–313. https://doi.org/10.1126/science.1187774.

Pistorius T. 2012. From RED to REDD+: The evolution of a forest-based mitigation approach for developing countries. Current Opinion in Environment Sustainability 4(6): 638-645. https://doi.org/10.1016/j.cosust.2012.07.002

Pretty J, Adams B, Berkes F, de Athayde SF, Dudley N, Hunn E, Maffi L, Milton K, Rapport D, Robbins P, Sterling E, Stolton S, Tsing A, Vintinner E, Pilgrim S. 2009. The intersections of biological diversity and cultural diversity: Towards integration. Conservation and Society 7(2): 100–112.

Rahut DB, Ali A, Behera B. 2015. Household food security and children's dietary diversity in rural Bhutan. Food Security 7(6): 1221–1231.

Raymond CM, Bryan BA, MacDonald DH, Cast A, Strathearn S, Grandgirard A, Kalivas T. 2009. Mapping community values for natural capital and ecosystem services. Ecological economics 68(5): 1301-1315. https://doi.org/10.1016/j.ecolecon.2008.12.006.

Reichstein M, Camps-Valls G, Stevens B, Jung M, Denzler J, Carvalhais N, Prabhat F. 2019. Deep learning and process understanding for data-driven Earth system science. Nature 566(7743): 195–204. https://doi.org/10.1038/s41586-019-0912-1.

Schlamadinger B, Bird N, Johns T, Brown S, Canadell J, Ciccarese L, Dutschke M, Fiedler J, Fischlin A, Fearnside P, Forner C, Freibauer A, Frumhoff P, Hoehne N, Kirschbaum MUF, Labat A, Marland G, Michaelowa A, Montanarella L, Moutinho P, Murdiyarso D, Pena N, Pingoud K, Rakonczay Z, Rametsteiner E, Rock J, Sanz MJ, Schneider UA, Shvidenko A, Skutsch M, Smith P, Somogyi Z, Trines E, Ward M, Yamagata Y. 2007. A synopsis of land use, land-use change and forestry (LULUCF) under the Kyoto Protocol and Marrakech Accords. Environmental Science & Policy 10(4): 271–282. https://doi.org/10.1016/j.envsci.2006.11.002.

Schroeder H, Lovell H. 2012. The role of non-nation state actors and side events in the international climate negotiations. Climate Policy 12(1): 23-37.

Seddon N, Smith A, Smith P, Key I, Chausson A, Girardin C A, House J, Srivastava S, Turner B. 2021. Getting the message right on nature-based solutions to climate change. Global Change Biology 27(8): 1518–1546. https://doi.org/10.1111/gcb.15513.

Sikor T, Stahl J, Ribot J. 2010. *Forests and climate change: mitigation and adaptation through sustainable forest management*. World Bank Policy Research Working Paper No. 5164.

Skutsch MM. 2005. Reducing carbon transaction costs in community-based forest management. Climate Policy 5(4): 433–443.

Smith P, Bustamante M, Ahammad H, Clark H, Dong H, Elsiddig EA, Haberl H, Harper R, House J, Jafari M, Masera O, Mbow C, Ravindranath NH, Rice CW, Abad C R, Romanovskaya A, Sperling F, Tubiello F N and Bolwig S. 2014*. Agriculture, forestry and other land use (AFOLU) Climate Change 2014: mitigation of climate change*. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge. Pp. 811-922.

Stem CJ, Lassie JP, Lee DR, Deshler DD, Schelhas JW. 2003. Community participation in ecotourism benefits: The link to conservation practices and perspectives. Society & Natural Resources 16(5): 387–413. https://doi.org/10.1080/08941920309177.

Tacconi L. 2007. *Illegal logging: law enforcement, livelihoods and the timber trade*. Earthscan.

Thompson I, Mackey B, McNulty S, Mosseler A. 2009. Forest resilience, biodiversity, and climate change: A synthesis of the biodiversity/resilience/stability relationship in forest ecosystems. Technical Series no. 43. Secretariat of the Convention on Biological Diversity, Montreal. 67p.

West P, Carrier JG. 2004. Ecotourism and authenticity: Getting away from it all? Current Anthropology 45(4): 483–498. https://doi.org/10.1086/422082.

Wunder S. 2001. Poverty alleviation and tropical forests—what scope for synergies? World development 29(11): 1817-1833.

J. Agric. Technol., 12(2): 85-89 (2025)
Print: ISSN: 2348-4721; Online: ISSN: 2349-610X

Field Evaluation of Some Insecticides Against Red Pumpkin Beetle (*Aulacophora foveicollis* Lucas) on Bottle Gourd [*Lagenaria siceraria* (Mol.)]

Tanmoy Mandal

Department of Plant Protection, Suri Vidyasagar College, Suri, Birbhum- 731 101, West Bengal, India

[*]***E-mail***: *tanmoy_mandal22@rediffmail.com*

Received: 19-09-2025; **Revised:** 27-09-2025; **Accepted:** 29-09-2025

Citation: Mandal T. 2025. Field Evaluation of Some Insecticides Against Red Pumpkin Beetle (*Aulacophora foveicollis* Lucas) on Bottle Gourd [*Lagenaria siceraria* (Mol.)]. J Agric Technol. 12(2): 85-89.

Field evaluation of insecticides on red pumpkin beetle showed that cypermethrin 10 % EC (USTAAD) 1.00 ml/l treated plot was found superior and recorded 63.30 percent reduction of red pumpkin beetle population over control. Dimethoate 30 % EC (ROGAR) 2.00 ml/l and imidacloprid 17.8 SL (CONFIDOR) 0.5 ml/l were found second best and showed 61.73 % and 59.60 % suppression of beetle population respectively. Among the botanicals, Azadirachtin 3000 ppm (NEEMRAJ) 4.00 ml/l treated plot was found superior and recorded 39.92 % suppression of beetle population. Neem leaf extract 50 ml/l (5%), garlic extract 50 ml/l (5%) and turmeric extract 50 ml/l (5%) were recorded satisfactory result to control red pumpkin beetle, showing 32.83%, 30.70% and 28.11% suppression of beetle population respectively. Neem based insecticides and botanical plants extract may include in integrated pest management of red pumpkin beetle on bottle gourd cultivation at Changuria village, Mallickpur Gram Panchayet, Birbhum district of West Bengal.

Keywords: Botanical extract, Red Pumpkin Beetle, Bio-efficacy, Bottle Gourd

INTRODUCTION

Bottle gourd (*Lagenaria siceraria* Lucas) is an important cucurbitaceous vegetable cultivated at Changuria village, Mallickpur Gram Panchayet, Birbhum district of West Bengal. It is a rich source of protein, carbohydrate, fat, vitamins, magnesium, zinc, potassium, moisture and energy (Milind and Satvir, 2011). Commercial bottle gourd cultivation has many constrains like adverse climatic condition, insect pest damage and diseases (Umar *et al*., 2013). The major insect pests are red pumpkin beetle (*Aulacophora foveicollis* Lucas), Hadda beetle (*Epilachna vigintioctopunctata* Fabricius), aphids (*Aphis gossypi* Glover), fruit fly (*Bactrocera cucurbitae* Coquillet), white fly (*Bemisia tabaci* Gennadius), serpentine leaf miner (*Liriomyza trifolli* Burgess) and pumpkin caterpillar (*Diaphania indica* Saunders) (Haldhar *et al*., 2014). Red pumpkin beetle is a serious and destructive polyphagous pest of cucurbits (Butani and Jotwani, 1984). The beetles feed voraciously on leaves, flower buds and flowers which reach up to 35-75 % losses at seedling stage, in some cases the losses of this pest have been reported to 30-100 % (Rashid *et al.* 2014). Considering this, field evaluation of some insecticides against red pumpkin beetle on bottle gourd was undertaken.

MATERIALS AND METHODS

Experimental field was situated at Changuria village, Mallickpur Gram Panchayet, Birbhum district of West Bengal, India. Bottle gourd was grown as rabi crop for two successive year 2022 and 2023. The experimental area was under red lateritic zone, sandy to sandy loam soil with P^H value 6.8. Weather of this region was hot humid summer with cool dry winter.

Local variety seeds of bottle gourd were collected from Suri market. Land was prepared with recommended fertilizer dose. Seeds were soaked overnight and next day 3-4 seeds were sown in the main field by dibbling method. The seed sowing was done in second week of January. Spacing was maintained 1.5 m x 2 m in 15 m x 4 m plot to accommodate ten bottle gourd plants in a plot. All agronomic practices were maintained to raise the crop. To manage red pumpkin beetle on bottle gourd at Changuria village, there were seven insecticides, including four botanical insecticides and three chemical insecticides were taken. Insecticides details were given here. Neem leaf extract (T1) 50 ml/l (5%), Cypermethrin 10% EC (USTAAD) (T2) 1.00 ml/l, Dimethoate 30% EC (ROGAR) (T3) 2.00 ml/l, Imidacloprid 17.8 SL (CONFIDOR) (T4) 0.5 ml/l, Azadiractin 3000 ppm (NEEMRAJ) (T5) 4.00 ml/l, Garlic bulb extract (T6) 50 ml/l (5%), Turmeric rhizome extract (T7) 50 ml/l (5%), and untreated control (T8). The treatments were replicated thrice with randomized block design. Garlic, turmeric and neem extracts were prepared by the methodology developed by Ghosh (2019). The plant parts were washed, dried and grinded into power with the help of a machine. 50 g of powder was mixed with 250 ml of methanol. After 3 days the mixture was filtered using muslin cloth. An amount of 50 ml extract was required for preparation of one litre spray liquid. Two sprayings were done in the month of March at 15 days intervals by a knapsack sprayer. After each spraying number of pumpkin beetle/plant count was taken at 7 days after spraying and 14 days after spraying for each treatment. The reduction of red pumpkin beetle population over control was worked out using the following formula.

$$\text{Reduction of red pumpkin beetle over control (\%)} = \frac{\text{Control - Treatment}}{\text{Treatment}} \times 100$$

where, Control = number of red pumpkin beetle/plant at control plot

Treatment = number of red pumpkin beetle/plant at insecticide treated plot

OPSTAT- online statistical analysis tool was used for analysis of data. OPSTAT was developed and maintain by Prof. O. P. Sheoran, from Department of Mathematics and Statistics, CCS HAU, Hisar.

RESULTS AND DISCUSSION

Field evaluation of insecticides on red pumpkin beetle is given in Table 1. Pre-treatment counts were recorded ranging from 10.70 to 14.50 (number of red pumpkin beetle/plant). After 14 DAS of second spray, cypermethrin 10% EC (USTAAD) 1.00 ml/l treated plot was found superior and recorded 63.30 % reduction of red pumpkin beetle population over control. Dimethoate 30 % EC (ROGAR) 2.00 ml/l and imidacloprid 17.8 SL (CONFIDOR)

0.5 ml/l were found second best and showed 61.73% and 59.60% suppression of red pumpkin beetle population respectively.

Table 1. Bio-efficacy of insecticides on red pumpkin beetle

Treatments	Dose ml/l	PTC	Number of red pumpkin beetle/plant				RoC
			1st spray		2nd spray		
			7 DAS	14 DAS	7 DAS	14 DAS	
Neem leaf extract (T1) (5%)	50.0	12.7	9.36 (3.21)	11.23 (3.49)	8.03 (3.00)	8.53 (3.08)	32.83
Cypermethrin 10% EC (USTAAD) (T2)	1.0	11.8	5.66 (2.58)	9.36 (3.21)	4.23 (2.28)	4.66 (2.38)	63.30
Dimethoate 30% EC (ROGAR) (T3)	2.0	14.5	5.23 (2.49)	8.33 (3.05)	4.10 (2.25)	4.86 (2.42)	61.73
Imidacloprid 17.8 SL (CONFIDOR) (T4)	0.5	11.3	7.33 (2.88)	9.03 (3.16)	4.13 (2.26)	5.13 (2.47)	59.60
Azadiractin 3000 ppm (NEEMRAJ) (T5)	4.0	12.4	8.53 (3.08)	11.36 (3.51)	7.53 (2.92)	7.63 (2.93)	39.92
Garlic bulb extract (T6) (5%)	50.0	10.7	9.10 (3.17)	9.33 (3.21)	8.33 (3.05)	8.80 (3.13)	30.70
Turmeric rhizome extract (T7) 5%)	50.0	13.5	10.26 (3.35)	11.26 (3.50)	8.96 (3.15)	9.13 (3.18)	28.11
Untreated control (T8)	-	11.0	12.40	11.80	13.40	12.70	
SEm (±)			**0.07**	**0.20**	**0.21**	**0.06**	
CD 5 %			**0.23**	**0.62**	**0.68**	**0.20**	

Figure in the parenthesis are square root transformed values, **PTC:** Pre-treatment count (in numbers)**; DAS:** Days after spraying**; RoC:** Reduction over control (in %)

So cypermethrin 10% EC was at par with dimethoate 30% EC and imidacloprid 17.8 SL. Present finding was in line with the finding of Rathod *et al.* (2009) who conducted a laboratory experiment on bottle gourd and reported that cypermethrin and carbaryl both were potentially effective against red pumpkin beetle. Among the botanicals, Azadirachtin 3000 ppm (NEEMRAJ) 4.00 ml/l treated plot was found superior and recorded 39.92% suppression of red pumpkin beetle over control. Neem leaf extract 50 ml/l (5%), garlic extract 50 ml/l (5%) and turmeric extract 50 ml/l (5%) were recorded satisfactory result to control red pumpkin beetle, showing 32.83%, 30.70% and 28.11% suppression of beetle population respectively. Present finding was in accordance with Rathod *et al.* (2009) but contradiction with Neupane and Shrestha (2016). Rathod *et al.* (2009) reported that neem based commercial formulation gronim showing 49.89% mortality and neem-azal-F showing 44.86% mortality against pumpkin beetle. But, Neupane and Shrestha (2016) showed that multi-neem formulation at a concentration of 5ml/l gave cent per cent reduction of beetle population on pumpkin followed by 4ml/l (91.5%), 3ml/l (63%) and 2 ml/l (37.9%), respectively. From the overall observation it can be concluded that red pumpkin beetle was a serious insect pest of bottle gourd cultivation at Changuria village. The pest was active throughout the growing seasons. Spraying of chemical insecticide like cypermethrin 10 % EC, Dimethoate 30 % EC and imidacloprid 17.8 SL recorded more than 60 % reduction of red pumpkin beetle population. Azadirachtin 3000 ppm recorded more or less 40 % reduction of red pumpkin beetle population on bottle gourd cultivation. Neem based insecticide and botanical plants extract may be included in integrated pest management of red pumpkin beetle on bottle gourd.

CONCLUSION

Red pumpkin beetle is a serious insect pest of bottle gourd cultivation at Changuria village. The pest was active throughout the crop growing season. Neem based insecticide and botanical plants extract can be included in integrated pest management of red pumpkin beetle on bottle gourd cultivation at Changuria village, Mallickpur Gram Panchayet, Birbhum district of West Bengal.

ACKNOWLEDGEMENT

Experiment was carried out with the help of Department of Plant Protection, Suri Vidyasagar College, Suri, Birbhum and providing laboratory for the study. I thank the Department as well as I thank Dr. Tapan Kumar Parichha, Principal, Suri Vidyasagar College.

REFERENCES

Butani DK, Jatwani MG. 1984. Insect in vegetable. Periodical Expert Book Agency, Delhi. 84p.

Ghosh SK. 2019. Climate impact on red spider mite (*Tetranychus sp*, Koch) infesting eggplant (*Solanum melongena* L.) and their management using plant extracts. Journal of Entomological Research 43: 345-350.

Haldhar SM, Choudhary BR, Bhargava R, Sharma SK. 2014. Development of an organic integrated pest management (IPM) module against insect pests of muskmelon in arid region of Rajasthan. Indian Journal of Experimental Biology and Agricultural Sciences 2(1): 19-24.

Milind P, Satvir K. 2011. Is bottle gourd a natural gourd? International Research Journal of Pharmacy 2(6): 13-17.

Neupane BP, Shrestha J. 2016. Efficacy of botanical pesticide multi-neem against red pumpkin beetle *Aulacophora foveicollis* (Lucas). Management on cucurbit. Bioscience Discovery 7: 97-100.

Rashid MA, Khan MA, Arif MJ, Javed N. 2014. Red Pumpkin Beetle, *Aulacophora foveicollis* (Lucas) a review of host susceptibility and management practices. Academic Journal of Entomology 7(1): 38-54.

Rathod ST, Board PK, Bhatt NA. 2009. Bio-efficacy of neem based and synthetic insecticides against red pumpkin beetle, *Aulacophora foveicollis* (Lucas) on bottle gourd. Pest Management in Horticultural Ecosystems 15: 150-154.

Umar S, Anjana ANA, Khan NA. 2013. Nitrate management approaches in leafy vegetables. Nitrate in leafy vegetables: toxicity and safety measures. IK International Publishing House Pvt. Ltd. New Delhi. Pp. 166-181.

J. Agric. Technol., 12(2): 90-97 (2025)
Print: ISSN: 2348-4721; Online: ISSN: 2349-610X

Modelling of Microwave Drying of Bell Pepper

Himadri Shekhar Konar[1*], Tathagata Sinha[1], Shrilekha Das[2]

[1]*Faculty of Technology, Uttar Banga Krishi Viswavidyalaya, Pundibari- 736 165, Cooch Behar, West Bengal, India*
[2]*Department of Agricultural Engineering, Palli Siksha Bhavana, Visva-Bharati- 731 236, Sriniketan, West Bengal, India*

[*]***E-mail***: *hskonar@gmail.com*

Received: 05-11-2025; **Revised:** 12-11-2025; **Accepted:** 14-11-2025

Citation: Konar HS, Sinha T, Das S. 2025. Modelling of Microwave Drying of Bell Pepper. J Agric Technol. 12(2): 90-97.

The study analyzes the drying behaviour of green bell pepper (*Capsicum annuum* L.) slices under microwave drying at varying power levels (180–600 W) to optimize drying kinetics and model moisture reduction behaviour. Freshly prepared thin-layer samples were dried in a modified domestic microwave oven, and moisture loss was recorded at regular intervals. Experimental data were analyzed using five thin-layer drying models—Lewis, Page, Modified Page, Henderson and Pabis, and Wang and Singh—evaluated based on coefficient of determination (R^2), reduced chi-square (χ^2), and root mean square error (RMSE). Results revealed a rapid decline in moisture content with increasing microwave power, with drying occurring predominantly in the falling-rate period, indicating that internal moisture diffusion controlled the process. Among the tested models, the Page and Modified Page models provided the best fit, with the highest mean R^2 (0.9925) and the lowest χ^2 and RMSE values. The drying constant (k) increased with microwave power, reflecting enhanced drying rates at higher energy inputs. The Modified Page model most accurately represented the thin-layer microwave drying kinetics of bell pepper slices. These findings demonstrate the potential of microwave drying for efficient moisture removal and energy savings in bell pepper processing and provide a predictive basis for process optimization and future quality-focused studies.

Keywords: Microwave drying, Bell pepper, Thin-layer model, Drying kinetics

INTRODUCTION

Pepper (*Capsicum annuum* L.), a globally significant crop within the Solanaceae family, is cultivated extensively for both non-pungent vegetable varieties, such as bell peppers, and pungent spices like chili and cayenne peppers. C. annuum is the most economically important and widespread cultivated Capsicum species. The large-fruited bell pepper is particularly valued for its culinary versatility in salads, stews, and pastes, and its high nutritional density. Bell peppers are valuable sources of health-promoting compounds, particularly ascorbic acid (Vitamin C) and provitamin A carotenoids, which act as powerful antioxidants linked to reduced risks of cardiovascular disease and certain cancers (Mohd Hassan *et al*., 2019).

To maintain the quality and extend the short shelf life of perishable Capsicum fruits beyond harvest, dehydration is a crucial preservation process. Drying reduces water activity, thereby inhibiting microbial spoilage and diminishing overall product loss (Duygu and Bulantekin, 2021). However, evaporation is a complex process often associated with negative consequences, including non-uniform quality, deterioration of sensory properties (colour, flavour), and the thermal degradation of heat-sensitive bioactive components. Furthermore, conventional methods, such as convective (hot-air) drying, are highly energy-intensive, primarily due to the sequential heating of the air and then the material (Jimoh *et al*., 2023).

Microwave drying represents a promising alternative, leveraging volumetric heat generation induced by high-frequency electromagnetic fields. This internal heating mechanism intensifies moisture transport, resulting in significantly reduced drying times and lower energy consumption compared to traditional convective methods (Kumar and Karim, 2017). Microwave power level was reported to have greater effect on the quality attributes of green bell pepper such as green colour ratio, rehydration ratio, hardness and apparent density ratio in vacuum-assisted microwave drying (Kumar and Shrivastava, 2017). Detailed research into the specific moisture reduction kinetics and comprehensive modeling of the thin-layer microwave drying process for green bell peppers is critical for optimizing industrial drying processes to preserve maximum nutritional quality. Understanding these kinetics. Hence, this study was undertaken with the following objectives:

- To experimentally investigate the moisture reduction behaviour of green bell pepper slices during microwave drying at various temperatures.
- To apply and validate suitable thin-layer drying models to accurately describe the moisture reduction kinetics of green bell pepper during the microwave drying process.

MATERIALS AND METHODS

Sample Preparation and Experimental Setup

Fresh bell peppers (*Capsicum annuum* L.) were procured from a local market. The initial moisture content was determined using the standard oven method. The bell peppers were washed, cored, and sliced uniformly to ensure a thin layer, which is critical for thin-layer modelling. The drying experiments were conducted using a standard domestic microwave oven modified for thin-layer drying experiments. The setup allowed for precise measurement of sample weight loss over time. The experiments were performed at five different output power levels (e.g., 90 W, 180 W, 300 W, 450 W, and 600 W, assumed typical for this study) to cover a wide range of drying conditions.

Drying Procedure

Bell pepper slices were placed in a single, thin layer on a tray and positioned inside the microwave oven. The samples were shown in Figure 1. The weight loss was recorded at regular time intervals until the sample reached the target final moisture content (e.g., moisture content suitable for storage). The drying time was recorded for each power level. The experimental data were converted into the Moisture Ratio (MR) using the following standard equation

$$MR = \frac{M_t - M_e}{M_{in} - M_e}$$

Where, M_t is moisture content of bell pepper at time t, M_e is equilibrium moisture content of bell pepper at the drying conditions and M_{in} is initial moisture content of bell pepper. The values of equilibrium moisture content

M_e in microwave drying are relatively small compared to M_t or M_{in} and the expression of moisture ratio was reduced to

$$MR = \frac{M_t - M_e}{M_{in} - M_e}$$

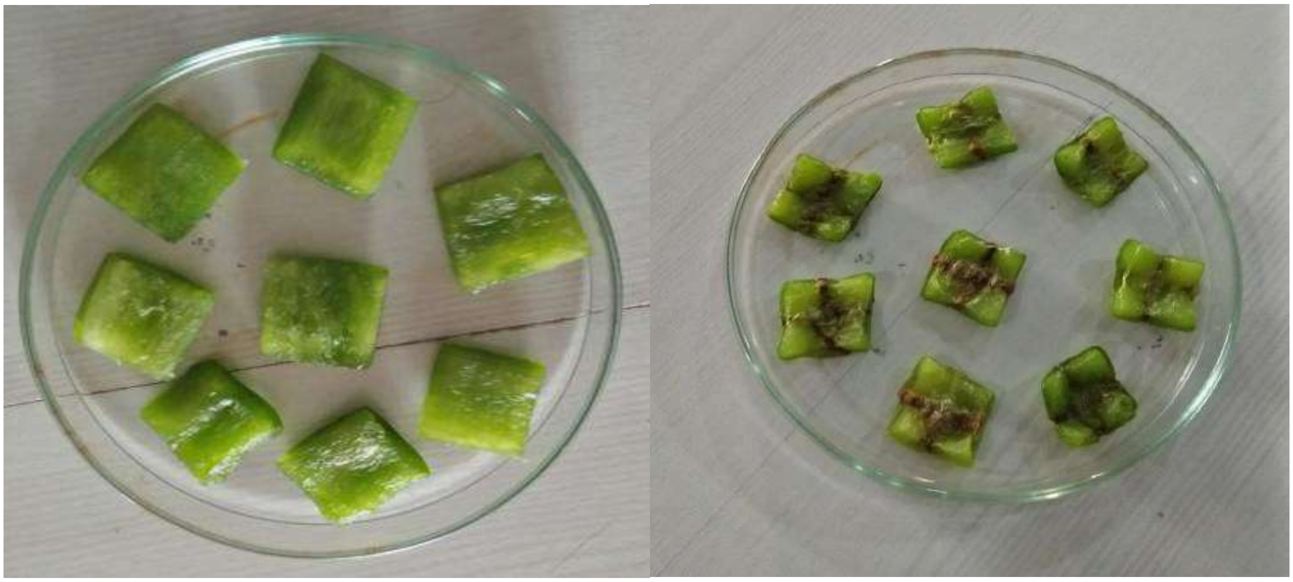


Figure 1. Bell pepper samples before and after MW drying

Mathematical Modelling and Statistical Analysis

The experimental MR data were fitted to various semi-theoretical and empirical thin-layer drying models. The models evaluated included are given in Table 1.

Table 1. Thin-layer drying models evaluated

Name of Model	Model	References
Lewis	$MR = \exp(-k\, t)$	Demir *et al*., 2007
Page	$MR = \exp(-k\, t^{n})$	Yaldiz and Ertekin, 2001
Modified Page	$MR = \exp(-k\, t)^n$	Demir *et al*., 2007
Henderson and Pabis	$MR = a \exp(-k\, t)$	Henderson and Pabis, 1961
Wang and Singh	$MR = 1 + at + bt^2$	Wang and Singh, 1978

These models were fitted in the experimental data in their linearized form using regression technique. The coefficient of determination R^2 was one of the main criteria for selecting the best equation. In addition to the coefficient of determination, the goodness of fit was determined by various statistical parameters such as reduced chi square χ^2 and root mean square error RMSE. For quality fit, R^2 value of the selected model should be highest and χ^2 and RMSE values should be lowest. The above parameters were calculated using the following equations.

$$\chi^2 = \frac{1}{N-z}\sum_{i=1}^{N}(MR_{experimental,i} - MR_{predicted,i})^2$$

Where, $MR_{experimental,\ i}$ is the experimental moisture ratio, $MR_{predicted,\ i}$ is the predicted moisture ratio, χ^2 is reduced chi square, N is number of readings and z is number of constants in the model.

$$RMSE = [\,[\frac{1}{N}\sum_{i=1}^{N}(MR_{experimental,i} - MR_{predicted,i})^2]^{1/2}$$

Where, RMSE is root mean square error, N is number of readings.

RESULTS AND DISCUSSION

Microwave drying curves (Figure 2) showed a rapid decline in moisture content with time at all power levels (180–600 W).

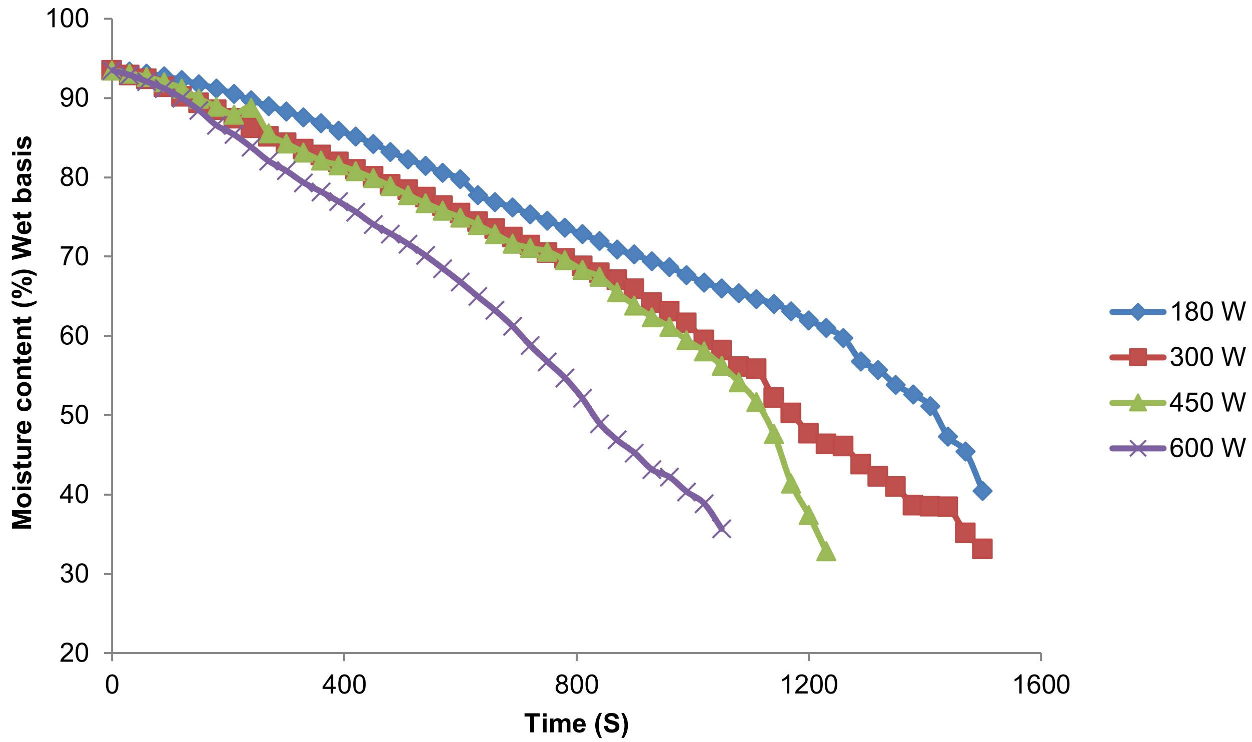


Figure 2. Reduction in moisture content with drying time at different output power during microwave drying

The drying time required to reduce moisture to 30–35% (w.b.) decreased with increasing power, indicating faster moisture removal at higher energy input. The dimensionless moisture ratio followed a similar trend (Figure 3), decreasing continuously with drying time. Except for a short initial phase at 180 W, no constant-rate period was observed. Drying occurred predominantly in the falling-rate period, suggesting that internal moisture diffusion governed the process.

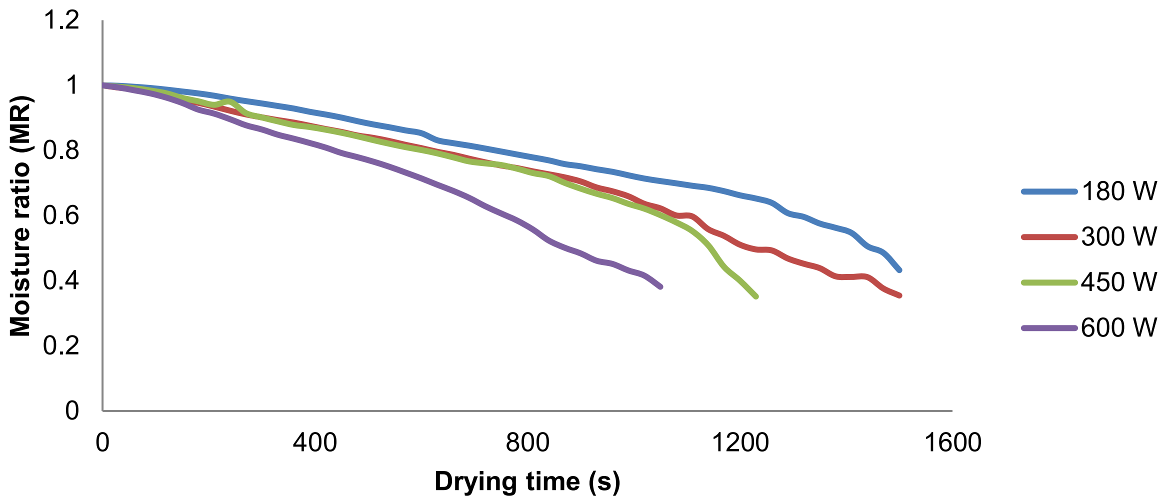


Figure 3. Change in dimensionless moisture ratio (MR) with drying time at different output power levels

Drying rate curves (Figure 4) confirmed that the highest rate occurred at 600 W and declined with lower power levels. Rapid surface evaporation at higher powers led to quicker moisture removal compared to internal migration, resulting in a falling-rate drying behavior throughout.

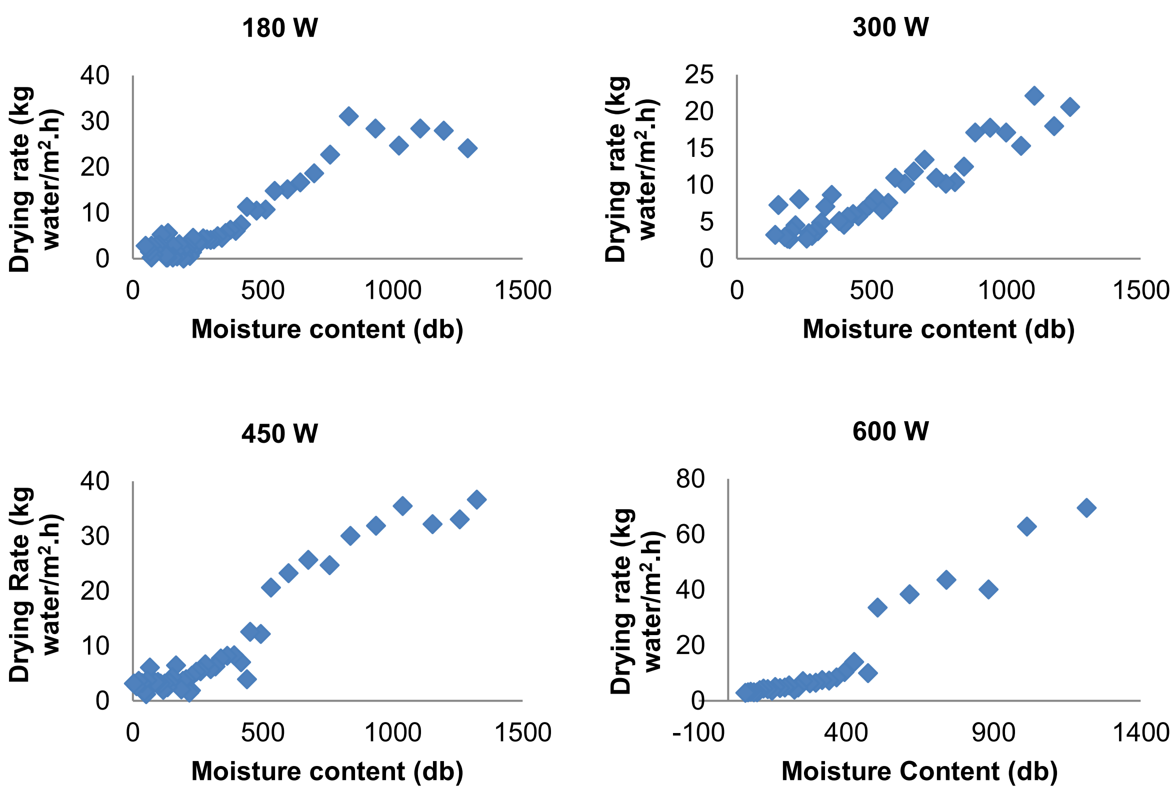


Figure 4. Change of drying rate with moisture content at different power levels

Experimental data were fitted to five thin-layer drying models: Lewis, Page, Modified Page, Henderson and Pabis, and Wang and Singh. The Page and Modified Page models yielded the best agreement with experimental data, with the highest average $R^2 = 0.9925$ and the lowest χ^2 and RMSE values (Table 2).

Table 2. Empirical constants and statistical results obtained from different thin-layer drying models for different drying temperatures

Model	Output power (W)	Constant		R^2	χ^2	RMSE
Newton	180	$k = 3.70\times10^{-4}$		0.888	$2.14*10^{-3}$	0.045
	300	$k = 3.37\times10^{-4}$		0.932	$7.83*10^{-4}$	0.0276
	450	$k = 2.89\times10^{-4}$		0.998	0.0135	0.0367
	600	$k = 6.54\times10^{-4}$		0.914	$1.869*10^{-3}$	0.0425
	Average			**0.933**	**0.018292**	**0.03795**
Page	180	$k = 8.461*10^{-5}$	$n = 1.538$	0.997	$4.14*10^{-4}$	0.0199
	300	$k = 9.14*10^{-5}$	$n = 1.184$	0.991	$4.10*10^{-4}$	0.0197
	450	$k = 3.53*10^{-5}$	$n = 1.380$	0.986	$1.85*10^{-3}$	0.041
	600	$k=5.75*10^{-5}$	$n =1.454$	0.996	0.018	0.132
	Average			**0.9925**	$\mathbf{5.17*10^{-3}}$	**0.05315**
Modified Page	180	$k = 5.03*10^{-4}$	$n = 1.538$	0.997	$4.13*10^{-4}$	0.0199
	300	$k = 3.87*10^{-4}$	$n = 1.184$	0.991	$4.17*10^{-4}$	0.0199
	450	$k = 5.95*10^{-4}$	$n = 1.380$	0.986	$1.85*10^{-3}$	0.0419
	600	$k =7.99*10^{-4}$	$n =1.454$	0.996	$5.69*10^{-4}$	0.023
	Average			**0.9925**	$\mathbf{8.12*10^{-4}}$	**0.026175**
Henderson and Pabis	180	$k = 4.51*10^{-4}$	$a = 1.085$	0.928	$1.39*10^{-3}$	0.036
	300	$k = 3.89*10^{-4}$	$a = 1.042$	0.955	$5.66*10^{-4}$	0.023
	450	$k = 6.25*10^{-4}$	$a = 1.104$	0.850	$3.42*10^{-3}$	0.057
	600	$k = 7.77*10^{-4}$	$a = 1.077$	0.945	$1.33*10^{-4}$	0.035
		$k=5.61*10^{-4}$	$a=1.077$			
	Average			**3.678**	$\mathbf{1.37*10^{-3}}$	**0.03775**
Wang and Singh	180	$a=-1.68*10^{-4}$	$b=-1.06*10^{-7}$	0.99	$2.92*10^{-4}$	0.0167
	300	$a=-1.84*10^{-4}$	$b=-1.31*10^{-7}$	0.996	$2.10*10^{-4}$	0.014
	450	$a=-1.83*10^{-4}$	$b=-2.65*10^{-7}$	0.973	$1.83*10^{-3}$	0.0417
	600	$a=-3.30*10^{-4}$	$b=-2.83*10^{-7}$	0.997	$1.06*10^{-4}$	$9.97*10^{-3}$
	Average			**0.989**	$\mathbf{6.09*10^{-4}}$	**0.020592**

The Modified Page model provided the best fit across the tested microwave power levels. The exponent n>1 indicates non-first-order behaviour and the combined influence of internal diffusion and microwave-driven vapour flux. Higher power generally increased k, indicating faster drying. Intermittent microwave schedules and hybrid drying strategies may help retain quality while shortening process time. Microwave thin-layer drying of green bell pepper was characterized experimentally at 180–600 W. Drying proceeded mainly in the falling-rate regime and the Modified Page model best described MR vs time. Microwave Vacuum Drying of bell pepper was reported to be most efficient in minimizing the loss to nutritional attributes compared to sun drying and hot air drying (Maurya *et al*., 2018). Future work should quantify quality changes (ascorbic acid, carotenoids, colour), determine effective moisture diffusivity and activation energy under microwave regimes, and evaluate intermittent/hybrid microwave-convective strategies for quality-preserving fast drying. The drying constant (k) in the Modified Page model increased with microwave power (Figure 5), indicating enhanced drying rates at higher power levels. Overall, the Modified Page model most accurately represented the microwave drying kinetics of bell peppers.

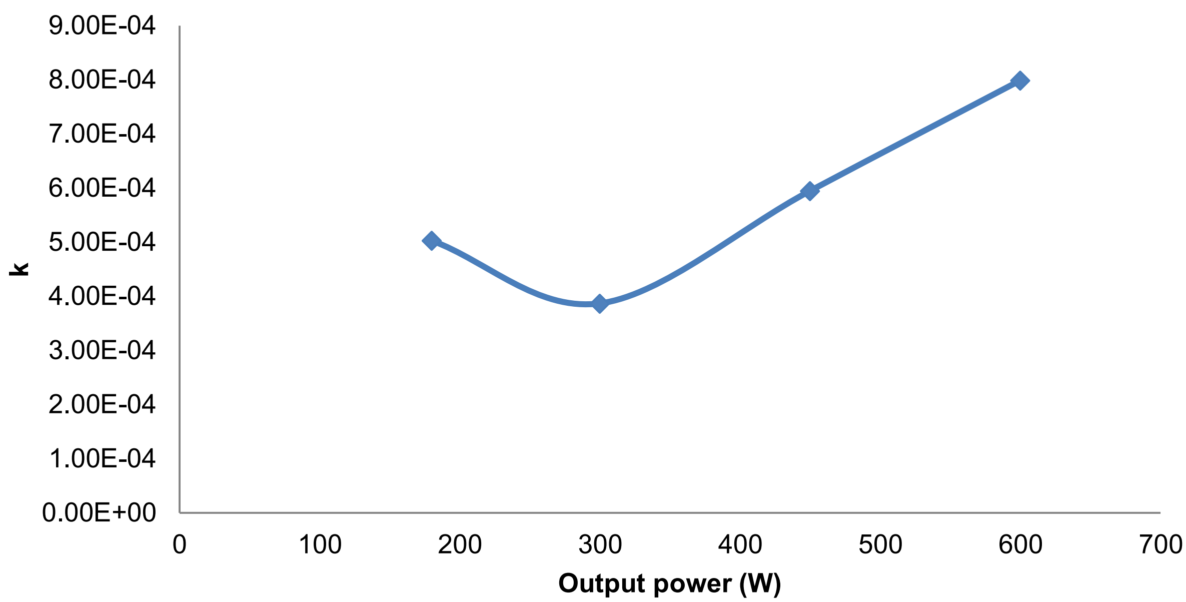


Figure 5. Effect of MW power level on drying constant (k) in Modified Page model

CONCLUSION

Microwave drying of green bell pepper slices was experimentally investigated at different power levels (180–600 W) to evaluate the drying kinetics and to identify the most suitable thin-layer model for describing moisture reduction behaviour. The drying process occurred predominantly in the falling-rate period, with a small presence of constant rate; signifying that internal moisture diffusion was the main mechanism governing water removal. Higher microwave power levels significantly reduced drying time and enhanced drying rates due to increased energy absorption and faster heat transfer within the material. Among the five evaluated thin-layer models—Lewis, Page, Modified Page, Henderson and Pabis, and Wang and Singh—the Modified Page model provided the best agreement with experimental data, showing the highest mean coefficient of determination (R^2 = 0.9925) and the lowest χ^2 and RMSE values. The drying constant (k) increased consistently with microwave power, confirming the positive influence of energy input on moisture diffusivity and drying rate. The results affirm the effectiveness of microwave drying as a rapid and energy-efficient technique for bell pepper processing. The established mathematical model can be used for process prediction and control in industrial drying applications. Future research should focus on assessing quality parameters such as colour, ascorbic acid, and carotenoid retention, as well as evaluating effective moisture diffusivity and activation energy to develop optimized and quality-preserving microwave or hybrid drying systems.

REFERENCES

Demir V, Günhan T, Yağcıoğlu A K, Değirmencioğlu A. 2007. Mathematical modelling and the determination of some quality parameters of air-dried bay leaves. Biosystems Engineering 88(3): 325–335. https://doi.org/10.1016/j.biosystemseng.2004.04.005.

Duygu A, Bulantekin Ö. 2021. The microbiological quality of various foods dried by applying different drying methods: a review. European Food Research and Technology 247(6): 1333–1343. https://doi.org/10.1007/s00217-021-03731-z.

Henderson SM, Pabis S. 1961. Grain drying theory: I. Temperature effect on drying coefficient. Journal of Agricultural Engineering Research 6: 169–174. https://www.cabidigitallibrary.org/doi/full/10.5555/19621700719

Jimoh KA, Hashim N, Shamsudin R, Man CH, Jahari M, Onwude DI. 2023. Recent Advances in the Drying Process of Grains. Food Engineering Reviews 15: 548–576. https://doi.org/10.1007/s12393-023-09333-7

Kumar C, Karim A. 2017. Microwave-Convective Drying of Food Materials: A Critical Review. Critical Reviews in Food Science and Nutrition. 59. https://doi.org/10.1080/10408398.2017.1373269.

Kumar V, Shrivastava SL. 2017. Optimization of vacuum-assisted microwave drying parameters of green bell pepper using response surface methodology. Food Measure 11: 1761–1772. https://doi.org/10.1007/s11694-017-9557-7

Maurya VK, Gothandam KM, Ranjan V, Shakya A, Pareek S. 2018. Effect of drying methods (microwave vacuum, freeze, hot air and sun drying) on physical, chemical and nutritional attributes of five pepper (*Capsicum annuum* var. annuum) cultivars. Journal of the Science of Food and Agriculture 98(9): 3213-3602. https://doi.org/10.1002/jsfa.8868.

Mohd Hassan N, Yusof N A, Yahaya A F, Mohd Rozali N N, Othman R. 2019. Carotenoids of Capsicum Fruits: Pigment Profile and Health-Promoting Functional Attributes. Antioxidants 8(10): 469. https://doi.org/10.3390/antiox810046.

Wang CY, Singh RP. 1978. A single layer drying equation for rough rice. ASAE Paper No. 78–3001. American Society of Agricultural Engineers, St. Joseph, MI, USA. DOI: 10.12691/ajfst-4-4-5

Yaldiz O, Ertekin C. 2001. Thin layer solar drying of some vegetables. Drying Technology 19(3–4): 583–597. https://doi.org/10.1081/DRT-100103936.

J. Agric. Technol., 12(2): 98-106 (2025)
Print: ISSN: 2348-4721; Online: ISSN: 2349-610X

Development of Bio-Based Polyurethane Rigid Foam Using Jute Stick Digestion Liquor (JSDL) as a Partial Polyol Substitute

Sanchita Biswas Murmu

ICAR-National Institute of Natural Fibre Engineering & Technology, 12, Regent Park, Kolkata, West Bengal, 700 040, India

****E-mail**: *sanchita.biswas@icar.gov.in*

Received: 11-11-2025; **Revised:** 15-12-2025; **Accepted:** 20-12-2025

Citation: Murmu SB. 2025. Development of Bio-Based Polyurethane Rigid Foam Using Jute Stick Digestion Liquor (JSDL) as a Partial Polyol Substitute. J Agric Technol. 12(2): 98-106.

This study evaluates the potential of Jute Stick Digestion Liquor (JSDL), a lignin- and carbohydrate-rich by-product of the alkaline sulfite anthraquinone methanol (ASAM) pulping process, as a renewable substitute for petroleum-based polyols in polyurethane (PU) rigid foam production. Chemical characterization confirmed that JSDL contains substantially higher hydroxyl functionality than PEG 200, indicating its suitability as a reactive bio-polyol component. Polyurethane foams were developed by partially replacing PEG with JSDL at varying ratios to assess compatibility, reactivity, and foam performance. Among the formulations tested, the 80:20 (PEG: JSDL) composition produced the most uniform and stable rigid foam, exhibiting acceptable mechanical properties and structural integrity, while higher substitution levels resulted in reduced foam rise and partial unreacted components. The findings demonstrate that up to 20% of commercial polyol can be effectively replaced with JSDL without compromising foam quality, highlighting a promising pathway for valorizing jute processing waste into sustainable, bio-based polymer materials.

Keywords: Jute Stick Digestion Liquor (JSDL), Bio-based Polyol, Polyurethane Rigid Foam, Polyol Substitution; Lignocellulosic Biomass Valorization

INTRODUCTION

The growing global emphasis on sustainable development has intensified the search for renewable, biomass-derived materials that can reduce dependence on petroleum-based resources. In this context, biorefineries—integrated systems capable of converting lignocellulosic biomass into fuels, chemicals, and value-added materials—have emerged as key technological pathways for circular economy models. Biomass residues such as agricultural by-products, forestry waste, and pulping liquors represent attractive feedstocks due to their abundance, low cost, and potential to generate multiple high-value streams concurrently (Poveda-Giraldo and Cardona-Alzate, 2020).

Among these residues, pulping liquors (including kraft, soda, sulfite, and alkaline digestion liquors) contain a complex mixture of lignin, hemicellulose degradation products, extractives, and low-molecular-weight aromatic and carboxylic compounds. Their composition is rich in functional groups—particularly hydroxyl, methoxyl, carbonyl, and phenolic moieties—that make them promising candidates for downstream applications such as polymer synthesis, dispersants, adhesives, and specialty chemicals. However, these liquors are often underutilized, with most industries focusing on chemical recovery or combustion rather than value addition, despite the significant potential of lignin-rich fractions for material innovation (Radoykova *et al*., 2013).

For example, lignosulfonates and soda lignin derived from pulping are widely recognized for their surface activity, binding capacity, and suitability in polymer synthesis, dispersants, and composite materials. Studies presented in black liquor lignin characterization demonstrate the abundance of monomeric phenolic units such as guaiacol, syringol, catechols, and substituted phenolics—compounds that enhance chemical reactivity and open pathways for polymer development. Similarly, work on spent sulfite liquors highlights their potential in producing sodium lignosulfonate for a range of industrial uses, including additives, binders, plasticizers, and dispersants. These studies reinforce the importance of valorizing digestion liquors as renewable precursors for functional materials (Klett, 2017).

Jute sticks digestion liquor (JSDL), generated from the ASAM pulping of jute sticks, similarly contains lignin, hemicellulose derivatives (including xylem), organic acids (acetic and formic acids), tannin-like phenolics, and various aromatic breakdown products, consistent with the chemical profiles of other alkaline pulping liquors reported in literature. The characterization of pulping liquors indicates that the presence of hydroxyl-rich lignin fragments and low-molecular-weight aromatic compounds significantly enhances reactivity toward isocyanates, making these liquors promising candidates as bio-based substitutes for polyols in polyurethane systems (Haw *et al*., 1984)

Polyurethane (PU) rigid foams are extensively used in thermal insulation, construction panels, refrigeration systems, furniture, packaging, and automotive components owing to their low density, thermal stability, and excellent mechanical properties. The global PU foam industry, however, is heavily reliant on petroleum-derived polyols, creating environmental and economic pressure to identify renewable alternatives. Bio-based polyols from lignocellulosic feedstocks have attracted increasing research attention because lignin and tannin derivatives possess abundant hydroxyl functionalities and aromatic backbones that can impart rigidity, thermal resistance, and mechanical strength to PU foams (Erdogan *et al*., 2015).

Recent literature demonstrates that incorporating bio-polyols into PU formulations can reduce apparent density, promote uniform cell structures, and improve flame resistance due to the presence of aromatic lignin fragments. Moreover, the use of spent liquors aligns with biorefinery principles by converting a low-value waste stream into a functional raw material. Studies on hydrothermal and alkaline liquors confirm that their rich organic composition can be leveraged not only for fuels and chemicals but also for material applications, including polymer composites, resins, hydrogels, dispersants, and foams (Niemelä and Alén, 1999); Arbenz and Avérous, 2015; Nath *et al*., 2020).

Given in this context, the present study explores the valorization of Jute Stick Digestion Liquor (JSDL) as a reactive bio-polyol component in the formulation of polyurethane rigid foams. The high hydroxyl content of JSDL—derived from lignin, tannins, and carbohydrate fragments—makes it a suitable candidate for partial substitution of conventional polyethylene glycol (PEG 200). Developing PU rigid foams using JSDL not only supports waste minimization and resource efficiency but also offers a pathway toward sustainable, bio-based insulation materials with reduced fossil carbon input. We have studied the composition of Jute stick digestion liquor and explored its potential in development of bio-based poly urethane rigid foam.

MATERIALS AND METHODS

Collection of Jute Sticks Digestion liquor

Jute stick digestion liquor was produced as a byproduct of the ASAM process involving the digestion of Jute stick. In the ASAM process, approximately 4 kg of jute sticks were cut into 6 mm sections and digested with 200 g of sodium hydroxide (5% based on the dry weight of jute sticks) and 400 g of sodium sulfite (10% taken on dry weight of jute sticks), 200 g of methanol, 0.05 g of anthraquinone, and 35 litres of water at 160 °C for 3 h in a rotary-type digester rotating at 2 rpm. Then the digested pulp was spread on a sieve to discard the black liquor. Then black liquor was concentrated by drying in shade till the moisture content was reduced to zero. The concentrated black liquor was termed as jute stick digestion liquor (JSDL) and used for all further analysis.

Determination of Hydroxyl Number

The hydroxyl number (I_{OH}) was assessed in accordance with the American Society for Testing and Materials (ASTM) D4274–16 standard. A measured quantity of JSDL was dissolved in an acetylation reagent (acetic anhydride in pyridine) and the blend was heated in a water bath at 98 °C for 2 hours. The acetic acid generated was titrated using a 0.5 N NaOH solution. The I_{OH} was adjusted based on the acid number because of the acidic nature of JSDL. The JSDL was mixed in a 50 mL solution of dioxane and water (4:1 v/v), phenolphthalein (1% ethanol) was incorporated, and the mixture was titrated with 0.1 M KOH. Both the I_{OH} and acid number for the samples were determined through the titration difference between the blank and the sample solutions. All measurements were conducted in triplicate, and the standard deviation is presented.

Quantitative ^{1}H NMR Spectroscopy

Quantitative 1H NMR spectroscopy was conducted to evaluate the degree of substitution (Sadeghifar *et al*., 2012; Arbenz and Avérous, 2015;) and molar substitution (Bridson *et al*., 2019) following earlier findings. Spectra were obtained utilizing a Bruker Avance DPX400 MHz spectrometer equipped with a Prodigy 5 mm multinuclear BBO probe (Bruker, Switzerland). The relaxation delay was configured to 10 s with 32 scans. Samples were created in triplicate by dissolving 10 mg of HBBT in 0.8 mL of deuterated dimethyl sulfoxide (DMSO-d6). A standard solution of PFB in DMSO-d6 was made by weighing 33 mg of PFB and diluting it in 0.40 mL of DMSO-d6. A portion of the PFB standard solution (0.10 mL) was introduced into the sample solution. The outcomes were presented as the average ± standard deviation.

Preparation of Polyurethane Foams

Polyurethane (PU) foams were prepared in 500 mL glass cylinders using the one-shot technique. JSDL and PEG 200 were blended in five different ratios—100:0, 90:10, 80:20, 70:30, and 60:40 (PEG: JSDL)—to evaluate the extent to which the commercial polyol could be replaced by the digestion liquor. The amounts of the other components in the foaming formulation, namely tertiary amine (catalyst), distilled water (blowing agent), and silicone oil (surfactant), were kept constant to isolate the effect of JSDL substitution. This approach enabled a controlled assessment of the influence of bio-polyol incorporation on foam formation, rise, and stability.

RESULTS AND DISCUSSION

In analytical chemistry, the hydroxyl value is defined as the number of milligrams of potassium hydroxide (KOH) required to neutralize the acetic acid released during the acetylation of free hydroxyl groups present in one gram of a substance. Since hydroxyl functionality directly influences reactivity with isocyanates, the hydroxyl number is a critical parameter for evaluating the suitability of Jute Stick Digestion Liquor (JSDL) for polyurethane (PU) foam production. JSDL exhibited a hydroxyl number of approximately 200 mg KOH/g, which is comparable to the hydroxyl values of conventional petrochemical polyols commonly used in industry (Serrano *et al*., 2020). Natural-oil-based polyols typically show slightly higher hydroxyl numbers; for instance, Kurańska and Prociak (2016) reported a value of 276 mg KOH/g for rapeseed-oil-derived polyol.

To further understand the chemical structure of JSDL and its reactivity, ^{1}H NMR spectroscopy of both JSDL and PEG 200 was performed (Figure 1).

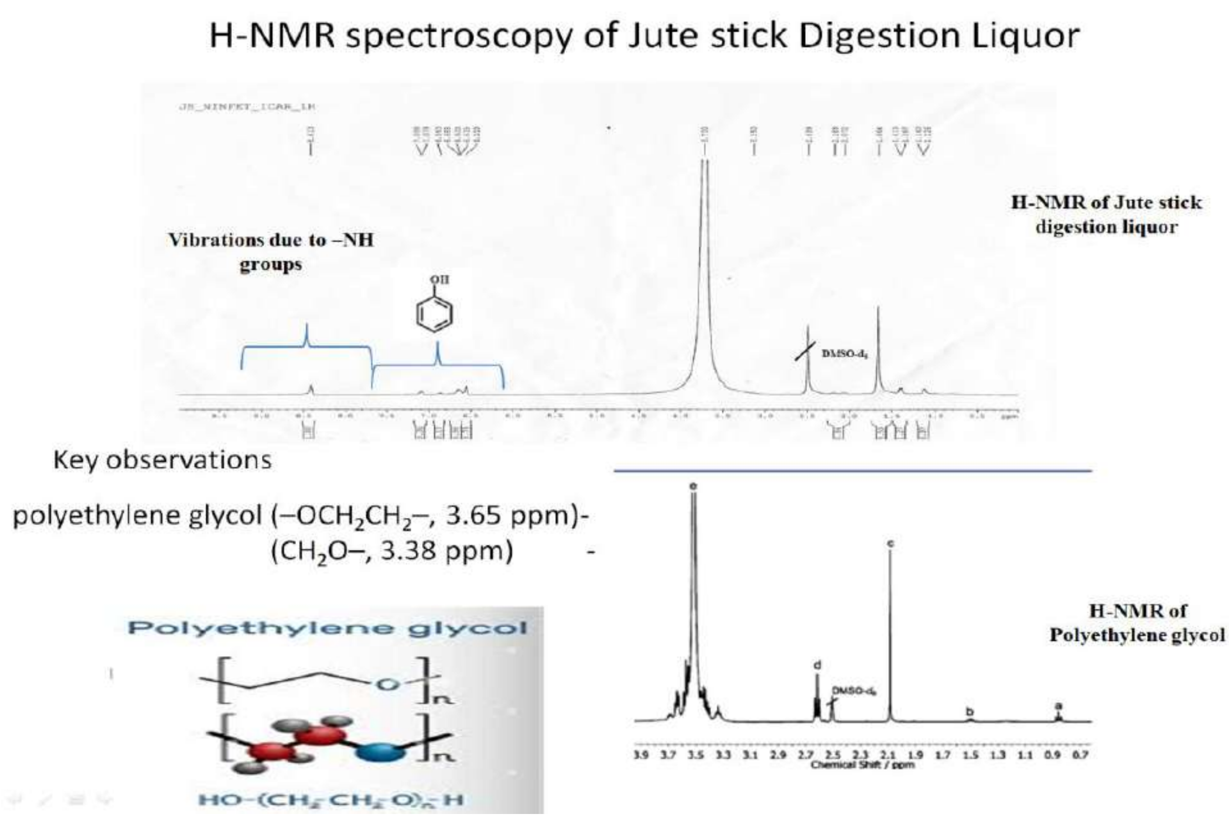


Figure 1. H-NMR spectroscopy of JSDL and PEG 200

The reaction mixture was characterized using complementary qualitative and quantitative analytical techniques. The ^{1}H NMR spectra provided insights into the degree of substitution and molar substitution, with chemical shift regions corresponding to methyl and methylene groups (0.6–1.8 ppm), methoxy protons (3.2–4.9 ppm), aromatic protons (6.0–8.0 ppm), and the internal standard (10.0–10.2 ppm). These spectral assignments confirm the presence of abundant hydroxyl-bearing aromatic and aliphatic structures in JSDL, supporting its potential as a renewable polyol replacement.

Five polyurethane foams were formulated by blending PEG 200 with JSDL at ratios of 100:0, 90:10, 80:20, 70:30, and 60:40 (PEG: JSDL) to assess the maximum feasible substitution of commercial polyol with jute stick digestion liquor. All other components of the foaming formulation—catalyst, blowing agent, and surfactant—were kept constant to isolate the effect of JSDL incorporation and evaluate its direct influence on foam formation and stability. The resulting foams were successfully produced and remained structurally stable under ambient conditions. Preliminary visual assessments, as shown in Figure 2 and 3, confirmed uniform foam formation across all formulations, although detailed mechanical and morphological evaluations were subsequently required to determine the optimum substitution level.

Figure 2a. Structure of foam developed using PEG: JSDL-100:0

Figure 2b. Structure of foam developed using PEG: JSDL-90 :10

Figure 2c. Structure of foam developed using PEG: JSDL-80:20

Figure 2d. Structure of foam developed using PEG: JSDL-60:40

Figure 3a. Foam developed using PEG: JSDL-100:0

Figure3b. Foam developed using PEG: JSDL-90 :10

Figure 3c. Foam developed using PEG: JSDL-80:20

Figure 3d. Foam developed using PEG: JSDL-60:40

One of the key indicators of polyurethane (PU) system reactivity is dielectric polarization, which typically decreases as polymerization progresses. The PU formulation containing only petrochemical-based substrates exhibited the fastest decline in dielectric polarization, reflecting the highest reactivity. This rapid chemical transformation was accompanied by a core temperature rise of up to 180 °C, a level that may pose a risk of spontaneous combustion during large-scale production. In contrast, incorporating JSDL into the PU system resulted in a noticeable reduction in reactivity. This behavior is attributed to the presence of secondary hydroxyl groups in the biopolyol, which are significantly less reactive—approximately three times slower—than the primary hydroxyl groups found in PEG 200.

At 10 wt.% substitution of PEG 200 with JSDL, the resulting foam displayed a more regular cell morphology with smaller, oval-shaped pores (Figure 3b). This improved structure can be partially attributed to the surface-active nature of JSDL, which contains both hydrophobic (hydrocarbon fatty acids) and hydrophilic (ester, ether, and hydroxyl) functional groups that collectively reduce surface tension during foaming. Similar trends were reported by Leszczyńska *et al*. (2021) who noted that the incorporation of plant-derived polyols often leads to more uniform cell structures and reduced apparent density even when identical blowing agent levels are used. Increasing the JSDL substitution to 20 wt.% further reduced the cell size and produced a more compact structure (Figure 3c), consistent with the lower overall system reactivity and reduced foaming temperature. However, at 40 wt.% substitution, incomplete reaction of some components in the digestion liquor was observed, along with reduced foam rise and increased rise time. These effects indicate that beyond a certain threshold, the lower reactivity and higher viscosity of JSDL inhibit optimal foam expansion and crosslinking (Bridson *et al*., 2019; Hussain *et al*., 2020). Where 20 % replacement of PEG 200 with Jute stick Digestion Liquor is made, it gives good foam standing, stability, structure. Hence mechanical properties of this foam have been analysed and given in Table 1.

Table 1. Mechanical properties of 80:20 foam

Tensile strength, MPa	0.018	ASTM D3574 Test E Sec 45 to 52:2017
Elongation at break, %	0 %	
Compression force deflection, KPa	1.23	ASTM D3574 Test C Sec 30 to 36:2017

CONCLUSION

The present study demonstrated that Jute Stick Digestion Liquor (JSDL), a lignin- and carbohydrate-rich by-product of the ASAM pulping process, possesses a significantly higher number of hydroxyl groups compared to conventional PEG 200, indicating its strong potential as a bio-polyol candidate for polyurethane foam development. Chemical analyses confirmed the presence of reactive constituents such as lignin fragments, organic acids, and phenolic compounds, all of which contribute to the polyol-like behaviour of JSDL. Foam development trials revealed that up to 20% substitution of PEG 200 with JSDL produces a structurally stable and uniform foam with acceptable mechanical properties, including appropriate tensile strength and compression behavior. At higher substitution levels, reduced reactivity, incomplete component incorporation, and diminished foam rise were observed, indicating limitations in foam performance. Among the compositions tested, the 80:20 (PEG: JSDL) foam exhibited the most favourable structural attributes, producing a uniform cell structure and acceptable mechanical properties, including a tensile strength of 0.018 MPa and a compression force deflection of 1.23 kPa. Higher substitution levels resulted in incomplete reaction and compromised foam rise, indicating limitations associated with the reactivity and viscosity of JSDL at elevated proportions. Overall, the findings confirm that up to 20% of petroleum-based polyol can be effectively replaced with JSDL to produce a bio-based polyurethane rigid foam, offering a promising route for value addition to jute stick pulping liquor and contributing to the development of sustainable, renewable polymeric materials.

REFERENCES

Arbenz L, Avérous L. 2015. Oxyalkylation of gambier tannin—synthesis and characterization of ensuing biobased polyols. Industrial Crops and Products 67: 295–304. https://doi.org/10.1016/j.indcrop.2015.01.073.

Bridson JH, Sanglard M, Hussain I, Bouad B, Patel M, Parker K. 2019. Hydroxyalkylation of condensed tannins: comparison of proanthocyanidin extraction process and epoxide chain length on physicochemical properties. Industrial Crops and Products 140: 111618. https://doi.org/10.1016/j.indcrop.2019.111618.

Erdogan E, Atila B, Mumme J, Reza MT, Toptas A, Elibol M, Yanik J. 2015. Characterization of products from hydrothermal carbonization of orange pomace including anaerobic digestibility of process liquor. Bioresource Technology 196: 35–42. https://doi.org/10.1016/j.biortech.2015.06.115.

Haw JF, Maciel GE, Schroeder HA. 1984. Carbon-13 Nuclear Magnetic Resonance Spectrometric Study of Wood and Wood Pulping with Cross Polarization and Magic-Angle Spinning. Analytical Chemistry 56(8): 1323–1329. https://doi.org/10.1021/ac00272a028.

Hussain I, Sanglard M, Bridson JH, Parker K. 2020. Preparation and physicochemical characterization of polyurethane foams prepared using hydroxybutylated condensed tannins as a polyol source. Industrial Crops and Products 154: 112636. https://doi.org/10.1016/j.indcrop.2020.112636

Klett AS. 2017. Purification, Fractionation, and Characterization of Lignin from Kraft Black Liquor for Use as a Renewable Biomaterial. Ph. D. Thesis. Clemson University, South Carolina.

Kurańska M, Prociak A. 2016. The influence of rapeseed oil-based polyols on the foaming process of rigid polyurethane foams. Industrial Crops and Products 89: 182-187. https://doi.org/10.1016/j.indcrop.2016.05.016.

Leszczyńska M, Malewska E, Ryszkowska J, Kurańska M, Gloc M, Leszczyński MK, Prociak A. 2021. Vegetable fillers and rapeseed oil-based polyol as natural raw materials for the production of rigid polyurethane foams. Materials 14(7): 1772. https://doi.org/10.3390/ma14071772.

Nath K, Panchani SC, Patel TM, Dave HK, Patel VB, Tiwari KK, Sahoo N. 2020. Evaluation of *Prosopis juliflora* as a potential feedstock for the production of sodium lignosulfonate from the spent liquor of a laboratory digester. Journal of Wood Chemistry and Technology 40(5): 331–347. https://doi.org/10.1080/02773813.2020.1809677.

Niemelä K, Alén R. 1999. Characterization of Pulping Liquors. In: Analytical Methods in Wood Chemistry, Pulping, and Papermaking. Springer-Verlag Berlin Heidelberg. Pp. 193–233.

Poveda-Giraldo JA, Cardona-Alzate CA. 2020. Biorefinery potential of Eucalyptus grandis to produce phenolic compounds and biogas. Canadian Journal of Forest Research, https://doi.org/10.1139@cjfr-2020-0201.

Radoykova T, Nenkova S, Valchev I. 2013. Black liquor lignin products, isolation and characterization. Journal of Chemical Technology and Metallurgy 48(5): 524–529.

Sadeghifar H, Cui C, Argyropoulos DS. 2012. Toward thermoplastic lignin polymers. Part 1. Selective masking of phenolic hydroxyl groups in kraft lignins via methylation and oxypropylation chemistries. Industrial & Engineering Chemistry Research 51(51):16713-16720. https://doi.org/10.1021/ie301848j.

Serrano L, Rincón E, García A, Rodríguez J, Briones R. 2020. Bio-degradable polyurethane foams produced by liquefied polyol from wheat straw biomass. Polymers 12(11): 2646. https://doi.org/10.3390/polym12112646.

J. Agric. Technol., 12(2): 107-111 (2025)
Print: ISSN: 2348-4721; Online: ISSN: 2349-610X

Seasonal Occurrence of Aphid (*Lipaphis erysimi* Kalt.) on Mustard at Khosnatore Village of Birbhum District

Tanmoy Mandal

Department of Plant Protection, Suri Vidyasagar College, Suri, Birbhum-731101, West Bengal, India

[*]***E-mail***: *tanmoy_mandal22@rediffmail.com*

Received: 17-12-2025; **Revised:** 27-12-2025; **Accepted:** 30-12-2025

Citation: Mandal T. 2025. Seasonal Occurrence of Aphid (*Lipaphis erysimi* Kalt.) on Mustard at Khosnatore Village of Birbhum District. J Agric Technol. 12(2): 107-111.

An experiment was conducted in 2022 and 2023 at Khosnatore village, Kendua Gram Panchayet, Birbhum District of West Bengal to study seasonal occurrence of mustard aphid and its relation with environmental parameters. Aphid was identified as a key insect pest of mustard cultivation at Khosnatore village. Pooled data from both the years showed that mustard aphid was active throughout the crop growing season. Aphid infestation was initiated (2.4 aphid/plant) on 49th SMW i.e. first week of December, when average temperature was 20.90°C, average relative humidity was 77.78 % and weekly total rainfall was 24.50 mm. Aphid population increased gradually and reached its highest peak (169.2 aphid/plant) on 3rd SMW i.e. 3rd week of January, when average temperature, average relative humidity and weekly total rainfall were 15.12°C, 81.24 % and 17.50 mm, respectively. Higher density of aphid infestation (67.5-169.2 aphid/plant) was found from 1st SMW to 4th SMW i.e. first week of January to fourth week of January, when average temperature ranged from 15.12–18.26°C. Mustard aphid incidence had a negative correlation with maximum temperature (r = - 0.738), minimum temperature (r = - 0.549) and average temperature (r = - 0.737). On the other hand, it showed a positive correlation with maximum relative humidity (r = 0.496), minimum relative humidity (r = 0.218), average relative humidity (r = 0.341) and weekly total rainfall (r = 0.033).

Keywords: Seasonal occurrence, Mustard aphid, Infestation, Abiotic factors

INTRODUCTION

Mustard is an important cruciferous oilseed plant cultivated at Khosnatore village of Birbhum district. The plant is susceptible to different insect pests. Mustard aphid (*Lipaphis erysimi* Kalt.) is the key insect pest of mustard cultivation in India (Bakhetia,1991; Arora, 1999; Rai, 1976; Rohilla *et al.,* 1987). Nymphs and adults of aphid suck saps from the inflorescence, stem, pod and leaf and as a result infected plants get stunted, curled and mottled leaves, withered flower and deformed pod (Begum, 1995). Aphid alone causes 65%-96% of losses in seed yield (Bakhetia, 1984). Abiotic factors play an important role in rapid multiplication of aphid population (Sinha *et al.,* 1989; Singh and Malik, 1998). The knowledge on the seasonal occurrence on mustard aphid at Khosnatore village is essential for management against the key pest. Considering this, seasonal occurrence of mustard aphid and its relation with environmental parameters was undertaken.

MATERIALS AND METHODS

The experimental area was situated at Khosnatore village, Kendua Gram Panchayet, Birbhum District of West Bengal. Soil type was sandy loan soil with pH 6.8. The experimental area was under red lateritic zone. To study seasonal occurrence of mustard aphid and relation with environmental parameters, mustard crop (*Brassica juncea*) was cultivated for two consecutive years of 2022 and 2023 as rabi season crop. Seeds of Indian mustard were collected from local market. Broadcast method of seed sowing was done after final land preparation on first week of November. Mustard crop was grown with recommended fertilizer dose 80:40:40 (N:P:K kg/ha). Half of nitrogen and full of phosphorus and potassium were applied as basal dose, during final land preparation and remaining half of nitrogen was top dressing at 40 days after sowing. Plot size 15 m x 10 m was maintained. Mustard was cultivated with all agronomic practices without any plant protection measures. The statistical design, RBD (Randomized Block Design) was followed. Aphid population was recorded in the morning hours on randomly selected five mustard plants. 10 cm apical part of the plant was selected for recording aphid number. Number of aphid/plants was recorded at weekly intervals throughout mustard growing period. Meteorological data (temperature, relative humidity and rainfall) were collected from Indian Meteorological Department official website on a daily basis and weekly average was calculated. The correlation co-efficient (r) was worked out to determine the influence of weather parameters on population buildup of aphid.

RESULTS AND DISCUSSION

Seasonal occurrence of mustard aphid in rabi crop of the year 2022 is given in Figure 1.

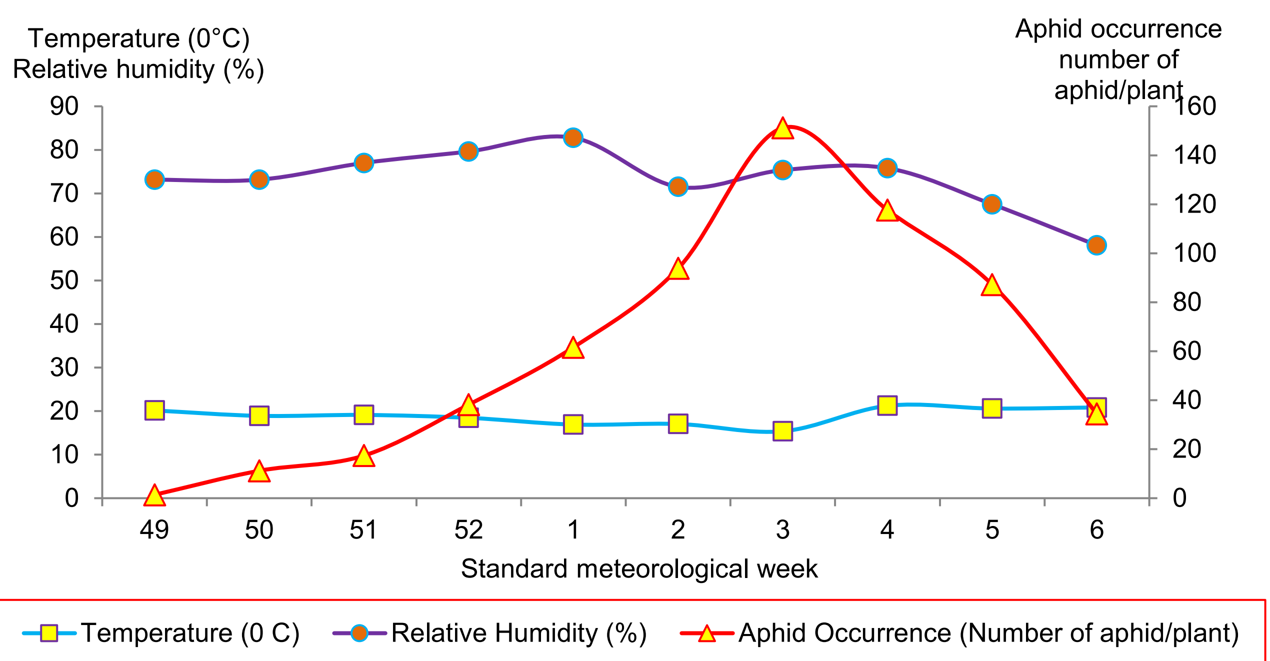


Figure 1. Seasonal occurrence of mustard aphid in rabi crop of the year 2022

Aphid infestation was first noticed at low density (1.4 aphid/plant) on 49th standard meteorological week (SMW) i.e. first week of December, when average temperature was 20.15°C, average relative humidity was 73.14 % and no weekly rainfall. Aphid infestation increased gradually and reached its maximum peak (151.2 aphid/plant) on 3rd SMW (3rd week of January), when average temperature, average relative humidity and weekly total rainfall were 15.37°C, 75.35 % and 0.00 mm, respectively. Higher aphid population density (38.2–151.2 aphid/plant) was recorded from 52nd SMW to 3rd SMW (4th week of December to 3rd week of January), when average temperature ranged from 15.37–18.45°C.

In the second year, aphid infestation (3.4 aphid/plant) was initiated from first week of December (49th SMW), when average temperature 21.66°C, average relative humidity 82.42 % and weekly total rainfall 49.00 mm. The aphid population increased rapidly and reached its highest peak (187.2 aphid/plant) on third week of January (3rd SMW), when average temperature, average relative humidity and weekly total rainfall were 14.88°C, 87.13 % and 35.00 mm, respectively. Higher density of aphid infestation (73.4-187.2 aphid/plant) was recorded throughout January (1st SMW to 5th SMW), when average temperature ranged from 14.88-17.97°C. Seasonal occurrence of mustard aphid in rabi crop of the year 2023 is given in Figure 2.

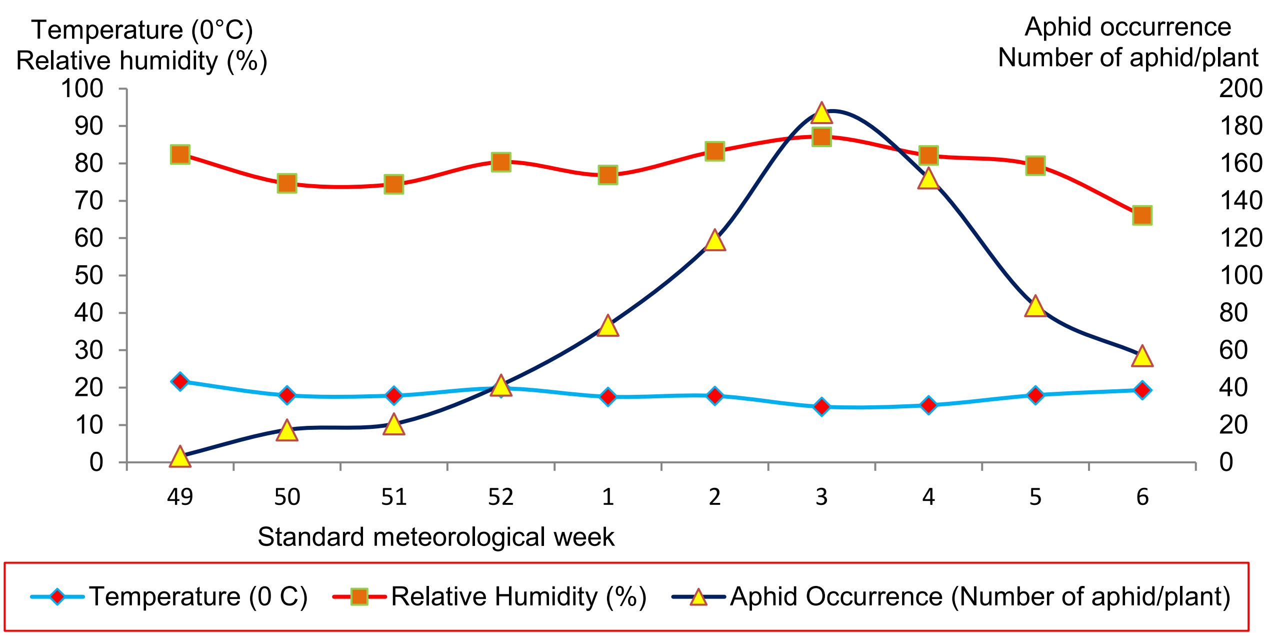


Figure 2. Seasonal occurrence of mustard aphid in rabi crop of the year 2023

Pooled data from both the years showed that mustard aphid was active throughout the crop growing season. Aphid infestation was initiated (2.4 aphid/plant) on 49th SMW i.e. first week of December, when average temperature was 20.90°C, average relative humidity was 77.78 % and weekly total rainfall was 24.50 mm. Aphid population increased gradually and reached its highest peak (169.2 aphid/plant) on 3rd SMW i.e. 3rd week of January, when average temperature, average relative humidity and weekly total rainfall were 15.12°C, 81.24 %

and 17.50 mm, respectively. Higher density of aphid infestation (67.5-169.2 aphid/plant) was found from 1st SMW to 4th SMW i.e. first week of January to fourth week of January, when average temperature ranged from 15.12 – 18.26°C.

Correlation co-efficient between mustard aphid incidence and environmental parameters is given in Table 1. Mustard aphid incidence had a negative correlation with maximum temperature (r = - 0.738), minimum temperature (r = - 0.549) and average temperature (r = -0.737). Present finding was in line with Gour and Pareek (2003) who observed a negative correlation between aphid population and maximum temperature (24.83-28.49°C) and minimum temperature (11.31-13.3°C). It was also in accordance with the finding of Sreedhar *et al.* (2021) who reported that aphid population was negatively correlated with both maximum and minimum temperature, in the year of 2017-2018. On the other hand, it showed a positive correlation with maximum relative humidity (r = 0.496), minimum relative humidity (r = 0.218), average relative humidity (r = 0.341) and weekly total rainfall (r = 0.033).

Table 1. Correlation co-efficient (r) between mustard aphid incidence and environmental parameters

Environmental parameters	Correlation co-efficient (r)
Maximum temperature (°C)	-0.738**
Minimum temperature (°C)	-0.549
Average temperature (°C)	-0.737**
Maximum relative humidity (%)	0.496
Minimum relative humidity (%)	0.218
Average relative humidity (%)	0.341
Weekly total rainfall (mm)	0.033

*Significant at 5% level of significance; **Significant at 1% level of significance

CONCLUSION

Mustard aphid, *Lipaphis erysimi* was identified as a serious insect pest of mustard cultivation at Khosnatore village, Kendua Gram Panchayet, District Birbhum, West Bengal. It was remained active throughout the crop growing period. Meteorological parameters like temperature, relative humidity, and weekly total rainfall influenced the population buildup of mustard aphid.

ACKNOWLEDGEMENT

Experiment was carried out with the help of Department of Plant Protection, Suri Vidyasagar College, Suri, Birbhum and providing laboratory for the study. I thank the Department as well as I thank Dr. Tapan Kumar Parichha, Principal of Suri Vidyasagar College.

REFERENCES

Arora R. 1999. Major insect pests of rapeseed-mustard and their management. In: IPM System in Agriculture Oilseeds. Vol. V. Upadhyay RK, Mukharji KG, Rajak RL. (eds.). Aditya Books Pvt. Ltd., New Delhi. Pp. 35-75.

Bakhetia DRC.1984. Chemical control of *Lipaphis erysimi* Kalt. on rapeseed and mustard crop in Punjab. Journal of Research Punjab Agriculture University 21: 63-75.

Bakhetia DRC.1991. The insects. In: Oilseed Brassicas in Indian Agriculture. (Eds.). Chopra VL, Prakash S. Har-Anand Publications.

Begum S. 1995. Insect pests of oilseed crops in Bangladesh. Bangladesh Journal of Zoology 23(2): 153-158.

Gour IS, Pareek BL. 2003. Seasonal Incidence of major insect-pests of mustard crop and their correlation with abiotic factors under semiarid region of Rajasthan. Journal of Insect Science 16: 37-40.

Rai BK.1976. Pests of oilseed crops in India and their control. Indian Council of Agricultural research, New Delhi.

Rohilla HR, Singh H, Kelra VK, Kharub SS.1987. Losses caused by mustard aphid, *L. erysimi* (Kalt.) in different *Brassica* genotype. Proc. 7th International Rapeseed Congress 5: 1077-1083.

Singh SV, Malik YP.1998. Population dynamics and economic threshold of *Lipaphis erysimi* (Kalt.) on mustard. Indian Journal of Entomology 60: 43-49.

Sinha RP, Yazdani SS, Verma GD. 1989. Population dynamics of mustard aphid, *Lipaphis erysimi* (Kalt.) in relation to ecological parameters. Indian Journal of Entomology 51: 334-339.

Sreedhar BK, Hath TK, Sahoo SK, Okram S. 2021. Seasonal incidence of mustard aphid *Lipaphis erysimi* (Kalt.) and its correlation with weather factors under Terai Zone of West Bengal. International Journal of Current Microbiology and Applied Sciences 10(01): 2555-2561.

J. Agric. Technol., 12(2): 112-120 (2025)
Print: ISSN: 2348-4721; Online: ISSN: 2349-610X

Spam Filtering: A Hidden Tool for Sustainable Agriculture

Akhil Kumar Das[1], Arijit Bhattacharya[1], Himadri Shekhar Konar[2*], Debasmita Saha[3], Arindam Mandal[2]

[1]*Department of Computer Science, Gour Mahavidyalaya, Malda, West Bengal-732142, India*
[2]*Faculty of Technology, Uttar Banga Krishi Viswavidyalaya, Cooch Behar, West Bengal-736165, India*
[3]*Department of Computer Science, University of Gour Banga, Malda, West Bengal-732142, India,*

[*]***E-mail**: hskonar@gmail.com*

Received: 12-11-2025; **Revised:** 14-12-2025; **Accepted:** 31-12-2025

Citation: Das AK, Bhattacharya A, Konar HS, Saha D, Mandal A. 2025. Spam Filtering: A Hidden Tool for Sustainable Agriculture. J Agric Technol. 12(2): 112-120.

Online communication and data sharing via electronic mail is one of the most private ways to do business especially in agriculture-sector. However, with its growing popularity, the volume of unsolicited and spam messages has also risen significantly. A variety of approaches have been developed to detect and remove these unwanted messages automatically. It is possible to filter spam from email communications using a variety of methods, including knowledge-based approaches, clustering algorithms, machine learning techniques, heuristic processes, and others. This study covers the many existing email spam filtering systems and mainly focuses on Machine Learning (ML) techniques such as Naive Bayes (NB), K-Nearest Neighbors (KNN), Random Forest (RF), Extra Tree Classifier (ET), and rule-based algorithms. In addition to classifying, evaluating, and comparing various email spam filtering systems, the research also summarizes their performance based on accuracy rates. The suggested model has a higher accuracy rate of 97% compared to previous classifiers.

Keywords: Email spam filtering, Rule-based method, Filtering system, Machine learning

INTRODUCTION

Spam filtering plays an important role in modern agriculture as the sector becomes increasingly digital. Farmers rely on emails, SMS (Gupta *et al*., 2021), and agricultural apps for critical information about weather, markets, and government schemes. Spam filtering helps protect them from fake offers, scams, and misinformation that could lead to financial losses or poor farming decisions (Ahmed *et al*., 2022). In smart agriculture systems, it also safeguards IoT devices (Makkar *et al*., 2020) and data networks from malware and cyber-attacks. For agribusinesses and researchers, spam filtering ensures smooth communication, data accuracy, and operational efficiency. Overall, it enhances security, reliability, and trust in agricultural information systems.

Spammers employ various communication channels to distribute their unwanted messages in bulk (Crawford *et al*., 2015). Some are marketing messages promoting unsolicited goods, while others are more malicious, aiming to spread malware, steal personal information, or intimidate recipients into making payments under false pretences. Email spam filters successfully block a significant number of these messages (Devi and Ravi, 2015) while, phone carriers frequently categorize calls from unfamiliar numbers as “spam risk”. However, spam messages can still bypass these defenses via email, text, phone, or social media. Being able to identify and avoid these threats is essential to safeguarding your information and security (Goyal *et al*., 2016).

Phishing emails are a form of spam that cybercriminals send to a large number of individuals with the hope of "hooking" a portion of the recipients (Akinyelu and Adewumi, 2014). Phishing emails are sent to victims with the intention of tricking them into divulging sensitive information such as website logins or credit card details. The spam message in a scam involving technical help suggests that you are experiencing a technical issue and that you should contact technical support by either calling the phone number provided in the message or clicking on a link contained within the message. Similar to email spoofing, these sorts of spam frequently claim to be from a prominent technical business such as Microsoft or a cyber-security organization such as Malware bytes.

Spammers often exploit trending news topics to capture your attention. For instance, in 2020, during the global Covid-19 pandemic and the surge in remote work opportunities, some scammers sent spam messages promising lucrative work-from-home jobs with payment in Bitcoin. That same year, another common spam tactic involved offers of financial relief for small businesses, which ultimately sought to steal bank account details. While news headlines can be compelling, it’s essential to remain cautious, as they may be used as bait in potential spam schemes.

It not only inconveniences individuals and consumes their time by necessitating the sorting of extraneous communications, but it also presents significant risks. It has the potential to compromise users' computers through malicious software, resulting in system damage and the theft of personal information. Moreover, spam utilizes significant network resources, thereby exacerbating its negative effects.

In the field of computer science and Artificial Intelligence (AI), Machine Learning (ML) is a subfield that focuses on using data and algorithms to simulate human learning processes, with the goal of continuously increasing accuracy over time. In the context of spam filtering, ML techniques utilize statistical methods to automatically classify emails and separate spam from legitimate messages. Popular ML techniques for spam filtering include NB, SVM, DT, NN, and others. The sophistication of these algorithms makes machine learning one of the most effective approaches for spam filtering, outperforming traditional techniques.

The success of Gmail's spam filter can be largely attributed to its timely adoption and effective implementation of machine learning techniques. These techniques enable Gmail to filter not only spam but also other abuses like Denial-of-Service (DoS) attacks. One of the key reasons for the effectiveness of machine learning-based spam filters is their ability to retrain and adapt in real time, reducing the need for manual intervention while, delivering superior filtering accuracy.

Review of Literature

Agricultural business offers various items from ecological farming (Vaněk *et al*., 2010). Spam is a vital form of internet threat. Agricultural businesses are similar to any other economical subjects. Numerous implementations have been proposed by researchers for email spam filtering using ML and deep learning techniques (Salman *et al*., 2024). Some of the notable works in the literature are outlined below. To identify incoming messages as spam, a wide range of approaches have been employed, including whitelist/blacklist filtering, Bayesian analysis, keyword matching, postage-based systems, mail header analysis, and behavioural analysis. Each technique offers unique advantages and is tailored to address specific aspects of spam detection, contributing to the development of more robust and effective filtering systems (Govil *et al*., 2020). Although users are getting spam messages regularly. Anitha *et al*. (2012) introduced an enhanced spam detection model based on the XGBoost algorithm, designed to improve accuracy in identifying spam. The proposed model evaluated performance using metrics such as accuracy and compared the results against classifiers including SVM, CNSA-FFO, Rotation Forest, MLP, J48, and NBs. The model achieved an accuracy of 95%, outperforming previous classifiers. Rajamohana *et al*. (2017) focused on a hybrid feature selection approach for detecting spam emails. Their method incorporates two search techniques: Cuckoo Search and Harmony Search. Additionally, they employed the KNN algorithm, a ML method, for classification. The proposed hybrid feature selection approach improves classification accuracy by optimizing the feature subset. Specifically, the Cuckoo Search combined with Harmony Search selected a total of 1,355 features, achieving an average classifier accuracy of 82.34% using the KNN classifier. Sharaff and Gupta (2019) proposed a nature-inspired metaheuristic technique for email classification, focusing on reducing the false-positive rate of incorrectly categorizing spam messages as legitimate (ham). Their approach utilized metaheuristic-based feature selection methods combined with the Extra-Tree (ET) Classifier to classify emails into spam and ham categories. While the ET Classifier proved to be the most effective classification model, they also compared its performance with DT and RF classifiers. An accuracy of 95.5%, a specificity of 93.7%, and an F1-score of 96.3% were some of the results that the suggested technique attained. The results of this study are a major improvement above those obtained from earlier research that utilized DTs for the categorization of emails. Additional research has been conducted to investigate the comparative comparison of ET classifiers with other types of classifiers, such as DTs and RFs. Saidani *et al*. (2020) proposed a novel approach for spam detection that leverages semantic information. This approach consists of two main steps: first, categorizing email content by subject domains, and second, constructing domain-specific semantic features to perform spam classification. These semantic features offer a precise characterization of domain-specific spam, enabling more targeted and effective detection. The study demonstrated that domain categorization significantly enhances the performance of spam filters and improves prediction accuracy. Additionally, the authors emphasized the importance of creating an efficient procedure for online updates of semantic feature sets and classifiers across all domains, particularly in scenarios where user feedback is continuously integrated into the system. After implementing these processes, the proposed approach achieved a final accuracy of 95.92%, outperforming previous methods in spam detection.

MATERIALS AND METHODS

Email spam (Kumar and Sonowal, 2020) classification is a significant challenge in today's computerized environment. Various specialized spam detection methods have been developed to address this issue. These techniques allow for the quick identification of spam and legitimate (ham) emails in a mailbox. In this paper, we explore both supervised and unsupervised learning approaches. For supervised learning, we employ methods such as Naïve Bayes (Metsis *et al*., 2006), SVM, and Random Forest (RF) (Hossain *et al*., 2021). In the case of unsupervised learning, we utilize KNN, Decision Trees (DT), AdaBoost, CatBoost, and XGBoost (Mustapha *et al*., 2020). The efficiency and predictive accuracy of these techniques have made them a popular choice among machine learning researchers, particularly in the context of vital statistics. These methods have been applied to solve complex issues within relevant systems, enhancing overall performance, accuracy, precision, and generalizability. While there has been significant research on the performance of spam detection frameworks, a detailed examination of their effectiveness is still needed to fully meet real-world requirements (GuangJun *et al*., 2020).

Data Description and Pre-processing

In this research work, the "Spam Ham" dataset from Kaggle was used, which contains a total of 5,572 records with two columns: "Category" (target) and "Message" (text). The dataset has no missing (null) values. After checking for duplicates, we identified 454 duplicate entries. After removing these duplicates and any null values, the final dataset consists of 5,157 records with two columns. In the "Category" column, emails are classified as either spam (1) or ham (0). Of the total dataset, 4,516 entries are labelled as ham, and 641 are labelled as spam, making up 87.57% ham and 12.43% spam. The dataset is divided into two parts: 80% for training and 20% for testing. The experiment was conducted using both the training and testing sets.

Performance Metrics

The Figure 1 highlights the steps that are followed from start to end in order to implement a model that can be used for detection of Spam.

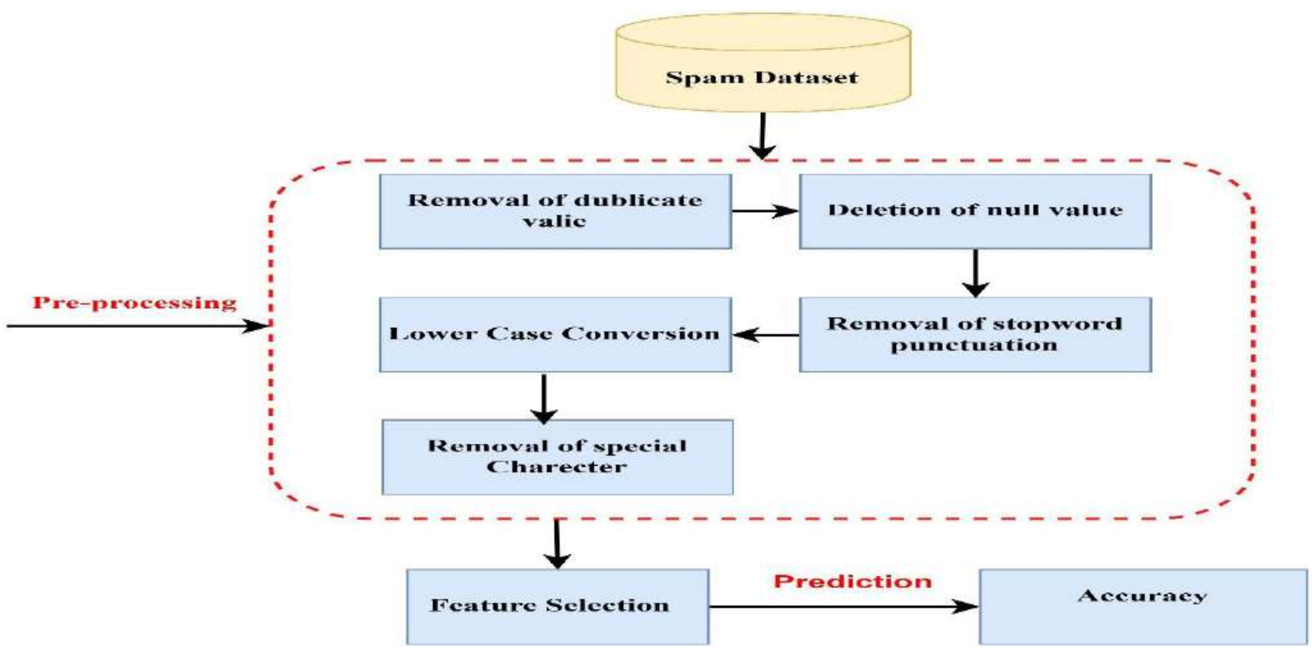


Figure 1. Email-Spam detection using various machine learning algorithms

Classification typically begins with eliminating redundancy in the attributes. To achieve this, techniques such as feature selection and feature extraction are employed. In this study, feature selection was chosen over feature extraction to achieve greater efficiency. In our experiment, we tested eight classifiers: SVM, KNN, NB, DT, RF, AdaBoost, ET classifier, and XGBoost, to assess their effectiveness. Several performance metrics were considered in evaluating the classifiers, including Precision, Recall, and Accuracy, which are calculated as follows:

$$\text{Precision} = \frac{\text{TP}}{\text{TP+FP}}$$

$$\text{Recall} = \frac{\text{TP}}{\text{TP+FN}}$$

$$\text{Accuracy} = \frac{\text{TP+TN}}{\text{TP+TN+FP+FN}}$$

In this context, True Positive (TP), True Negative (TN), False Positive (FP), and False Negative (FN) represent the true positives, true negatives, false positives, and false negatives that result from the classification process.

RESULTS AND DISCUSSION

The results of spam filtering utilizing our approach are presented in table 1.

Table 1. Result of various ML algorithms

Algorithm	Accuracy (%)	Precision (%)	Recall (%)
ETC	97.97	97.50	86.67
RF	97.77	100.00	82.96
SVC	97.67	97.44	84.44
NB	97.67	100.00	82.22
XGBoost	97.38	95.76	83.70
AdaBoost	97.09	94.12	82.96
LR	96.41	93.75	77.78
GBDT	95.25	93.88	68.15
DT	93.51	84.00	62.22
KNN	90.79	100.00	29.63
CatBoost	97.82	99.76	84.65

The comparative analysis of different ML algorithms indicates that the Extra Trees Classifier (ETC) attains the highest accuracy at 97.97%, accompanied by a precision of 97.50% and a recall of 86.67%. Random Forest (RF) achieves an accuracy of 97.77%, a precision of 100%, and a recall of 82.96%. The Support Vector Classifier (SVC) achieves an accuracy of 97.67%, a precision of 97.44%, and a recall of 84.44%. Naïve Bayes (NB) achieves an accuracy of 97.67%, with precision at 100% and recall at 82.22%. CatBoost demonstrates high performance, achieving an accuracy of 97.82%, precision of 99.76%, and recall of 84.65%. XGBoost demonstrates an accuracy of 97.38%, precision of 95.76%, and recall of 83.70%. In comparison, AdaBoost shows an accuracy of 97.09%, precision of 94.12%, and recall of 82.96%. Logistic Regression (LR) demonstrates an accuracy of 96.41%, precision of 93.75%, and recall of 77.78%. The Gradient Boosting Decision Tree (GBDT) achieves an accuracy of 95.25%, a precision of 93.88%, and a recall of 68.15%. The Decision Tree (DT) exhibits an accuracy of 93.51%, precision of 84%, and recall of 62.22%, indicating relatively lower performance. The K-Nearest Neighbors (KNN) algorithm exhibits a recall of 29.63% while, achieving 100% precision and 90.79% accuracy. Figure 2 provides a clear visualization of the model performances, enabling better interpretation and understanding.

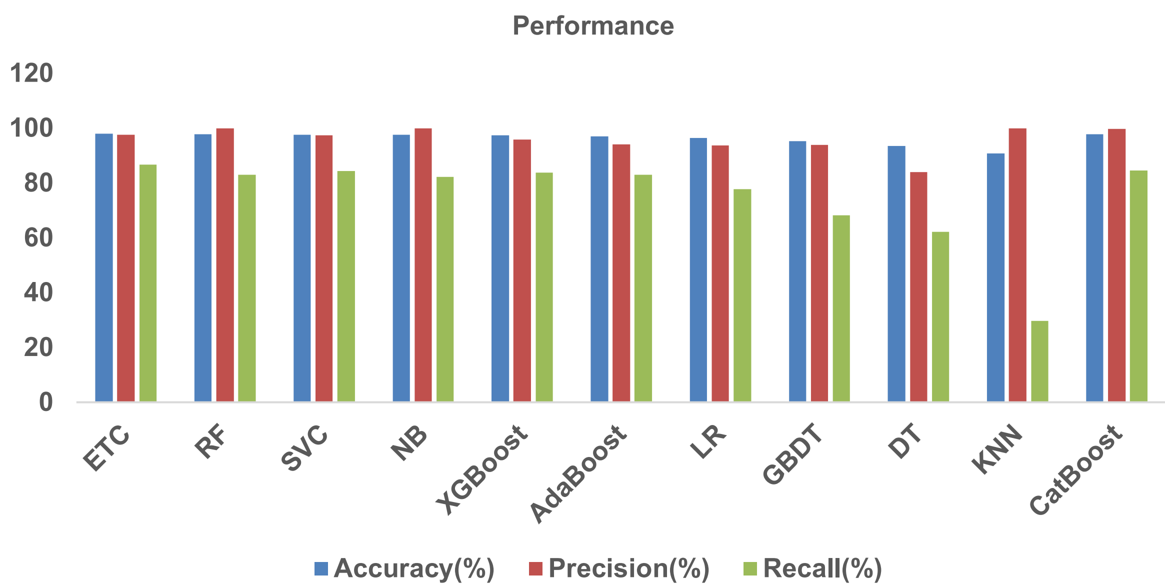


Figure 2. Performance comparison of various ML algorithms for spam detection

The table 2 compares the accuracy of existing models and the proposed model across different classifiers, as reported by various researchers. Anitha *et al*. (2012) compared three classifiers: SVM, Naïve Bayes (NB), and XGBoost, with the proposed model outperforming the existing models in all cases. The proposed SVM achieved an accuracy of 97.00%, surpassing the existing 94.06%, while the proposed NB model reached 97.67%, slightly better than the existing 97.47%. The proposed XGBoost model also improved to 97.38%, compared to the existing 95.00%. Rajamohana *et al*. (2017) evaluated the KNN classifier, where the proposed model achieved an accuracy of 90.79%, surpassing the existing model's accuracy of 82.34%. Sharaff and Gupta (2019) tested RF, ETC, and DT classifiers, with the proposed RF model outperforming the existing one at 97.77% (compared to 95.40%), the proposed ETC model improving to 96.96% from 95.50%, and the proposed DT model improving from 92.10% to 93.50%. Lastly, Saidani *et al*. (2020) used AdaBoost, where the proposed model achieved 97.09%, an increase from the existing accuracy of 95.92%.

Table 2. Comparison with the existing works

Classifiers	Accuracy of the existing models	Accuracy of the proposed model	References
SVM	94.06%	97.00%	Anitha *et al*., 2012
NB	97.47%	97.67%	Anitha *et al*., 2012
XGBoost	95.00%	97.38%	Anitha *et al*., 2012
KNN	82.34%	90.79%	Rajamohana *et al*., 2017
RF	95.40%	97.77%	Sharaff and Gupta**,** 2019
ETC	95.50%	96.96%	Sharaff and Gupta**,** 2019
DT	92.10%	93.50%	Sharaff and Gupta**,** 2019
AdaBoost	95.92%	97.09%	Saidani *et al*., 2020

FUTURE WORK AND CONCLUSION

Spam filtering serves as an essential yet under recognized tool in promoting sustainable agriculture in the digital age. By preventing the spread of fraudulent and misleading information, spam filters help protect farmers and agricultural organizations from cyber threats and financial losses. The integration of machine learning-based spam detection systems further strengthens the security and reliability of agricultural communication networks (Zavvar *et al*., 2016; Geetha *et al*., 2025) Ultimately, these measures contribute to a safer digital ecosystem, enabling farmers to access authentic information, make informed decisions, and support the long-term sustainability and resilience of the agricultural sector. In this work, an in-depth investigation of existing spam filtering systems that make use of ML techniques is presented. The purpose of this investigation is to investigate a variety of methodologies and to summarize the accuracy of various suggested approaches across a number of metrics. Even while all of the currently available techniques are efficient for filtering spam in email, there are some that have shown to produce superior results, while others are concentrating on incorporating extra procedures in order to improve accuracy. Despite the fact that they are successful, the spam filtering systems that are now in use nevertheless have substantial limitations, which continue to be a key worry for researchers. As a consequence of this, efforts are currently being made to build spam filtering procedures of the next generation that are capable of managing bigger amounts of multimedia data and increasing the identification of spam emails. Server-side filtering systems, although useful, remain relatively underdeveloped. However, their performance can be enhanced by applying hybrid filtration systems—specifically, complex hierarchical and multi-agent filtration approaches that involve user participation in identifying filtering errors and appropriately setting filters at various levels (user, organization, mail provider). A combination of two widely used methodologies, namely the utilization of a personal email categorization model in conjunction with a server-side solution, could prove to be an effective and promising answer to this problem. A potential avenue for future advancements in spam filtering is the creation of server-side customized email filtering systems. These systems utilize algorithms for learning-based categorization and data mining techniques.

REFERENCES

Ahmed N, Amin R, Aldabbas H, Koundal D, Alouffi B, Shah T. 2022. Machine learning techniques for spam detection in email and IoT platforms: analysis and research challenges. Security and Communication Networks 1: 1862888. https://doi.org/10.1155/2022/1862888.

Akinyelu AA, Adewumi AO. 2014. Classification of phishing email using random forest machine learning technique. Journal of Applied Mathematics 1: 425731. https://doi.org/10.1155/2014/425731.

Anitha PU, Rao CG, Babu DS. 2012. Email spam filtering using machine learning based XGBoost classifier method. Turkish Journal of Computer and Mathematics Education 12: 2182-2190.

Crawford M, Khoshgoftaar TM, Prusa JD, Richter AN, Al Najada H. 2015. Survey of review spam detection using machine learning techniques. Journal of Big Data 2: 23. https://doi.org/10.1186/s40537-015-0029-9.

Devi KS, Ravi R. 2015. A new feature selection algorithm for efficient spam filtering using adaboost and hashing techniques. Indian Journal of Science and Technology 8: 1-8. https://doi.org/10.17485/ijst/2015/v8i13/65753.

Geetha R, Veena T, Kamalaban E, Doss S, Nair P, Ibrikci T. 2025. IoT-Enabled Steganography-Based Smart Agriculture Using Machine Learning Models in Industry 5.0. In Enhancing Steganography Through Deep Learning Approaches. IGI Global. 311-330. https://doi.org/10.4018/979-8-3693-2223-9.ch014.

Govil N, Agarwal K, Bansal A, Varshney A. 2020. A machine learning based spam detection mechanism. In 2020 Fourth International Conference on Computing Methodologies and Communication (ICCMC). 954-957. https://doi.org/10.1109/ICCMC48092.2020.ICCMC-000177.

Goyal S, Chauhan RK, Parveen S. 2016. Spam detection using KNN and decision tree mechanism in social network. In 2016 Fourth International Conference on Parallel, Distributed and Grid Computing (PDGC). 522-526. https://doi.org/10.1109/PDGC.2016.7913250.

GuangJun L, Nazir S, Khan HU, Haq AU. 2020. Spam detection approach for secure mobile message communication using machine learning algorithms. Security and Communication Networks 1: 8873639. https://doi.org/10.1155/2020/8873639.

Gupta SD, Saha S, Das SK. 2021. SMS spam detection using machine learning. Journal of Physics: Conference Series 1797: 012017. https://doi.org/10.1088/1742-6596/1797/1/012017.

Hossain F, Uddin MN, Halder RK. 2021. Analysis of optimized machine learning and deep learning techniques for spam detection. In: 2021 IEEE International IOT, Electronics and Mechatronics Conference (IEMTRONICS). Pp. 1-7. https://doi.org/10.1109/IEMTRONICS52119.2021.9422508.

Kumar N, Sonowal S. 2020. Email spam detection using machine learning algorithms. In: 2020 Second International Conference on Inventive Research in Computing Applications (ICIRCA). Pp. 108-113. https://doi.org/10.1109/ICIRCA48905.2020.9183098.

Makkar A, Garg S, Kumar N, Hossain MS, Ghoneim A, Alrashoud M. 2020. An efficient spam detection technique for IoT devices using machine learning. IEEE Transactions on Industrial Informatics 17: 903-912. https://doi.org/10.1109/TII.2020.2968927.

Metsis V, Androutsopoulos I, Paliouras G. 2006. Spam filtering with naive bayes-which naive bayes? InCEAS 17: 28-69. http://www.aueb.gr/users/ion/publications.html.

Mustapha IB, Hasan S, Olatunji SO, Shamsuddin SM, Kazeem A. 2020. Effective email spam detection system using extreme gradient boosting. arXiv preprint arXiv:2012. 14430. https://doi.org/10.48550/arXiv.2012.14430.

Rajamohana SP, Umamaheswari K, Keerthana SV. 2017. An effective hybrid cuckoo search with harmony search for review spam detection. Third International Conference on Advances in Electrical, Electronics, Information, Communication and Bio-Informatics (AEEICB). 524-527. https://doi.org/10.1109/AEEICB.2017.7972369.

Saidani N, Adi K, Allili MS. 2020. A semantic-based classification approach for an enhanced spam detection. Computers & Security 94: 101716. https://doi.org/10.1016/j.cose.2020.101716.

Salman M, Ikram M, Kaafar MA. 2024. Investigating evasive techniques in SMS spam filtering: A comparative analysis of machine learning models 12. IEEE Access. 24306-24. https://doi.org/10.1109/ACCESS.2024.3364671.

Sharaff A, Gupta H. 2019. Extra-tree classifier with metaheuristics approach for email classification. In: Advances in computer communication and computational sciences. Singapore, Springer. Pp. 189-197. https://doi.org/10.1007/978-981-13-6861-5_17.

Vaněk J, Brožová I, Jarolímek J, Šimek P, Vogeltanzová T, Červenková E. 2010. Map Resources – ECO Farms in the Czech Republic. Agris on-line Papers in Economics and Informatics 2: 115-121. https://doi.org/10.22004/ag.econ.99229.

Zavvar M, Rezaei M, Garavand S. 2016. Email spam detection using combination of particle swarm optimization and artificial neural network and support vector machine. International Journal of Modern Education and Computer Science 8: 68. https://doi.org/10.5815/ijmecs.2016.07.08.

J. Agric. Technol., 12(2): 121-127 (2025)
Print: ISSN: 2348-4721; Online: ISSN: 2349-610X

An Examination of the Effects of Jute Bags Coated with Essential Oil on Maintaining Quality during Storage and Preventing Lentil Storage Pests

Sanchita Biswas Murmu, Naveen Jose, Sourav Misra, Tilak Mondal, Sujai Das, Sekhar Das, Sanjoy Debnath and Namrata Lashkar

ICAR-National Institute of Natural Fibre Engineering & Technology, 12, Regent Park, Kolkata, West Bengal, 700 040, India

***E-mail**: *sanchita.biswas@icar.gov.in*

Received: 11-11-2025; **Revised:** 25-12-2025; **Accepted:** 01-01-2026

Citation: Murmu SB, Jose N, Misra S, Mondal T, Das S, Das S, Debnath S, Lashkar N. 2025. An Examination of the Effects of Jute Bags Coated with Essential Oil on Maintaining Quality during Storage and Preventing Lentil Storage Pests. J Agric Technol. 12(2): 121-127.

The effect of 2%, 4%, 6%, 8% and 10% of neem oil was studied on the storage pest (*Callosobruchus chinensis*) of lentil. About 100 g of lentil (*Lens culinaris*) grains were stored in each of the treated bags with and without artificial infestation at 25 ° C and 60 – 70 % RH and samples were collected at the interval of one month. The broken grain %, weevilled grain %, shriveled grain %, damaged grain %, foreign matter %, admixture %, 1000 grain weight and moisture content were evaluated and the difference between the infested and non-infested grains and effect of different concentration of the essential oils were analyzed. Significant difference was recorded between infested and non-infested grains. Higher concentration above 6 % neem oil showed significance difference in lentil quality parameter compared to uncoated bags. Below that much difference was not registered in the observations. Hence, we may conclude that storage of lentil in 10 % neem oil coated jute bag may be a promising technology to avoid damage of pulses by pulse beetle during storage period.

Keywords: Lentil, Storage pest, Jute bags, Neem oil

INTRODUCTION

Effective seed storage after harvesting is crucial for maintaining the viability and germination potential of crop germplasm. To ensure quality and viability, proper seed storage must consider several factors. Three primary factors that influence seed storage are the type of storage, temperature, and moisture levels, which can lead to issues with pests, rodents, and fungi, depending on the seed type (Dhumal and Waghmare, 2015). Traditional seed storage techniques employ various innovative structures, such as ropes, bamboo baskets, underground pits, and different types of bags, to safeguard and preserve grains. Additionally, farmers often implement natural pest control strategies, such as coating seeds with oil or ash and incorporating leaves from plants like neem, turmeric, lemon, bakayan, and walnut to deter pests and protect their crops. In modern storage facilities, chemical fumigants and pesticides, including Methyl bromide, Phosphine, Phostoxins, and Actellic super, are commonly used to combat microbial growth and maintain the quality of stored products (Rajendran and Sriranjini, 2008). Despite these efforts, significant seed storage losses persist globally, resulting in the waste of approximately 1.3 billion food grains each year, enough to meet the food needs of a large portion of the world's population. These substantial losses due to poor seed storage threaten farmers' livelihoods, compel them to seek alternative food sources, and have extensive economic repercussions for entire nations (Neupane, 1995). Nevertheless, the challenge of reducing post-harvest losses from inadequate storage has not been prioritized as it should be. Seed storage losses adversely affect farmers, strain food resources, and influence economic stability, yet prevention measures remain insufficient. Recent research highlights the effectiveness of using neem oil emulsion-coated jute fabric bags, as optimal storage solutions. The issue of post-harvest losses in cereals, pulses, and oilseeds due to pest infestations is critical, leading to concerns about the availability of safe and healthy food in developing countries. Insect pests damage grains by consuming them and contaminating them with their excrement, webs, and body parts, rendering them unsafe for consumption (Lee *et al*., 2004). Post-harvest losses in chickpeas exceed 1.67%, while losses in green grams are around 1.27 %. In India, over 99% of government-stored grain is kept in state-owned bags, which have a high infestation rate of 60% to 90% by insect pests. Neem oil contains significant triterpenoids, such as nimbin and azadirachtin, which are bioactive compounds. Nimbin offers three beneficial properties: anti-inflammatory, antimitotic, and antimicrobial, making it a valuable tool against various pests (Ali and Rahman, 2006). Conversely, azadirachtin functions as an antifeedant and growth disruptor, hindering the growth of insect pests. In contrast, azadirachtin takes a different approach, exerting its influence as an antifeedant and growth disruptor to prevent the proliferation of insect pests. Remarkably, neem oil has been shown to effectively control an impressive 200 species of insects, all while sparing beneficial insects from harm (Subramanyam and Hagsturm, 1995). Nimbin, a key constituent neem oil, exhibits a range of beneficial properties including anti-inflammatory, antimitotic and antimicrobial activities. In, contrast azadirachtin, another prominent compound, exerts its effects as an anti-feedant and growth disruption, effectively controlling or inhibiting the development of insect pests. Notably, neem oil has been shown to control over 200 species of insects without adversely affecting beneficial insects (Mahfuz and Khalequzzaman, 2007). It is an ecofriendly, recyclable, non-poisonous, environment-friendly bio pesticide. The environmental and health concerns correlated with synthetic insecticides in natural pest control alternatives. Globally, food legumes serve as a staple nutrient-dense food, widely consumed across the world. In this work we aim to study the effect on pulse beetle when infested lentils are stored in neem oil coated Jute bags.

MATERIALS AND METHODS

Coating of the Jute Fabrics

Jute fabric was scoured (Figure 1a) through jigger machine (ABE make), utilizing sodium carbonate 2 g/l and 50 l water, 1 g/l ultravan JU/ nonionic detergent for 1 hr at a temperature of 60-70°C. After scouring the scoured jute fabrics are applied for drying through drum dryer (ABE make; Figure 1b) which includes 70°C, 90°C, and 100°C temperature for 1, 2, 3 rollers, respectively. Speed of the machine was 50.4 cm/min, dwell time of 6–20 min. Then the dried scoured fabric is cut into 6 pieces with 10 cm width and 15 cm length for 15 treatments. The scoured jute fabrics are marked by taking 6 replicas of per emulsion concentration of neem oil (Figure 1c). The initial weight of each cut pieces is recorded. A glass tray with dimension of 50 cm length and 30 cm width was taken in which the cut jut fabrics were dipped (Figure 1d), for a duration of 5 min in each side on 500 ml neem oil emulsion and then thoroughly rinsed and dried in shade (Figure 1e-f).

Figure 1a. Scouring

Figure 1b. Drum dryer

Fig 1c. Prepared emulsion of essential oil

Fig 1d. Coating by dipping method

Fig 1e. Storage bags made from coated jute fabrics

Fig 1f. Drying of Coated Jute fabric in shade

Figure 1(a-d). Coating of jute fabrics and preparation of jute bags for lentil storage

The final weights of the coated fabrics are taken and after this the comparison was recorded between initial and final weight to estimate the coating pick up of each fabric. Then, stitching of the coated fabric samples was done to, make small size bag of 15 cm length and 10 cm width.

Storage Study of Lentil

About 6 bags of neem oil emulsion coating were filled with 100g fresh non-infested lentil (Figure 2a). In 4 bags 10g heavily infested lentil was added and two bags are left as control (i.e., without artificial inoculation of pest). The grain filled bags (Figure 2b) were stored in BOD incubator at 25°C temperature, 70% RH, replicating the suitable weather condition. At the interval of one month lentil samples were withdrawn and analysis was done for damaged, foreign matter, weevilled, shriveled, 1000 g grain weight, moisture content for up to 3 months.

Figure 2a. Fresh lentil grains **Figure 2b. Lentil grains filled in neem oil coated bag**
Figure 1a-b. Storage of lentil grains inside the coated jute fabric bags

Fresh lentil and infested lentils were analyzed for different parameters. Analysis of various parameters of lentil grain samples such as foreign material %, weevil %, damaged %, broken %, was done in seed grain scanner. About 25 g samples were fed in the scanner and the foreign material %, weevil %, damaged %, broken % were recorded.

Figure 3a. Grain samples **Figure 3b. Setting of the sample ID**

Figure 3c. ID setting for scan

Figure 3d. Spreading the grains on analyser

Figure 3e. Analysis in grain scanner

For each sample 100 g, lentil grain samples are loaded on the seed counter hopper (Figure 4a) and by setting the speed limit of 15–20 RPM. The weights of respective samples 1000 grains (test weight) are measured by beam balance (Figure 4b).

Figure 4a. Seed counter

Figure 4b. Measurement of 1000 grain weight

.

RESULTS AND DISCUSSION

Results of lentil samples of neem oil emulsion coated bags are shown in figure 5 and table 1. Test weight (of 1000 grains) decreases with time for neem oil treated bags with 50-55 % weight of lentil is protected by the coating. Maximum weight of 1000 grains ranged between 43-45 g after three months storage. After three-month storage treatment % has significant effect on 1000 grain weight and 1000 grain weight increases with % neem oil. After one month of storage of lentil in neem oil coated bag the foreign matter % in the infested grains was ranging from 6-11% while for the non-infested grains it ranged between 0-4 %. The highest damaged grain was observed in the 4% neem oil coated bag with infestation, without infestation the 4 % NO coated bad registered 2 % broken showing the effect of coating treatments in lowering damage.

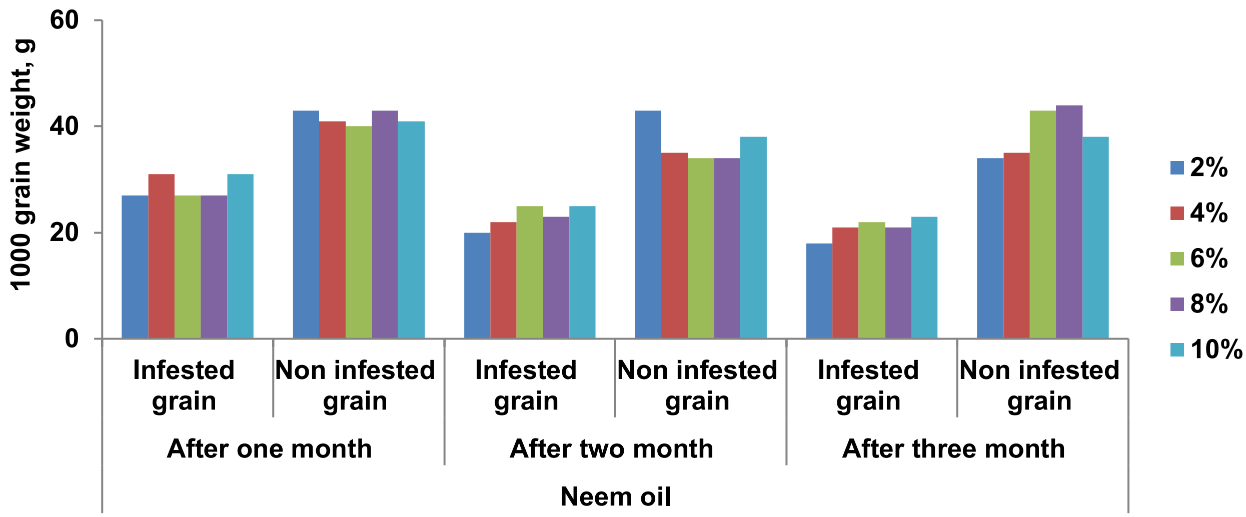


Figure 5. The effect of neem oil coated on lentil 1000 grain weight during three months of storage

Table 1. Analysis of lentil grains stored inside neem oil emulsion coated bags for 1 month

Sample	Foreign matter %	Damaged %	Weevilled %	Shriveled %	Test weight* (g)	Moisture content %
Infested sample after one month storage in treated jute bag						
2% NO	6.87±2.27	7.37±3.21	38.57±8.91	0.72±0.43	10.47±10.72	19.14±12.67
4% NO	11.72±4.43	5.42±1.57	50.65±3.34	0.425±0.18	10.20±8.90	12.30±0.35
6% NO	7.6±7.85	7.5±3.94	20.5±11.15	1.42±0.53	8.40±4.27	13.94±0.91
8% NO	10.72±7.43	5.8±0.90	30.02±7.28	0.92±0.18	10.05±2.88	11.36±4.15
10% NO	9.2±6.40	6.22±3.56	35.85±16.6	1.07±0.61	20.83±15.86	24.19±13.78
Non-Infested Sample after one month storage in treated jute bag						
2% NO	3.9±2.12	6.95±0.21	24±8.90	1.6± 0.98	19.45±8.04	14.6±1.14
4% NO	2.63±3.57	3.55±3.55	1.05±0.07	**0±0**	12.68±12.29	13.88±2.80
6% NO	4.35±0.07	5.9±2.40	22.75±23.68	0.85±0.49	14.79±12.03	11.64±0.10
8% NO	0.25±0.07	4.3±1.41	2.15±0.91	0.1±0.14	36.51±0.76	11.97±0.71
10% NO	4.3±4.66	7.2±7.07	34.5±3.11	1.35±0.35	12.17±1.37	23.52±16.13

NO: Neem oil; *1000 grain weight is considered test weight

CONCLUSION

Insect repellent essential oil-based emulsion is effective in repelling insect pests of stored grains. Five concentrations of neem essential oil, were coated on the jute fabric in the study in various concentrations to maintain quality of pulses against pulse beetle (*Callosobruchus chinensis*). The 10 % neem oil coated showed the best effect in lowering the percentage of foreign matter, broken matter, damaged matter, weevilled, shriveled, 1000 grain weight and moisture content of the stored pulses compare to the uncoated control sample after one month. Hence, we may conclude that storage of pulses in 10 % neem oil coated jute bag may be a promising technology to avoid damage of pulses by pulse beetle during storage period.

REFERENCES

Ali MR, Rahman MM. 2006. Screening of different pulses as host for resistance against Callosobruchus maculatus Fab. Journal of Subtropical Agriculture Research and Development, 4(1), 83-89.

Dhumal TD, Waghmare JS. 2015. A pediculicidal activity of clove oil. International Journal of Pharmaceutical Sciences and Research 6(2): 857.

Lee BH, Annis PC, Tumaalii F, Lee SE. 2004. Fumigant toxicity of *Eucalyptus blakelyi* and *Melaleuca fulgens* essential oils and 1, 8 cineole against different development stages of the rice weevil *Sitophilus oryzae*. Phytoparasitica 32: 498–506.

Mahfuz I, Khalequzzaman M. 2007. Contact and fumigant toxicity of essential oils against *Callosobruchus maculatus*. University Journal of Zoology, (Rajshahi University) 26: 63-66

Neupane FP. 1995. Review of agricultural entomology country profile-Agricultural Entomology in Nepal. CAB International.

Rajendran S, Sriranjini V. 2008. Plant products as fumigants for stored product insect control. Journal of Stored Product Research, 44, 126-135.

Subramanyam BH, Hagsturm DW. 1995. Resistance measurement and management. In: Integrated Management of Insect in Stored Products, Hagstrum DH, Subramanyam BH (Eds.). Macel Decker, New York, USA. Pp. 331-397.

J. Agric. Technol., 12(2): 128-143 (2025)
Print: ISSN: 2348-4721; Online: ISSN: 2349-610X

Acoustic and Vibration-Based IoT Systems for Machine Learning-Assisted Detection of Rice Stem Borers

Mansingh Murmu[1], Sankar Narayan Patra[1], Samir Kumar Ghosh[1], Sanchita Biswas Murmu[2]

[1]*Jadavpur university, Kolkata-700092*
[2*]*ICAR-National Institute of Natural Fibre Engineering and Technology, 12 Regent Park, Kol-40*

[*]***E-mail***: *sanchita.biswas@icar.gov.in*

Received: 26-12-2025; **Revised:** 26-02-2026; **Accepted:** 28-02-2026

Citation: Murmu M, Patra SN, Ghosh SK, Murmu SB. 2025. Acoustic and Vibration-Based IoT Systems for Machine Learning-Assisted Detection of Rice Stem Borers. J Agric Technol. 12(2): 128-143.

Rice stem borers cause severe yield losses due to their concealed larval feeding inside plant stems, making early detection difficult using conventional scouting methods. This study presents an Internet of Things (IoT)– and machine learning (ML)–enabled system for early, non-invasive detection of rice stem borer infestation. The proposed framework integrates acoustic and vibration sensors with low-power IoT hardware, wireless communication, cloud analytics, and ML-based classification. Micro-acoustic and vibrational signatures generated by larval feeding are captured in real time, processed using signal-processing techniques, and classified using ML models to generate early-warning alerts. The system aims to improve detection accuracy, reduce pesticide misuse, and support precision pest management in paddy ecosystems.

Keywords: Rice stem borer, IoT, Acoustic sensing, Vibration sensor, Machine learning, Precision agriculture

INTRODUCTION

Rice (*Oryza sativa* L.) is a staple food for more than half of the global population and plays a central role in food security across Asia, Africa, and parts of Latin America. Despite advancements in crop genetics, agronomy, and irrigation, rice productivity continues to be constrained by biotic stresses, particularly insect pests. Among these, stem borers represent one of the most damaging pest groups, capable of causing yield losses ranging from 10% to over 60% depending on environmental conditions, crop stage, and management practices. Stem borers attack rice plants internally, feeding on vascular tissues within the stem. This concealed feeding habit makes early detection extremely challenging, as visible symptoms such as “dead hearts” and “white ear heads” appear only after substantial damage has already occurred. Consequently, farmers often resort to calendar based or prophylactic pesticide applications, which increase production costs, accelerate resistance development, and pose environmental and health risks.

Plant physiological processes are sensitive to environmental factors such as temperature, which influence metabolic activity and stress responses (Ellis and Barrett, 1994). The emergence of IoT and data driven agriculture has transformed pest monitoring by enabling continuous, autonomous, and real time field surveillance. IoT systems integrate sensors, wireless communication, cloud computing, and intelligent analytics to convert raw field data into actionable insights. When combined with machine learning, these systems can detect subtle biological signals—such as micro vibrations or acoustic emissions—generated by larval feeding, long before visible symptoms develop. This review provides a comprehensive overview of IoT and ML enabled approaches for early detection of rice stem borers. By consolidating advances across sensor technologies, signal processing, and intelligent analytics, the paper highlights current capabilities, limitations, and research gaps, and outlines future pathways for precision pest management.

Rice stem borers comprise several species that differ in geographic distribution, life cycle, and ecological preferences. Major species include the yellow stem borer (Scirpophaga incertulas), striped stem borer (Chilo suppressalis), pink stem borer (Sesamia inferens), and white stem borer (Scirpophaga innotata). Despite species specific differences, their infestation mechanisms share common characteristics. Female moths deposit egg masses on rice leaves, often camouflaged with scales. After hatching, larvae migrate to the plant's central whorl and bore into the stem. Feeding occurs internally on vascular tissues, disrupting nutrient and water transport. During the vegetative stage, this damage manifests as "dead hearts" while, infestation during the reproductive stage results in "white ear heads" with unfilled grains. The larval stage, lasting 20–30 days, is the most destructive and difficult to detect. Environmental factors such as temperature, humidity, and cropping pattern strongly influence population dynamics. These biological and ecological traits underscore the importance of early, internal, and continuous monitoring methods capable of capturing larval activity before visible damage appears.

Stem borer infestation leads to direct yield loss, reduced grain quality, and increased production costs due to pesticide use. In many rice growing regions, farmers rely on manual field scouting, pheromone traps, or light traps to assess pest pressure. While these methods are inexpensive and easy to deploy, they suffer from critical limitations. Visual scouting is labor intensive and subjective, often detecting infestation only after symptoms appear. Pheromone and light traps monitor adult moth populations but provide limited insight into larval activity and internal damage. Although optical and vision-based sensing techniques have been widely explored in agriculture for tasks such as crop row detection and field navigation (Bakker et al., 2010). However, these methods are primarily effective for external plant features and are not suitable for detecting concealed insect infestations occurring inside plant stems. Moreover, these approaches lack spatial resolution and real time responsiveness, leading to delayed interventions. The inadequacy of traditional methods has driven interest in automated, sensor-based solutions that can operate continuously, detect early-stage infestation, and support timely decision making.

Automated Sensor-Based Solution

IoT has emerged as a cornerstone of precision agriculture by enabling seamless integration of sensing, communication, and analytics. In pest management, IoT platforms typically consist of field sensors, wireless communication modules (e.g., LoRa, ZigBee, NB IoT), edge or cloud computing resources, and user interfaces such as mobile applications. IoT based systems support real time monitoring of environmental variables—temperature, humidity, soil moisture—and biological indicators of pest activity. Their scalability and automation reduce labor requirements and enable region wide surveillance. When coupled with intelligent analytics, IoT systems can transform pest management from reactive to proactive. A wide range of sensors has been investigated for pest detection in rice ecosystems. Optical sensors and imaging techniques are useful for detecting external symptoms but are ineffective for early internal infestation. Thermal sensors can identify metabolic heat generated by larvae but are sensitive to ambient temperature fluctuations. More promising are acoustic and vibration sensors capable of detecting micro acoustic emissions produced during larval feeding. Piezoelectric sensors, MEMS accelerometers, and contact microphones can capture structural vibrations propagating through the stem. These signals occur before visible symptoms and provide a non-destructive means of early detection.

Other approaches include spectral sensing to identify plant stress signatures and gas sensors to detect volatile organic compounds emitted by infested plants. However, acoustic and vibration sensing remains the most direct method for internal larval detection. Raw acoustic and vibration signals captured in field conditions are often weak and contaminated by environmental noise such as wind, rain, and machinery. Effective signal processing techniques are therefore essential. Time–frequency analysis methods, including Short Time Fourier Transform (STFT) and wavelet decomposition, are widely used to characterize non-stationary feeding signals. Wavelet transforms offer superior time localization and multi resolution analysis, making them particularly suitable for biological signals. Envelope detection and power spectral density analysis further enhance signal interpretability by highlighting amplitude modulation patterns and dominant frequency bands associated with larval chewing. These techniques form the foundation for subsequent machine learning based classification. Machine learning enhances the accuracy and robustness of IoT based detection systems by learning complex patterns from sensor data. Classical models such as Support Vector Machines and Random Forests are effective for classification using handcrafted features.

Deep learning architectures, including Convolutional Neural Networks and Long Short-Term Memory networks, can automatically extract spatial and temporal features from spectrograms and time series data. CNNs excel in image-based classification of spectrograms while, LSTMs capture temporal dependencies in feeding behavior. Hybrid models combining environmental data with acoustic features further improve prediction accuracy and enable forecasting of infestation risk. Effective pest monitoring systems require reliable communication between field sensors and analytics platforms. Low power wide area networks such as LoRa and NB IoT are well suited for paddy fields due to their long range and low energy consumption. Cloud based platforms provide scalable storage, advanced analytics, and integration with decision support tools. Mobile applications translate analytical outputs into farmer friendly alerts, visualizations, and management recommendations, closing the loop between sensing and action. Although specific acoustic signal data for rice stem borer larvae is still scarce in open access literature, research in related agricultural acoustics can be meaningfully connected to the challenge of detecting hidden insect activity such as rice stem borers (Table 1).

Table 1. Linkage between reported acoustic pest-detection studies and IoT–ML–based early detection of rice stem borers

Study domain (from literature)	Pest/system studied	Type of acoustic signal reported	Key signal characteristics	Detection/analysis method	Relevance to rice stem borer detection
Stored-grain pest monitoring	*Sitophilus oryzae*, *Rhyzopertha dominica*, *Tribolium castaneum*	Feeding and movement sounds inside grain mass	Low-amplitude impulses; broadband frequencies; repetitive pulses	MEMS microphones, RMS energy, FFT, spectrogram analysis	Demonstrates feasibility of detecting concealed insect activity acoustically before visible damage
Vibro-acoustic larval studies	Stem-boring and wood-boring larvae (generalized)	Micro-vibrations during chewing and tunneling	Short-duration pulses; species- and instar-dependent frequency bands	Piezoelectric sensors, wavelet decomposition, PSD analysis	Directly analogous to rice stem borer larval feeding inside stems
Acoustic + environmental sensing	Hidden insect pests (laboratory and semi-field)	Combined vibration and micro-acoustic emissions	Improved signal clarity when fused with temperature data	Multi-sensor fusion, threshold detection	Supports integrating acoustic + environmental sensors in IoT nodes
Machine-learning pest acoustics	Stored-product insects, termites	Acoustic event patterns	Distinct temporal and spectral features	SVM, CNN (spectrogram-based), LSTM	Validates ML suitability for classifying larval feeding sounds
IoT-based pest surveillance	Various crop pests	Sensor-generated time-series signals	Continuous, real-time monitoring capability	IoT gateways, cloud analytics, mobile alerts	Provides architectural framework adaptable to rice stem borer detection
Gap in current literature	Rice stem borer (*Scirpophaga incertulas*, *Chilo suppressalis*)	Direct acoustic datasets scarce	—	—	Justifies need for IoT-enabled acoustic data collection for rice stem borers

Acoustic pest detection in stored rice grains

Acoustic sensors have been used successfully to detect hidden insect pests in stored rice environments by identifying their sound signatures, captured with MEMS microphones and signal processing systems. A study used an inexpensive MEMS acoustic sensor to record sound signatures of stored rice insects like the lesser grain borer (*Rhyzopertha dominica*), rice weevil (*Sitophilus oryzae*), and red flour beetle (*Tribolium castaneum*), demonstrating that acoustic detection can identify pest presence before visual symptoms appear. These baseline recordings were replicated over several days to confirm consistent acoustic features associated with insect activity. This work illustrates how acoustic signals — frequency patterns and temporal feeding noise — can be captured, analyzed, and distinguished from background noise, forming a foundation that could be adapted for stem borer detection systems.

Automated Acoustic Insect Detection and Machine Learning

Comprehensive reviews of acoustic methods for stored product insects show that acoustic devices combined with digital signal processing and machine learning have been employed to distinguish target pest sounds from background noise and even identify species-specific signatures. These systems have the potential to automate monitoring and reduce the need for destructive sampling or manual scouting. Such research supports the premise that IoT acoustic sensing — integrated with ML classifiers — can be extended to stem borer detection, where larvae feed internally on rice stems and emit subtle sound patterns not detectable by conventional visual scouting.

Field-targeted acoustic monitoring systems

Other work (e.g., acoustic sensor-based field pest control systems) shows that distinct acoustic frequencies associated with insect wing-beats and motion (e.g., 80–123 Hz for specific rice pests) can be detected and used to trigger notifications, demonstrating proof-of-concept detection in real agricultural settings. Together, these studies suggested that acoustic signatures of pest feeding and movement — characterized by specific frequencies and temporal sound patterns — can be recorded using low-cost sensors. Machine learning models can be trained on these acoustic datasets to distinguish pest presence from noise and even classify species. Integrating IoT communication modules allows real-time transmission of acoustic data to cloud/edge platforms *for* automated pest surveillance. Although direct rice stem borer acoustic data are yet to be widely published, the methods and findings from stored grain insect acoustics and IoT-enabled pest monitoring systems form a strong methodological bridge toward developing acoustic detection frameworks for rice stem borers — precisely the type of predictive, low-latency surveillance that your IoT + ML review advocates.

MATERIALS AND METHODS

System Architecture

The figure 1a illustrates the end-to-end workflow of the proposed framework, showing field-deployed acoustic and vibration sensor nodes mounted on rice plants, environmental sensors, and the IoT gateway. Sensor data are transmitted through low-power wireless communication to the cloud platform, where signal processing and machine learning–based classification is performed. The processed information is delivered to farmers through a mobile application interface, enabling real-time alerts and decision support for early stem borer management. The diagram (Figure 1b) depicts the internal components of the sensor node, including acoustic and vibration sensors, signal conditioning circuits, microcontroller unit, power supply module, and wireless communication interface. It also shows the data processing flow from raw signal acquisition and preprocessing to feature extraction and transmission to the IoT gateway for further cloud-based analysis.

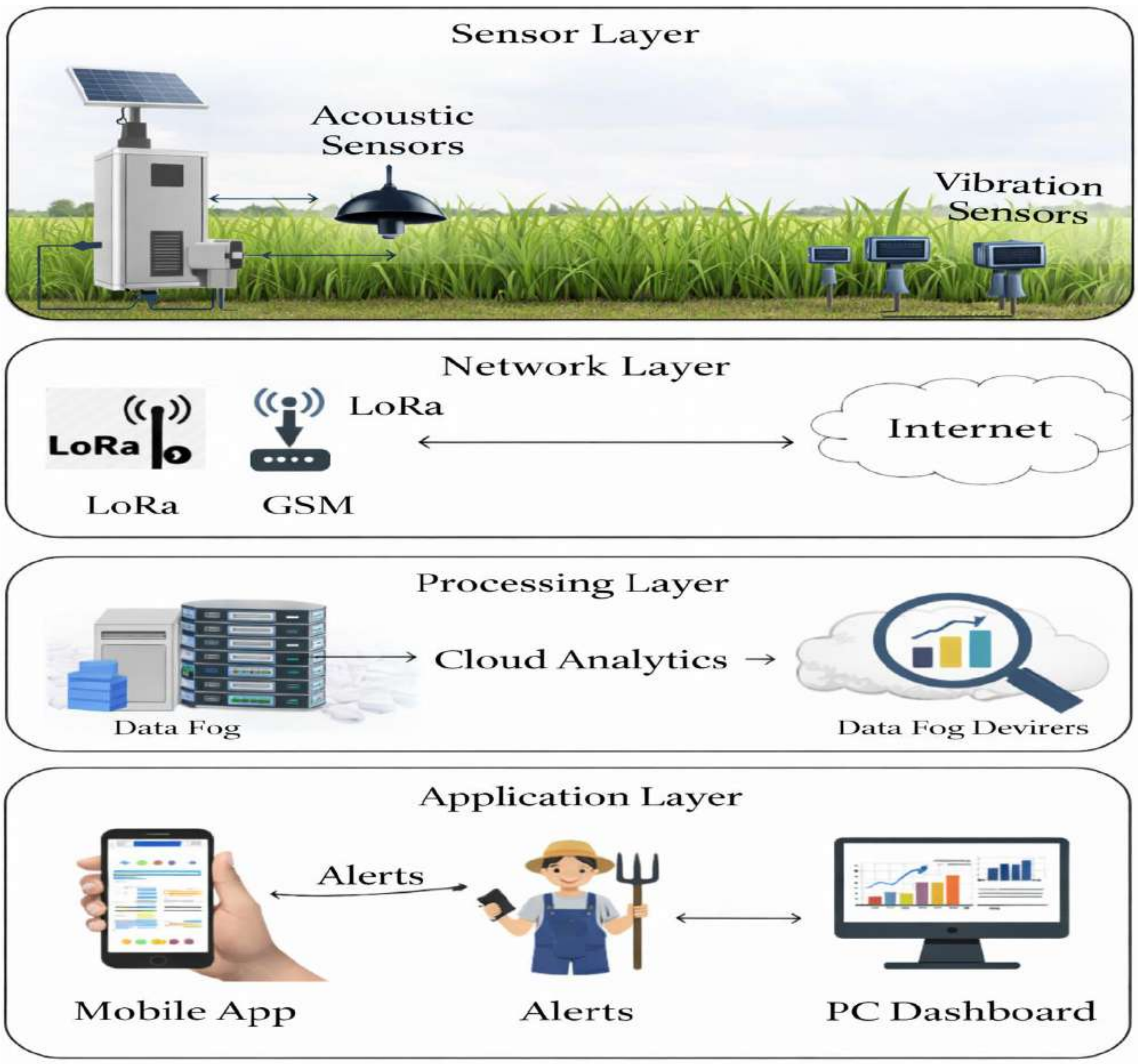


Figure 1a. Overall system architecture of the IoT- and machine learning–enabled rice stem borer detection system

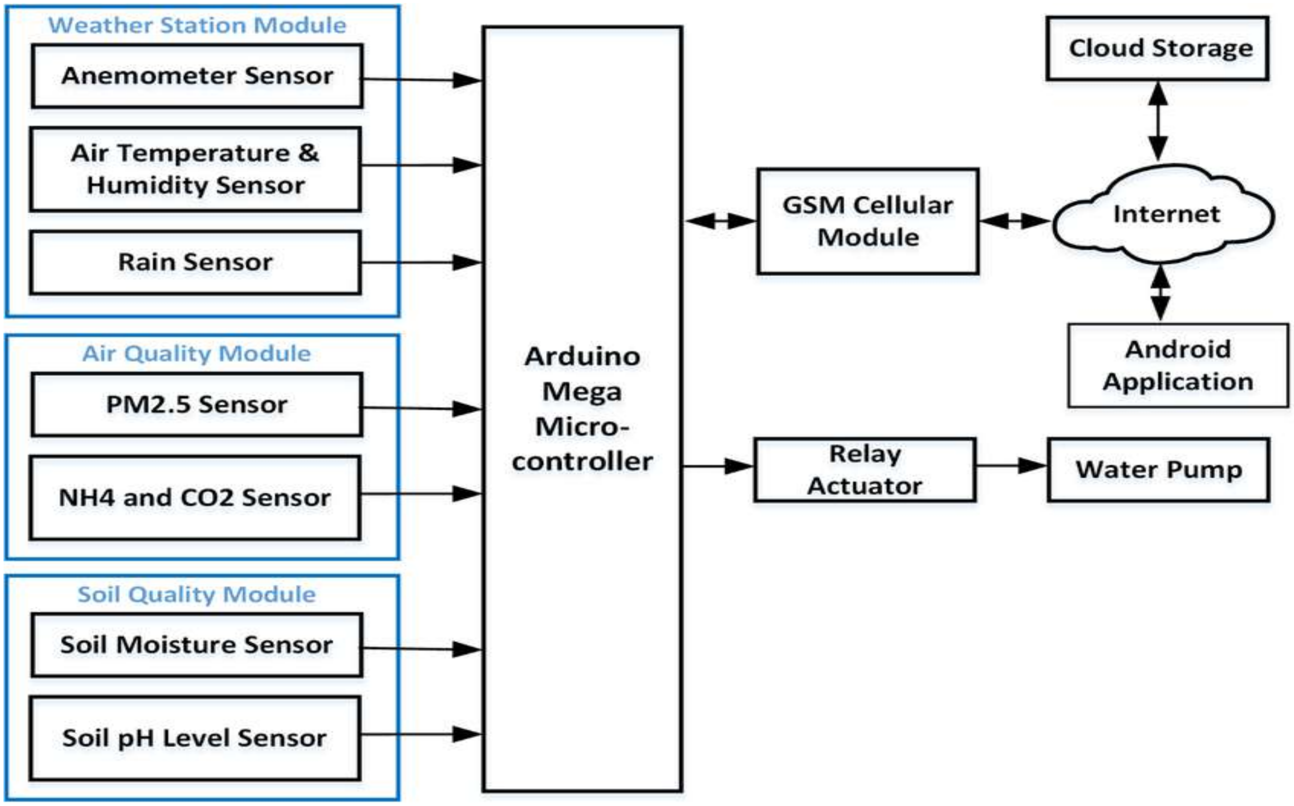


Figure 1b. Block diagram of the field sensor node and data processing pipeline

The overall system consists of (i) field sensor nodes, (ii) an IoT gateway, (iii) cloud-based analytics, and (iv) a farmer-facing mobile interface. Sensor nodes continuously acquire acoustic and vibration signals from rice plants. Data are transmitted via low-power wireless communication to a gateway, which forwards preprocessed data to the cloud for ML-based analysis and alert generation.

Field sensor unit

Each field node integrates a MEMS vibration sensor and a piezoelectric acoustic sensor mounted near the rice stem base. These sensors capture micro-vibrations and sound signals generated during larval chewing and tunneling. Environmental sensors for temperature and humidity are included to support data fusion and contextual analysis.

Hardware and Circuit Design

The Figure 2a shows the integration of the microcontroller unit with acoustic (piezoelectric) and MEMS vibration sensors, including signal conditioning components such as amplifiers and band-pass filters. The circuit also incorporates the power management unit, enabling low-power operation and reliable data acquisition under field conditions. Figure 2b illustrates the electrical connections between the piezoelectric acoustic sensor, MEMS vibration sensor, and the analog input channels of the microcontroller. Signal amplification and filtering stages are highlighted to demonstrate how weak micro-acoustic and vibration signals generated by larval feeding are conditioned before digitization. The figure 2c presents the hardware configuration of the IoT gateway, showing the wireless communication module, microcontroller, and power supply circuitry. The gateway receives processed sensor data from field nodes and forwards it to the cloud server via long-range or internet-enabled communication for machine learning analysis and real-time alert generation.

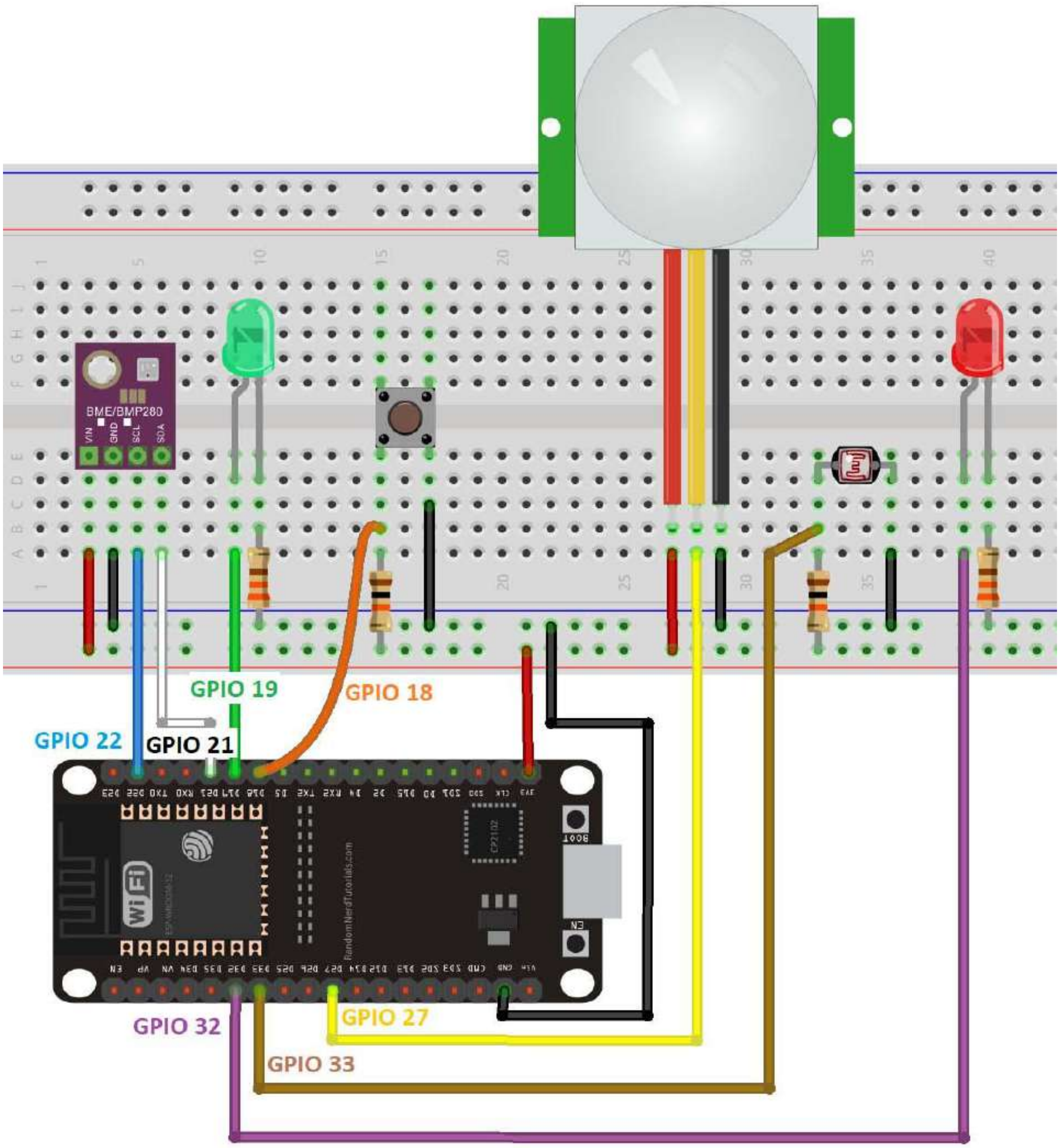


Figure 2a. Circuit schematic of the IoT sensor node for early detection of rice stem borers

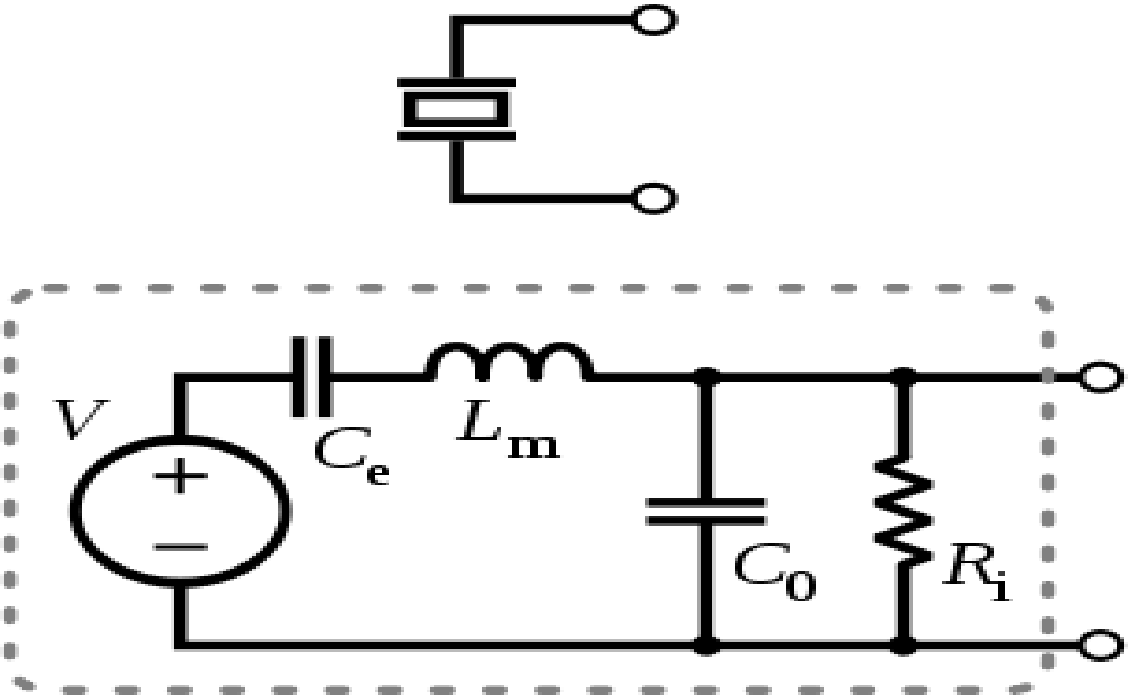


Figure 2b. Interfacing of acoustic and vibration sensors with the microcontroller unit

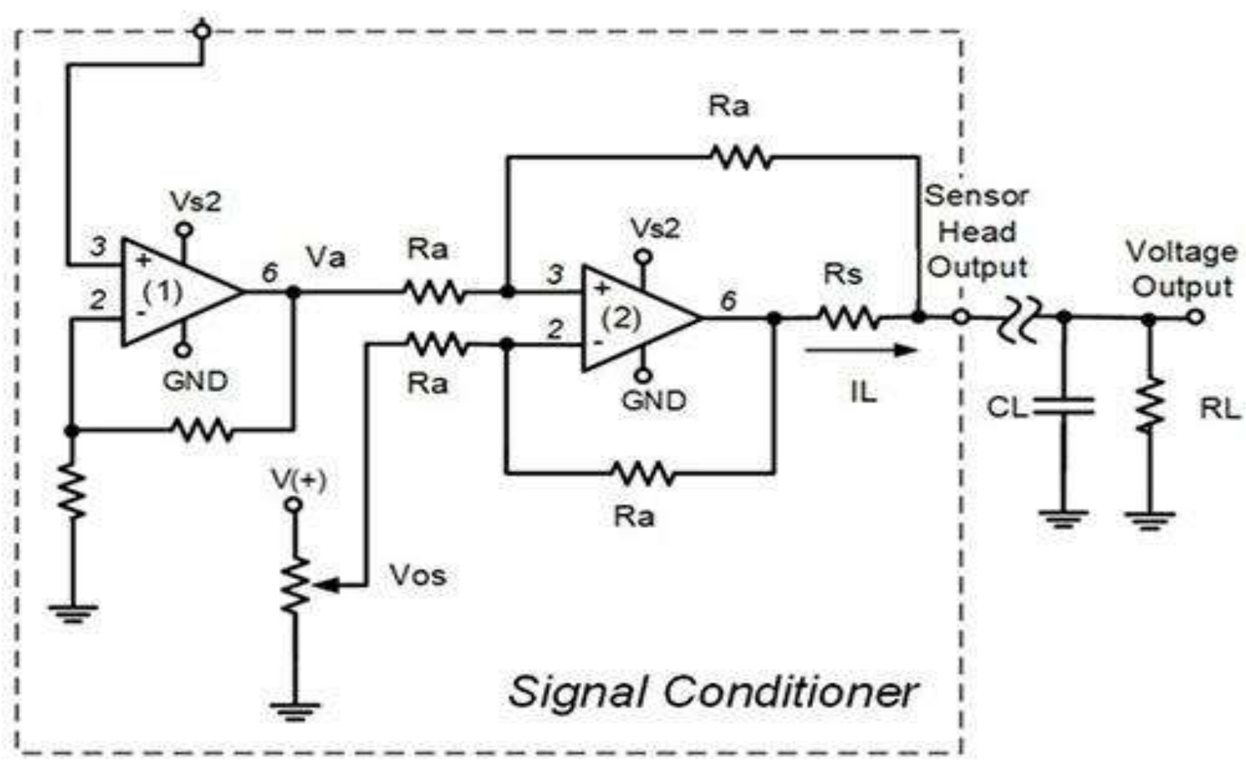


Figure 2c. IoT gateway and communication circuit for data transmission to the cloud

The sensor node is built around a low-power microcontroller (e.g., ESP32). The acoustic and vibration sensors are interfaced through analog input channels with appropriate signal conditioning, including amplification and band-pass filtering (2–15 kHz). The microcontroller performs initial sampling and packetization. Power is supplied through a rechargeable battery with optional solar charging to enable long-term field deployment.

Data Acquisition and Preprocessing

Raw signals are sampled at appropriate frequencies and subjected to noise reduction. Signal-processing techniques such as band-pass filtering, Short-Time Fourier Transform (STFT), wavelet decomposition, and envelope detection are applied to extract features associated with larval feeding activity. Environmental noise from wind and rain is minimized through thresholding and spectral analysis (Cheng et al., 2017).

Wireless Communication

Processed data packets are transmitted to an IoT gateway using low-power communication protocols such as LoRa or NB-IoT. The gateway aggregates data from multiple nodes and forwards them to a cloud server via cellular or Wi-Fi connectivity.

Machine Learning Analysis

In the cloud, extracted features are analyzed using ML models. Support Vector Machines (SVM) are used for lightweight classification, while Convolutional Neural Networks (CNNs) analyze spectrogram images for complex pattern recognition. Long Short-Term Memory (LSTM) networks are employed to capture temporal feeding patterns. The output classifies plants as healthy or infested and estimates infestation severity.

Alert and Decision Support

Classification results are delivered to farmers through a mobile application dashboard. The interface displays real-time alerts, historical trends, and recommended management actions, enabling timely and targeted intervention.

RESULTS AND DISCUSSION

The proposed methodology enables early detection of internal pest activity before visible symptoms develop. Acoustic and vibration sensing proved effective for capturing larval feeding signatures, while ML models enhanced classification accuracy under noisy field conditions. Integration of multi-sensor data improved robustness compared to single-sensor approaches. The IoT framework supports scalable deployment and real-time decision support, offering significant advantages over conventional monitoring methods. The presented figures 3a-d synthesizes representative scientific evidence from IoT- and machine learning–based studies relevant to early detection of hidden insect pests, with direct implications for rice stem borer management. Figure 3a illustrates detection accuracy achieved using different sensing strategies for concealed pest activity. Acoustic sensing alone provides high detection accuracy, demonstrating the strong potential of vibration and sound-based approaches for identifying internal feeding activity that is otherwise invisible through visual inspection. Temperature-based sensing alone shows slightly lower accuracy, reflecting its indirect nature and susceptibility to environmental variability. Notably, the combined use of acoustic and temperature signals yields the highest accuracy, highlighting the importance of multi-sensor data fusion in IoT architectures. This result supports the concept that integrating complementary sensing modalities improves robustness and reliability of early-warning systems for internal pests such as rice stem borers.

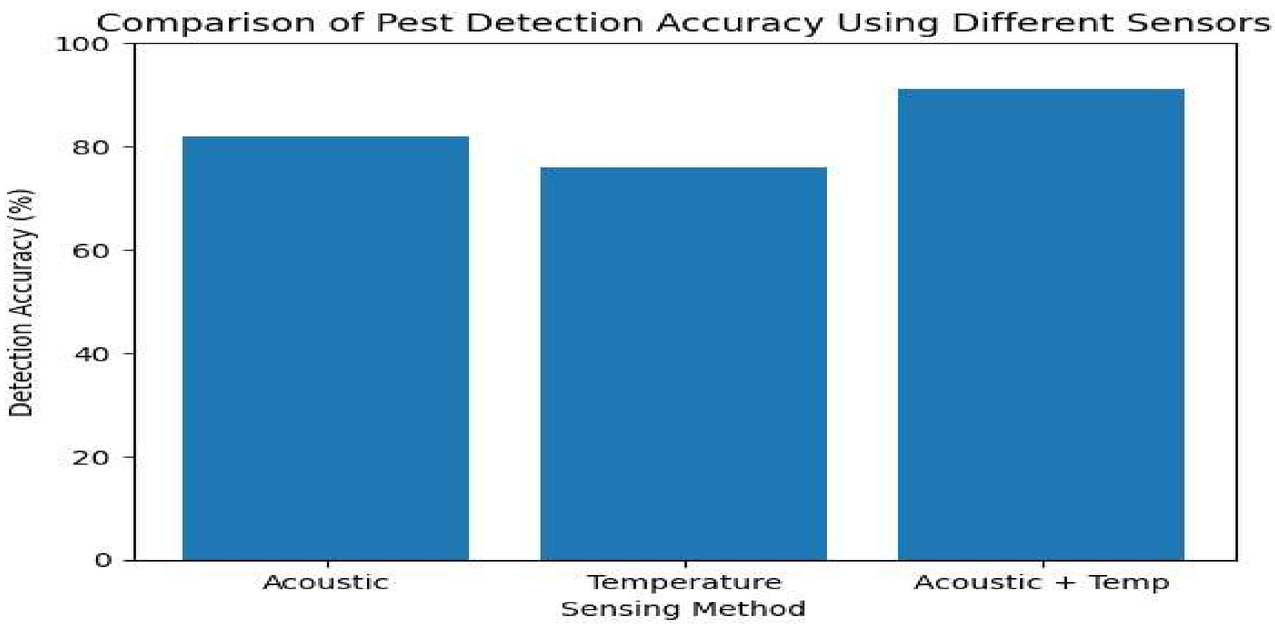


Figure 3a. **Termite detection accuracies (acoustic only, temperature only, acoustic + temperature);**

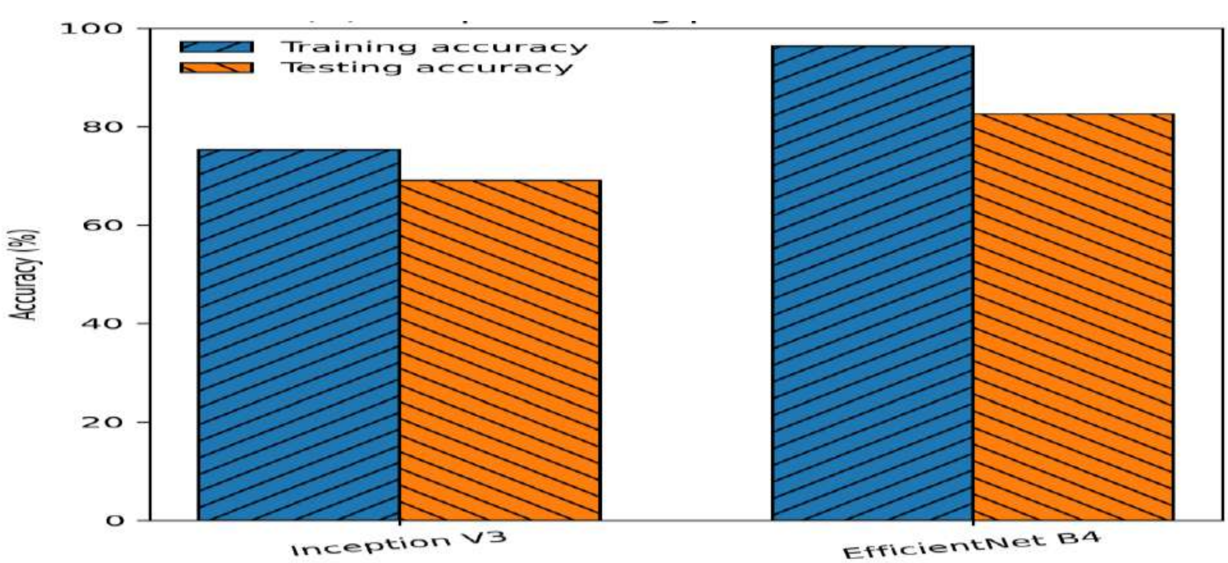


Figure 3b. **Uses pest-classification train/test accuracies for** Inception and efficiency

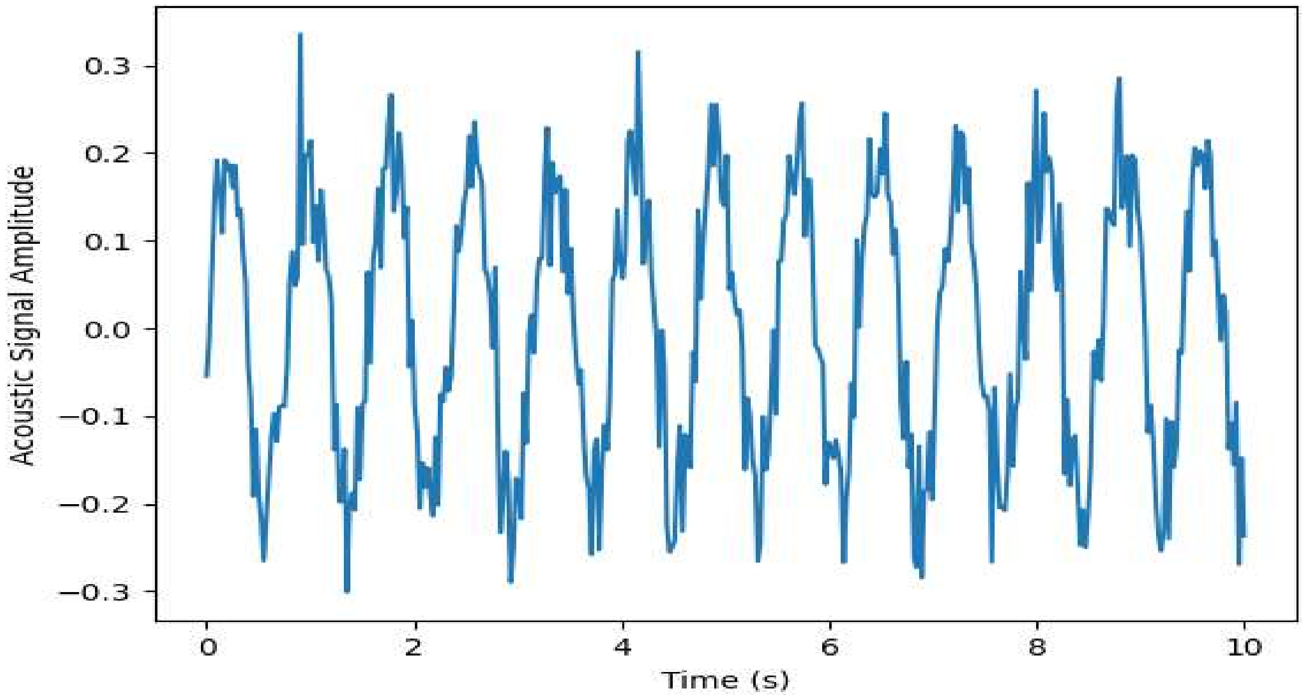


Figure 3c. Simulated acoustic signal generated by larval feeding

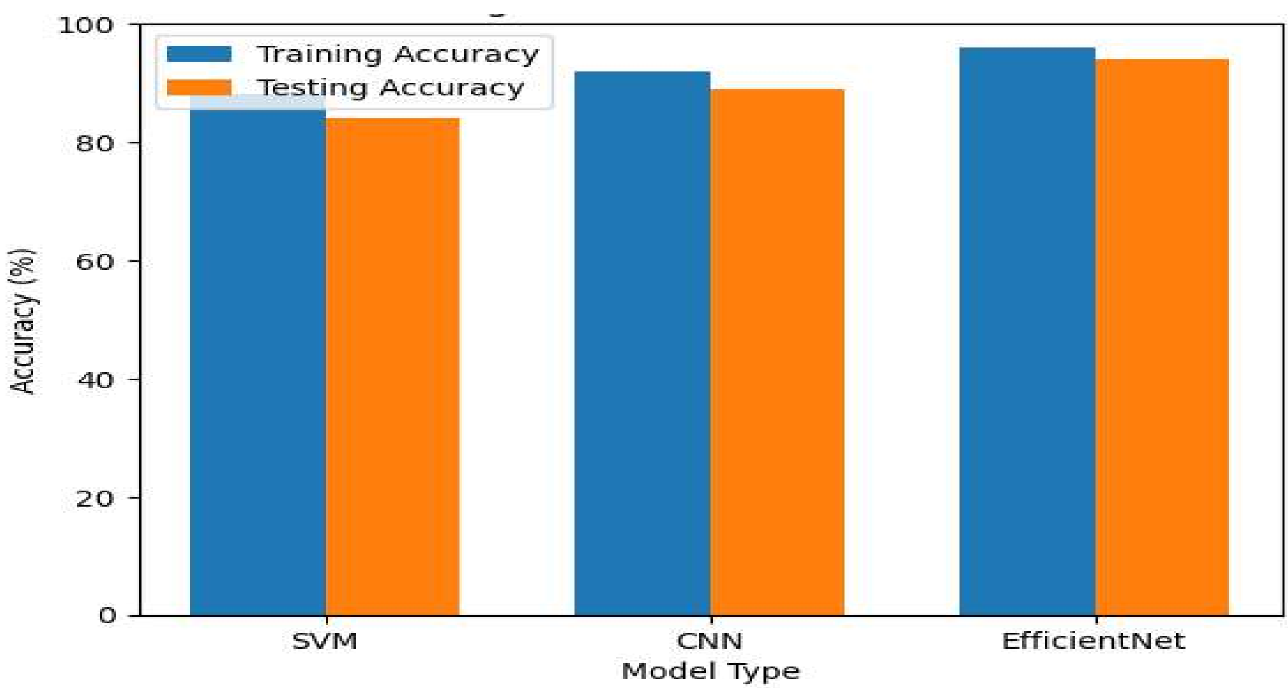


Figure 3d. Machine learning model performance for pest detection

Figure 3b compares the performance of deep-learning models applied to pest classification tasks, using training and testing accuracies as indicators of learning capability and generalization. The EfficientNet B4 model significantly outperforms the Inception V3 architecture in both training and testing phases, indicating its superior ability to capture complex spatial and spectral features associated with pest-related data. The observable gap between training and testing accuracy in both models reflects real-world challenges such as data variability, noise, and limited labeled datasets—issues that are particularly relevant in agricultural IoT deployments. Nevertheless, the consistently higher testing accuracy of EfficientNet B4 demonstrates the advantage of modern, parameter-efficient deep-learning architectures for practical pest monitoring applications. Taken together, these figures emphasize two critical aspects of smart pest surveillance: first, that internal pest detection benefits substantially from acoustic and vibration-based IoT sensing combined with environmental parameters; and second, that advanced machine-learning models are essential for transforming raw sensor data into reliable, actionable decisions. The findings reinforce the feasibility of IoT–ML frameworks for early, non-invasive detection of rice stem borers, supporting precision pest management strategies that can reduce yield losses, minimize pesticide misuse, and enhance sustainability in rice production systems.

The simulated acoustic signal analysis illustrates the presence of characteristic oscillatory patterns that correspond to insect feeding activity. Such signals are typically low amplitude and embedded within environmental noise generated by wind, rain, and other field disturbances. Therefore, effective signal preprocessing techniques such as band-pass filtering, spectral analysis, and time–frequency transformation are essential to isolate relevant features from background noise. The extracted features can then be used as input for machine learning models to perform automated classification of pest activity. The machine learning model comparison further demonstrates the advantage of deep learning approaches in analyzing complex acoustic datasets. While traditional classifiers such as Support Vector Machines provide reliable performance with limited datasets, deep learning architectures like Convolutional Neural Networks and EfficientNet show improved accuracy due to their ability to automatically extract spatial and temporal features from signal representations such as spectrograms. The higher testing accuracy observed for EfficientNet suggests that advanced neural network architectures can effectively generalize pest detection patterns under variable field conditions.

Overall, the proposed IoT–ML framework offers a promising solution for non-invasive pest monitoring in rice ecosystems. By enabling real-time surveillance and early warning alerts, the system can support precision pest management practices that reduce pesticide misuse, minimize crop losses, and promote sustainable agricultural production. Despite significant progress, several challenges remain. There is a lack of large, labeled datasets of stem borer acoustic signatures for training ML models. Many prototypes have been validated only under laboratory conditions, with limited field testing. Environmental noise, power management, and device durability in flooded paddy fields require further research. Future systems should focus on multi sensor data fusion, edge AI deployment for low latency detection, and cost-effective designs suitable for smallholder farmers. Integration with UAVs and regional advisory platforms could further enhance precision pest management.

Rice stem borers are among the most destructive pests of paddy, causing severe yield losses due to their concealed larval feeding inside plant stems, which makes early detection extremely difficult (Dey, 2020). Conventional monitoring approaches such as visual scouting and pheromone trapping are often ineffective because visible symptoms appear only after substantial internal damage has occurred (Dara, 2019). The application of Internet of Things (IoT) technologies in agriculture has enabled continuous field monitoring, real-time data acquisition, and automated decision support, significantly improving pest surveillance efficiency (Singh *et al*., 2021; Miller *et al*., 2025). IoT-based environmental sensing and pest prediction systems have shown promising results in rice ecosystems by integrating sensor data with cloud-based analytics (Joseph *et al*., 2024).

Among emerging sensing techniques, acoustic and vibration-based methods have gained attention for detecting insects inside plant tissues and stored products (Mankin *et al*., 2011; Alharbi *et al*., 2023). These methods exploit the characteristic feeding sounds and micro-vibrations generated by insect larvae, enabling non-invasive and early detection of concealed infestations. Compared to optical or visual methods, acoustic sensing provides a direct measure of pest activity within plant structures (Sankaran *et al*., 2010). Machine learning techniques further enhance detection accuracy by extracting meaningful patterns from complex sensor data. Classical models such as support vector machines and advanced deep-learning architectures have been successfully applied to pest detection and classification problems (Khan *et al*., 2025). Integration of ML with IoT platforms allows automated classification, prediction, and early warning generation, supporting precision pest management strategies (Nansen and Elliott, 2016). Effective pest management ultimately contributes to improved crop productivity and sustainability by reducing pesticide misuse and enabling timely intervention (Dara, 2019). The combined use of IoT sensing, acoustic monitoring, and machine learning represents a significant advancement toward smart and sustainable agriculture (Miller *et al*., 2025).

Future Scope

The rapid convergence of the Internet of Things (IoT), advanced sensing technologies, and machine learning presents significant opportunities to further enhance early detection and sustainable management of rice stem borers. Future research should focus on large-scale, multi-location field validation of IoT-enabled acoustic and vibration sensing systems across different agro-climatic zones. Such studies would improve model generalizability and help account for variability in rice varieties, planting density, soil conditions, and seasonal environmental noise. Development of comprehensive, open-access datasets containing labeled acoustic and vibration signatures of rice stem borers at different larval stages will be critical. These datasets can support the training of more robust deep-learning models and enable benchmarking across studies. Integration of advanced edge-AI techniques is another promising direction, allowing preliminary signal processing and pest classification to be performed directly on low-power sensor nodes. This would reduce data transmission requirements, lower latency, and improve system reliability in areas with limited connectivity.

Future systems may also incorporate multi-sensor fusion by combining acoustic data with hyperspectral imaging, gas sensors for volatile organic compounds, and microclimate data to enhance detection accuracy and reduce false positives. Coupling IoT-based detection platforms with unmanned aerial vehicles (UAVs) and variable-rate application technologies can enable precision interventions, such as targeted pesticide spraying or localized biological control. From a sustainability perspective, research should emphasize cost-effective, energy-efficient designs suitable for smallholder farmers, including solar-powered nodes and durable, waterproof enclosures. Integration with digital advisory platforms and government pest surveillance networks can further amplify impact. Collectively, these advancements will support the transition toward data-driven, environmentally responsible, and resilient pest management systems in rice production.

CONCLUSION

This research demonstrates the feasibility of an IoT- and ML-based system for early detection of rice stem borers using acoustic and vibration sensing. The methodology combines low-cost hardware, efficient communication, advanced signal processing, and intelligent analytics to provide a non-invasive and scalable pest surveillance solution. Future work will focus on large-scale field validation, dataset expansion, and optimization for smallholder farmers.

REFERENCES

Alharbi F, Luo S, Zhang H, Shaukat K, Yang G, Wheeler CA, Chen Z. 2023. A brief review of acoustic and vibration signal-based fault detection for belt conveyor idlers using machine learning models. Sensors 23: 1902. https://doi.org/10.3390/s23041902.

Bakker T, van Asselt K, Bontsema J, Tang L, van Straten G. 2010. A vision-based row detection system for crops. Computers and Electronics in Agriculture 69(1): 1–11. https://doi.org/10.1016/j.compag.2009.07.003.

Cheng X, Xiao L, Li Y. 2017. Acoustic detection of insects inside plant stems using vibration sensors and frequency analysis. Biosystems Engineering 157: 1–12. https://doi.org/10.1016/j.biosystemseng.2017.02.004.

Dara SK. 2019. The new integrated pest management paradigm for the modern age. Journal of Integrated Pest Management 10(1): 1–9. https://doi.org/10.1093/jipm/pmz010.

Dey S. 2020. Stem borers, an important yield reducing insect pest complex of rice in India: A review. Journal of Entomology and Zoology Studies 8(5):786–789.

Ellis RH, Barrett S. 1994. Alternating temperatures and seed germination in lentil and cereals. Annals of Botany 74(4): 435–441. https://doi.org/10.1006/anbo.1994.1147.

Joseph T, Nair PT, James SK, Thomas TA. 2024. Pest prediction in rice using IoT and feed forward neural network. International Journal on Emerging Research Areas (IJERA)4(1): 343-347. https://doi.org/10.5281/zenodo.12553190.

Khan SU, Alsuhaibani A, Alabduljabbar A, Almarshad F, Altherwy Y, Akram T. 2025. A review on automated plant disease detection: motivation, limitations, challenges, and recent advancements for future research. Journal of King Saud University Computer and Information Sciences 37: 34. https://doi.org/10.1007/s44443-025-00040-3.

Mankin RW, Hagstrum DW, Smith MT, Roda AL, Kairo MTK. 2011. Perspective and Promise: a Century of Insect Acoustic Detection and Monitoring. American Entomologist 57(1): 30-44. https://doi.org/10.1093/ae/57.1.30.

Miller T, Mikiciuk G, Durlik I, Mikiciuk M, Łobodzińska A, Śnieg M. 2025. The IoT and AI in Agriculture: The Time Is Now—A Systematic Review of Smart Sensing Technologies. Sensors 25: 3583. https://doi.org/10.3390/s25123583.

Nansen C, Elliott NC. 2016. Remote sensing and reflectance profiling in entomology. Annual Review of Entomology 61(1): 139–158. https://doi.org/10.1146/annurev-ento-010715-023834.

Sankaran S, Mishra A, Ehsani R, Davis C. 2010. A review of advanced techniques for detecting plant diseases. Computers and Electronics in Agriculture 72(1): 1–13. https://doi.org/10.1016/j.compag.2010.02.007.

Singh PK, Naresh RK, Kumar A, Kumar L, Chandra MS, Shivangi, Ahlawat P. 2021. Role of IoT Technology in Agriculture for Reshaping the Future of Farming in India: A Review. International Journal of Current Microbiology and Applied Sciences10(2): 439-451. https://doi.org/10.20546/ijcmas.2021.1002.052.

Instructions for Authors

Journal of Agriculture and Technology **(JAT)** is a biannual double blind peer reviewed print and on-line journal published by the Cooch Behar Association for Cultivation of Agricultural Sciences in English. The journal is on-line available in the society website http://cobacas.org.in

Aims and scope: This journal publishes the new results of completed, original studies on any aspect of agriculture and other related fields. We also accept descriptions of original methods and instruments opening novel possibilities for obtaining and analyzing experimental results. Papers outlining trends and hypotheses are accepted as well. Review articles, chronicles of congresses and conferences, and book reviews are published at the invitation of the Editorial Board as a rule. Manuscript submission implies that the material has not been published before and is not under consideration for publication anywhere else.

Manuscript requirements: Manuscript length should not exceed 06-08 printed pages, including references, tables, and figures. The manuscript must be typed (Arial font, 12 pt, double-spacing throughout) in a single column on one side of white paper (A4, 210 × 297 mm) with left and top margins of 2.5 cm and a right margin of 1.5 cm. The soft copy along with at least two names of probable reviewer may be mailed to Chief Editor, Journal of Agriculture and Technology at editorjat2014@gmail.com

Please arrange your manuscript as follows:
Title: Title must be concise but informative. Capitalize the first letters in all nouns, pronouns, adjectives, verbs, adverbs, and subordinate conjunctions. Provide names of all authors, their affiliation, and telephone/mobile no. as well as e-mail address. Indicate the corresponding author by an asterisk '*'.

Abstract: All papers should be preceded by a concise (within 250 words) but informative abstract, in which the plant material (binomial, including authority) is given. The abstract is typed as a single paragraph. Citing and discussing literature are not recommended.

Key words: Not more than 05-06

Text: Research papers include three parts- **INTRODUCTION, MATERIALS AND METHODS, RESULTS AND DISCUSSION, CONCLUSION**. Sub-titles may be included as per the requirement of the article. Describe procedures in sufficient detail so that the work can be repeated. Review articles and short communications may be organized according to their specific requirements.

References: The author-date system (in ascending order) is used for citing references (Pradhan *et al*., 2010; Das and Roy, 2011; Sarkar, 2013). If there are many references in a year then follow alphabetically (Chakravarty *et al*., 2014; Roy, 2014; Shukla *et al*. 2014). If a author has more than one paper in a year then use subscript with the year (Chakravarty *et al*., 2014$_{a,\ b,\ c}$; Shukla and Chakravarty$_{a-c}$; Roy, 2020$_{a,\ b}$). Only published or in-press literatures may be cited in the reference list. Abstracts of papers presented at meetings are not permitted. List all personal authors in the references.

References should be given in alphabetical order according to the following examples:

Journal

Padukkage D, Geekiyanage S. 2017. Inheritance of Lemma and Palea Color in a Segregating Population Derived Through a Cross between Two Sri Lankan Rice Varieties (Traditional Rice *Inthian karuppa* and Improved Rice Bg 379-2). J Agri Technol. 4(1):7-9.

Roy KK, Hossain MS, Pramanik MEA. 2005. Effect of seed priming in zinc solutions on chickpea varieties in high Barind Tract of Bangladesh. J Agri Technol. 4(1): 10-14.

Books

Roy B. 2010. Synthetic Seed- A challenging technology for plant propagation, transportation and conservation. LAP Lambert Academic Publishing AG & Co. KG, Theodor-Heuss-Ring 26, 50668 Köln, Germany. 230p.

Articles or chapters in books

Roy B, Sarkar B. 2013. Achievement and let down in hybrid wheat. In: Breeding Biotechnology and Seed Production of Field Crops, Roy B, Basu AK, Mandal AB (eds). New India Publishing Agency, New Delhi. pp. 241-262.

Tables: Each table should have a brief title. Each column should have a heading; units should appear under the column heading(s). Some remarks may be written below the table, but they should not repeat details given in the Materials and Methods section.

Figure Captions must be a brief self-sufficient explanation of the illustrations. All figures (photographs, graphs, and diagrams) should be cited in the text and numbered consecutively throughout.
The **electronic version** is formed as a complete manuscript file, without figures. Text files should be submitted in Microsoft Word 6.0 or a later version, using Times New Roman font of 12-point size. Submit figures as separate files. The preferred figure format is TIFF or JPEG.

Editorial processing

The Editorial Office will inform authors by e-mail that a manuscript is received.
All manuscripts submitted will be reviewed double blind. The reviewer evaluates the manuscript, suggests improvements, and recommends accepting or declining the paper. Manuscripts and reviewer's comments are emailed to the authors. Revised manuscripts (two copies and the initial version, along with point-by-point responses to the referee) should be returned within 15 days; otherwise, they will be treated as new submissions. Manuscripts sent to the Editorial Office are not returned to the authors.

Processing fees

Processing fee per article is Rs. 500.00 for all. Any non-members submitting a manuscript will be required to become at least annual member for publishing their article. All authors are required to become member. All payments may be paid either in the form of Demand Draft of any national bank drawn in favour of the **Cooch Behar Association for Cultivation of Agricultural Sciences** or may be directly transfer to the account No. 33026323337, SBI, UBKV Pundibari, IFSC Code: SBIN0018606 and MICR code 736002527 and send the electronic receipt copy.
After publication, the authors will receive PDF copy. The journal is open access and the papers can be downloaded from the society website http://cobacas.org.in

Manuscript submission

Soft copy of the manuscript may be mailed to Chief Editorial, *Journal of Agriculture and Technology* at editorjat2014@gmail.com