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

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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

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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.

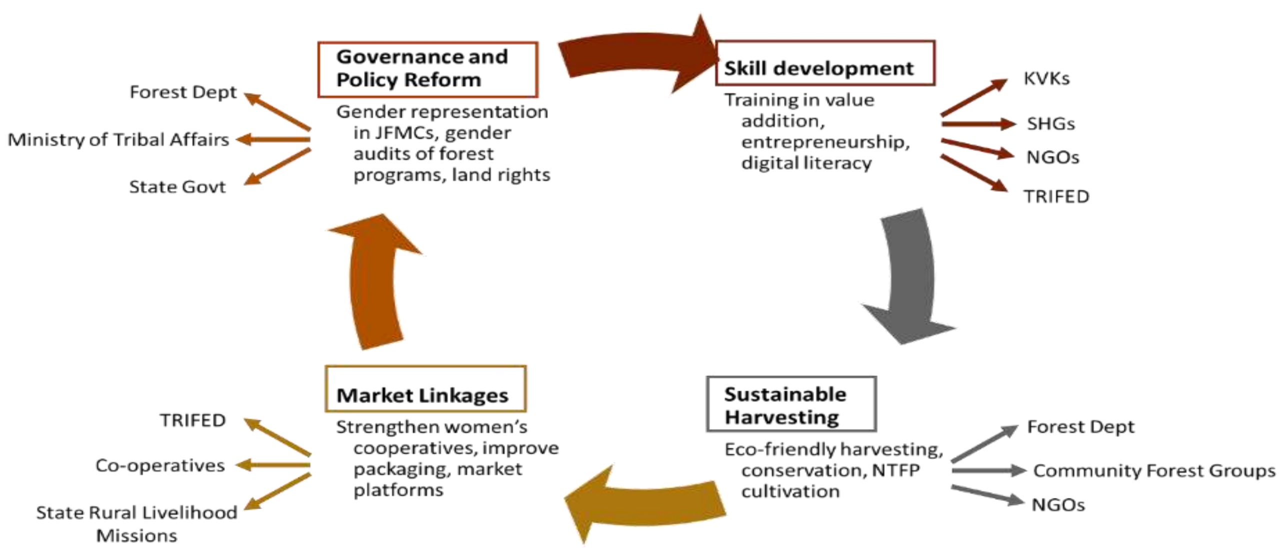

Figure 1. Strategic recommendations for tribal women's empowerment through NTFP

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.

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

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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).

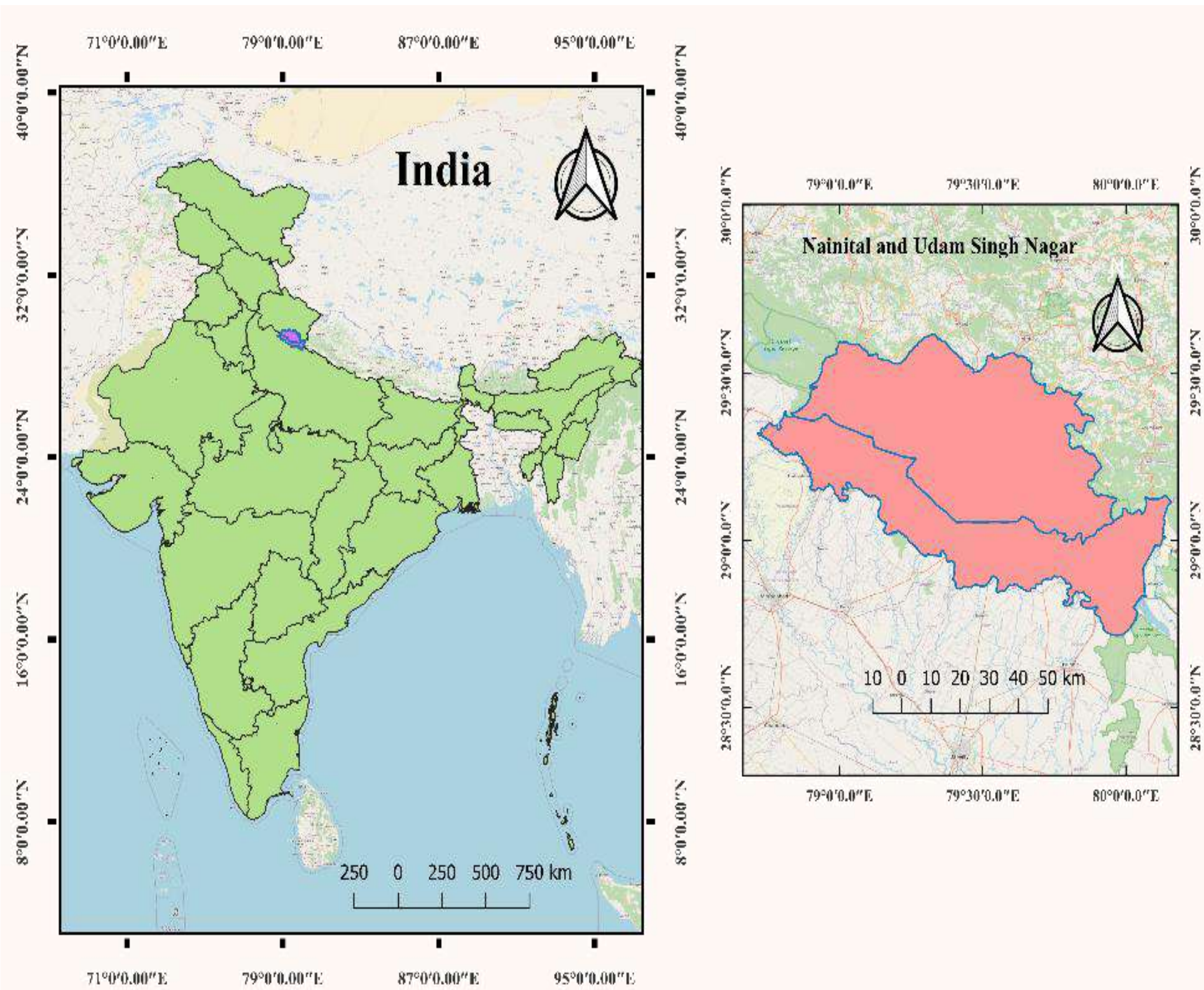


Figure 1. Spatial layout map of the study area

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

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

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:

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

$\hat{f}(x)$= 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.

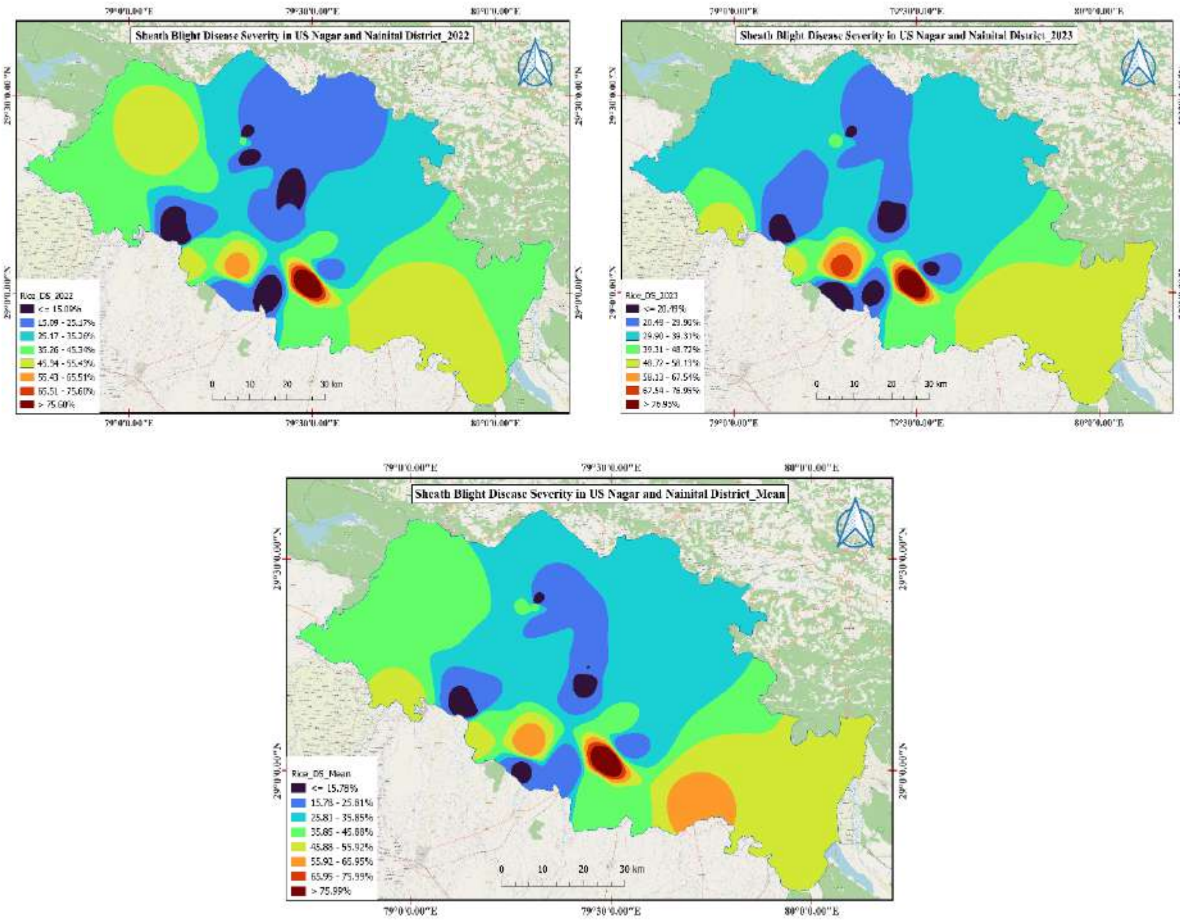


Figure 2. Sheath blight disease severity (%) estimation using IDW interpolation in US Nagar and Nainital districts

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.

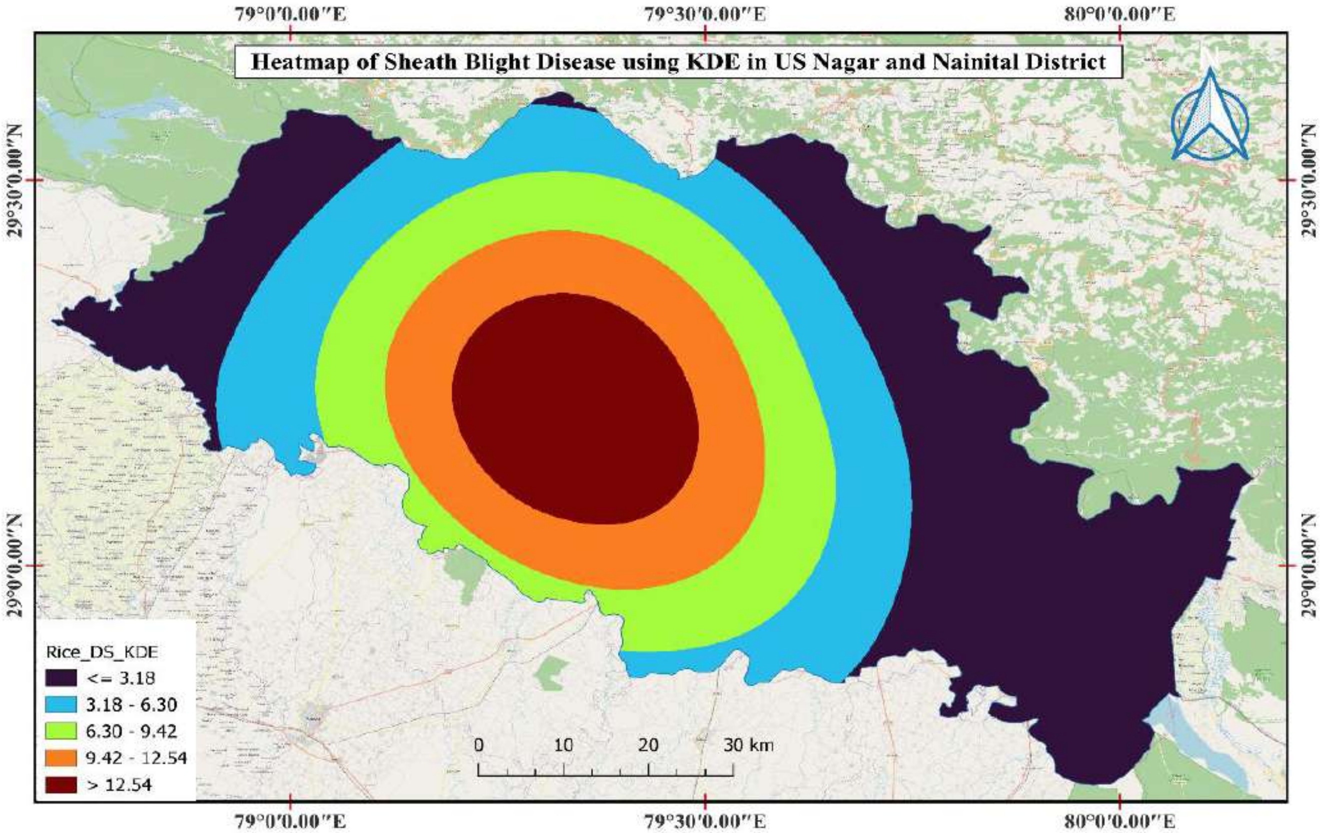


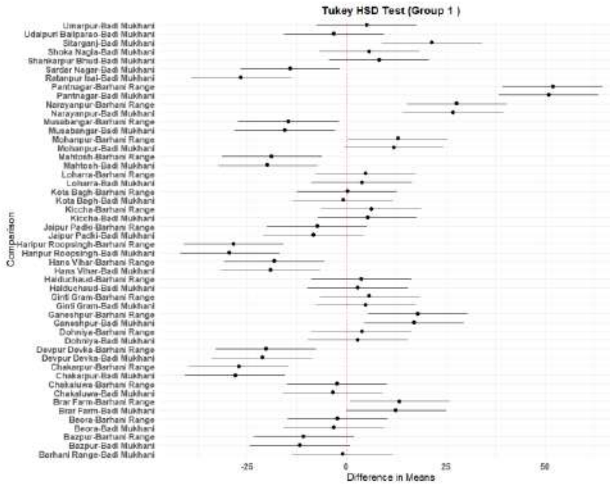
Figure 3. Heatmap of sheath blight using KDE method in US Nagar and Nainital district

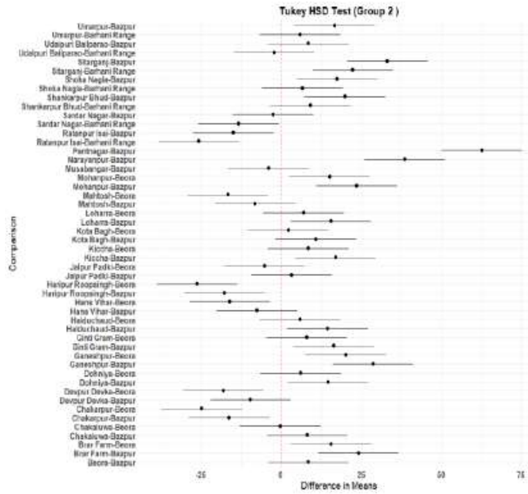
Tukey Test

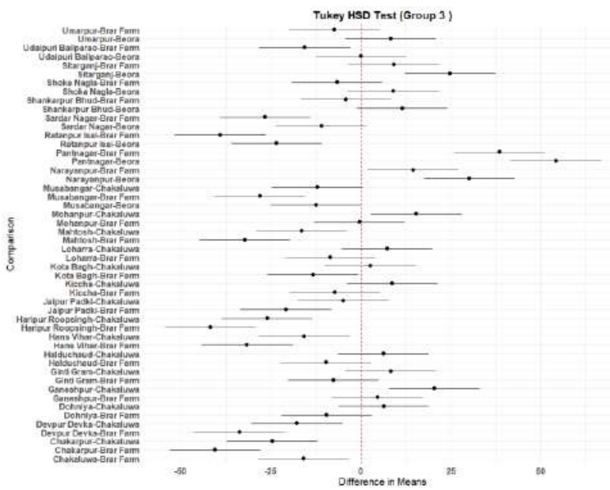
The severity of sheath blight disease in rice was compared across different areas using Tukey's post-hoc test. The analysis revealed significant variations ($p < 0.05$) in disease severity among the regions. These findings indicate that environmental factors or agronomic practices might contribute to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

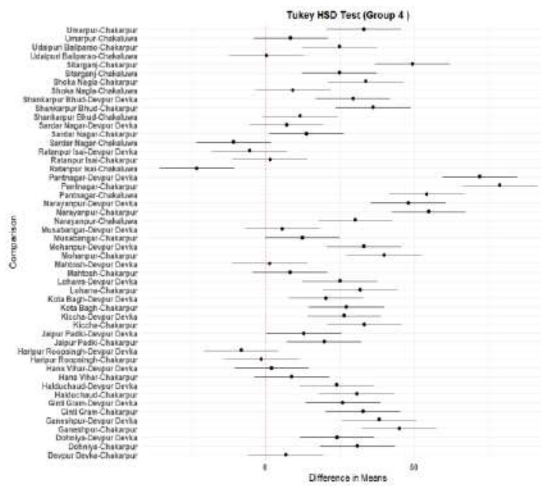
Kruskal Wallis and Dunn Test

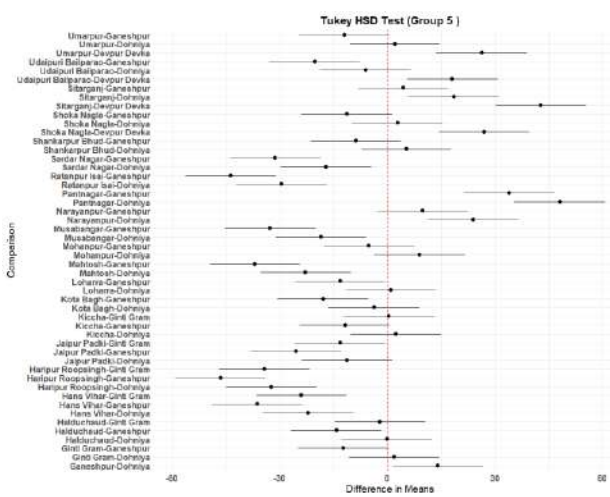
The Kruskal-Wallis test revealed significant differences in sheath blight disease severity across regions (χ^2 = 83.682, df = 29, p-value = 3.307e^{-07}). The results of the Kruskal-Wallis test and post-hoc Dunn test with Bonferroni adjustment revealed significant differences in sheath blight severity 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).

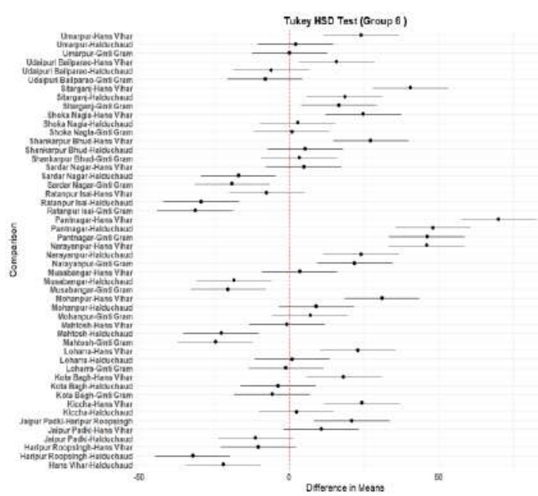

Tukey HSD Test (Group 1)
Comparison
-25
0
25
50
Difference in Means


Tukey HSD Test (Group 2)
Comparison
-25
0
25
50
75
Difference in Means


Tukey HSD Test (Group 3)
Comparison
-50
-25
0
25
50
Difference in Means


Tukey HSD Test (Group 4)
Comparison
0
50
Difference in Means


Tukey HSD Test (Group 5)
Comparison
-60
-30
0
30
60
Difference in Means


Tukey HSD Test (Group 6)
Comparison
-50
0
50
Difference in Means

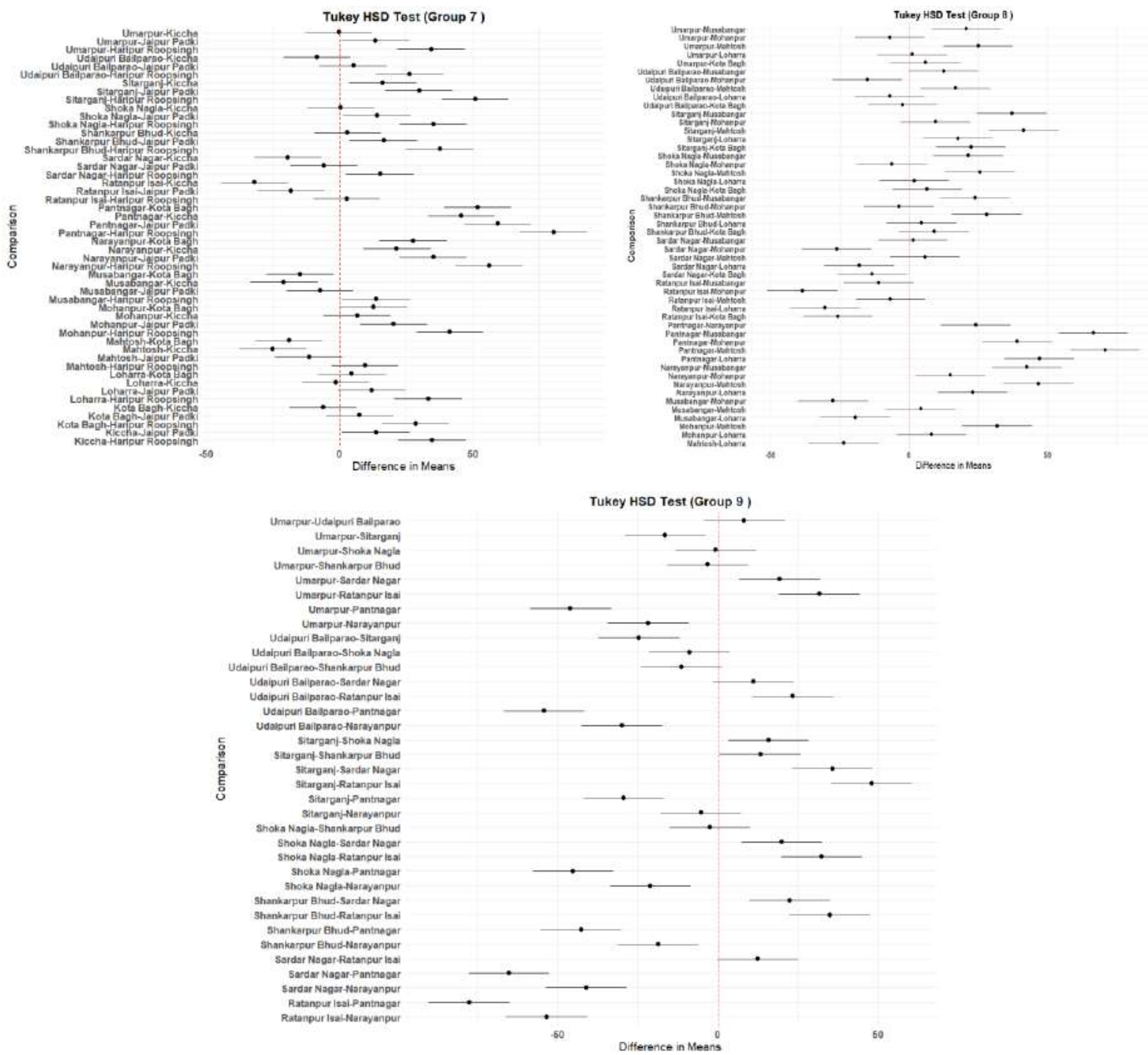


Figure 4. Tukey HSD Test for group wise comparison for rice disease severity

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 $\alpha = 0.05$, 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.

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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.

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

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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.

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

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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.

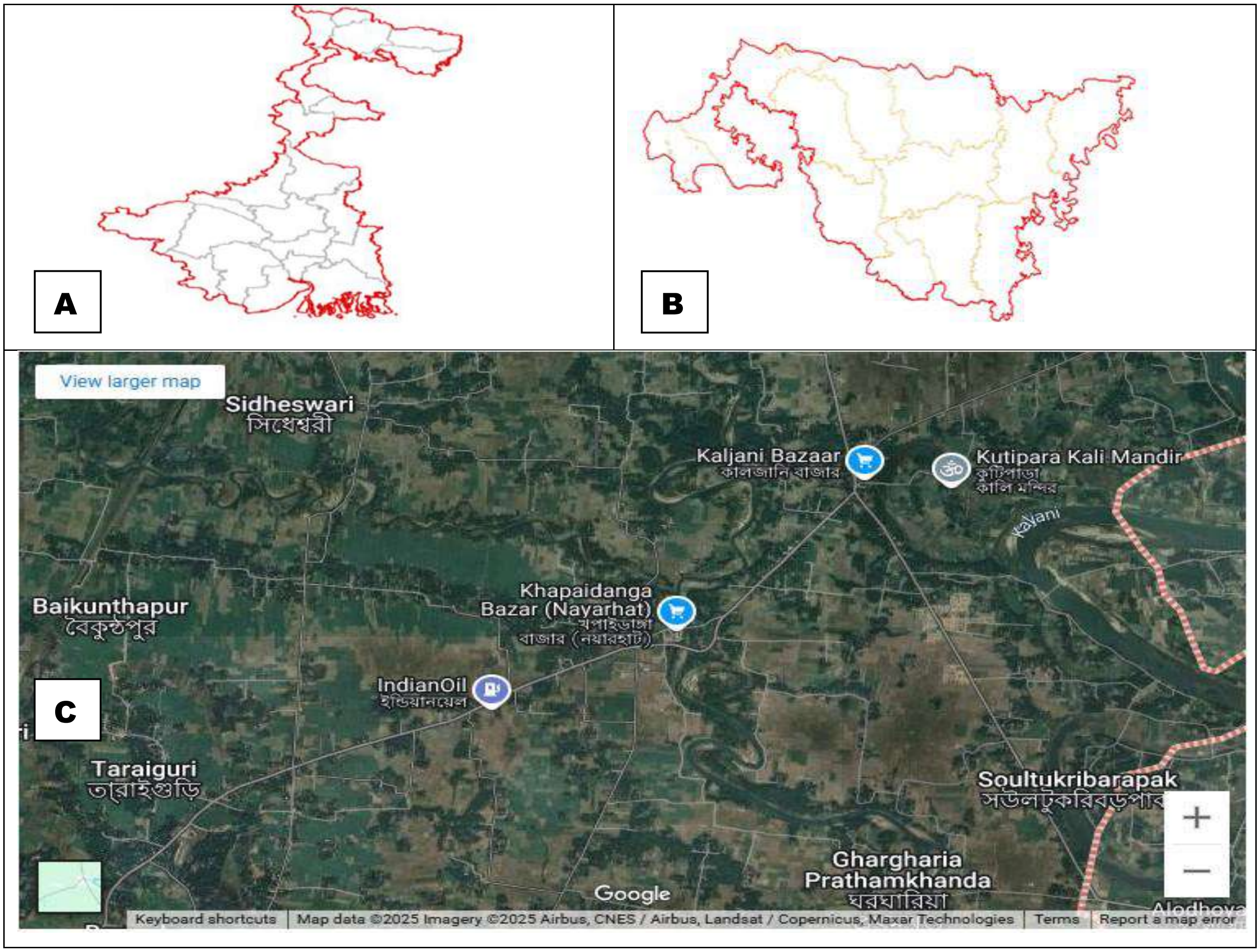


Figure 1. Map of the study area, A. West Bengal, B. Cooch Behar district, C. Khapaidanga village (Source: Internet)

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*., 2023a, 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).

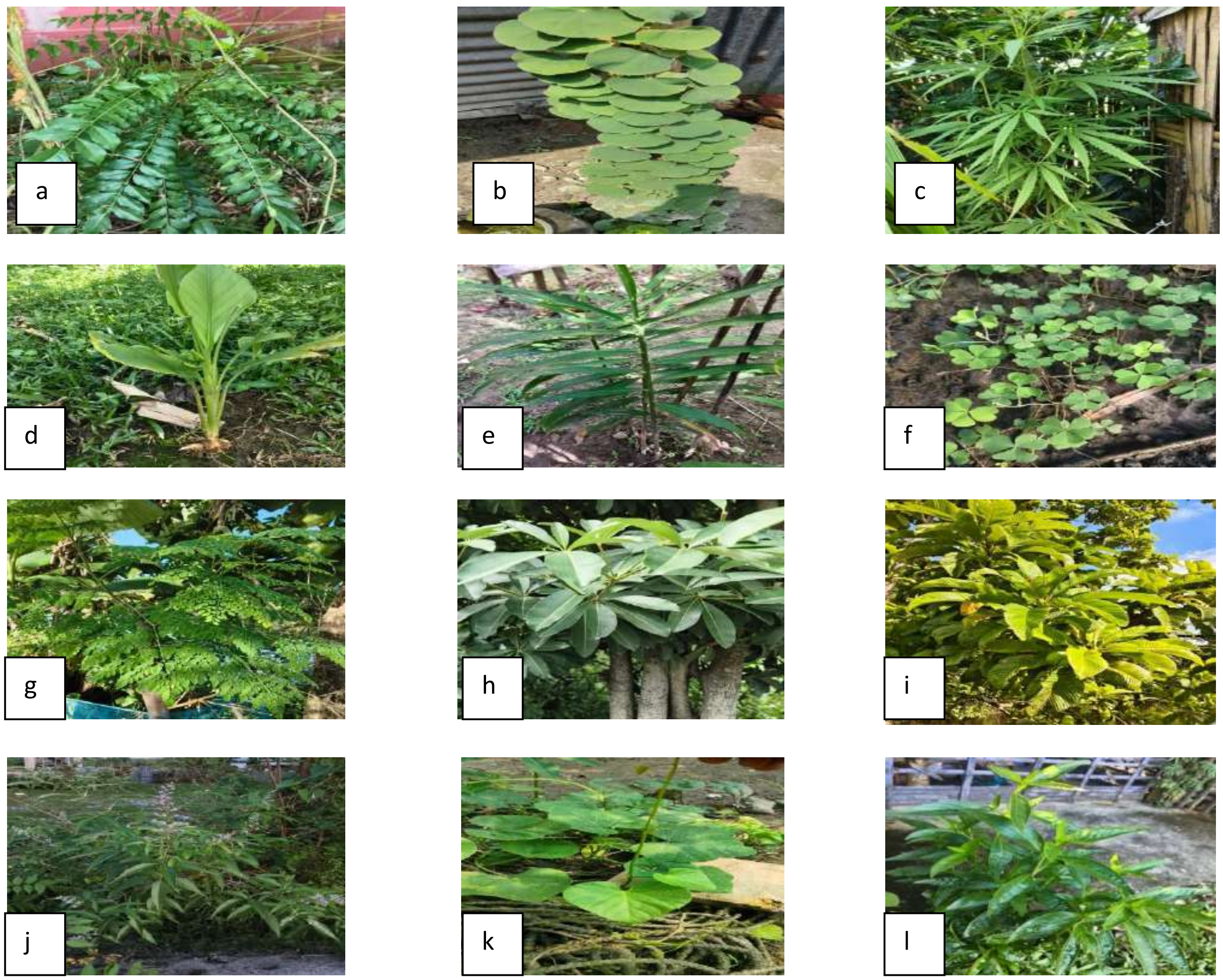


Plate 1. Some documented ethnomedicinal plants **a.** *Murraya koenigii*, **b.** *Cissampelos pareira*, **c.** *Cannabis sativa*, **d.** *Curcuma longa*, **e.** *Zingiber officinale*, **f.** *Oxalis corniculata*, **g.** *Moringa oleifera*, **h.** *Alstonia scholaris*, **i.** *Dillenia indica*, **j.**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

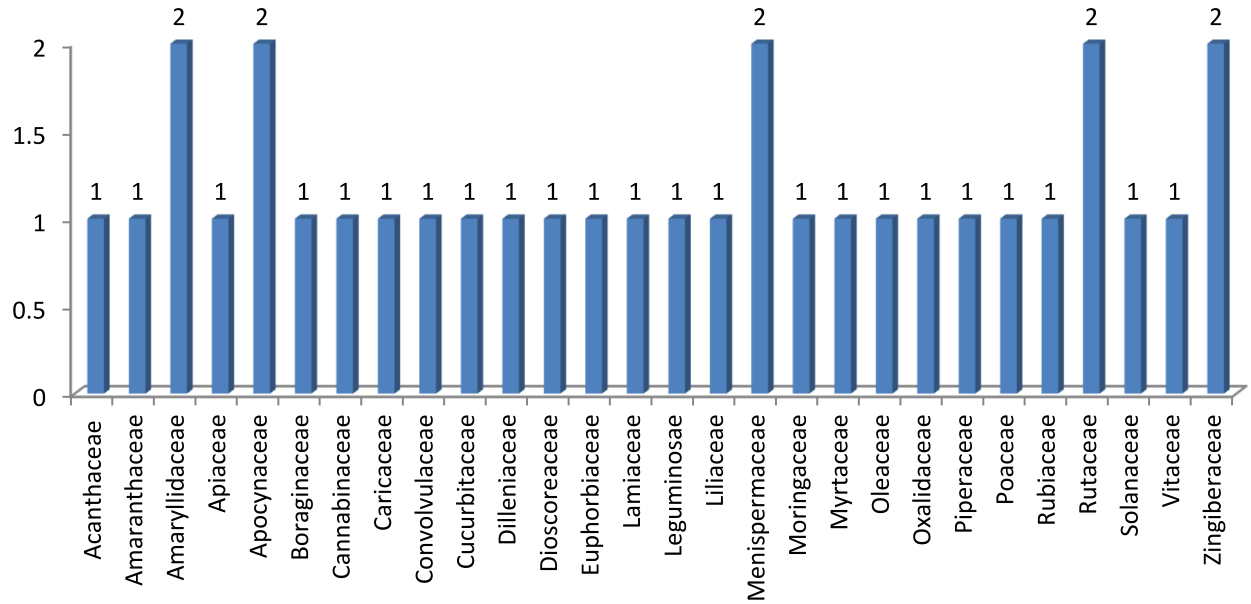


Figure 2. Ethnomedicinal plant families documented

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.

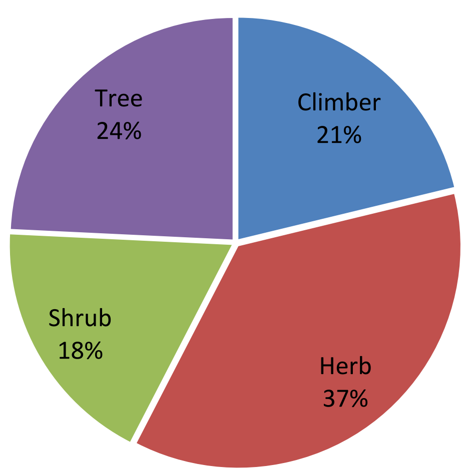


Figure 3. Growth habit of the ethnomedicinal plant species

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.

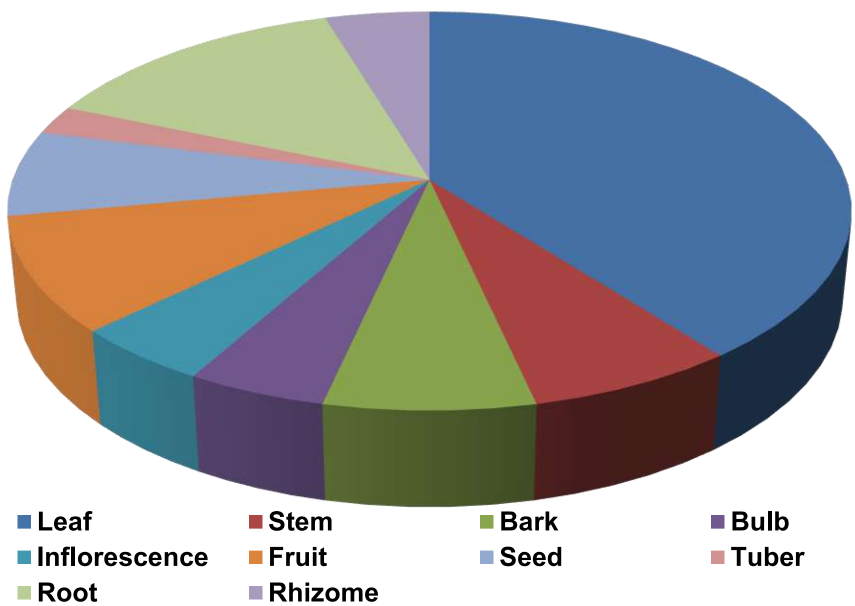


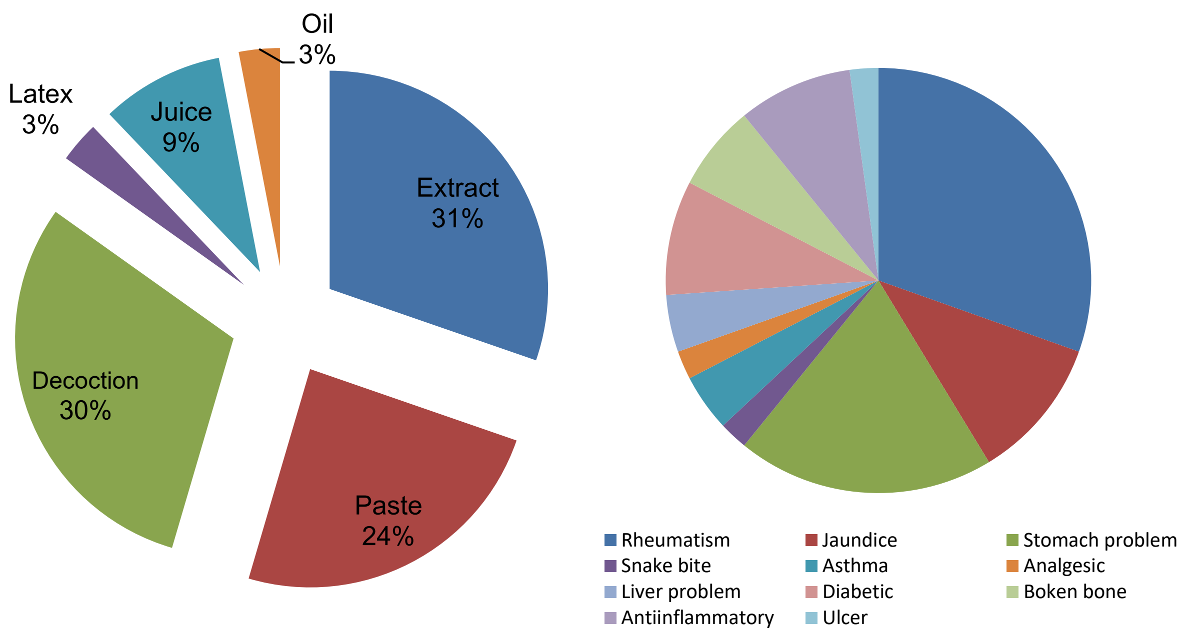
Figure 4. Plant parts of ethnomedicinal plant species used

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.

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Carbon Forestry and Ecosystem Services: Linking Livelihoods with Environmental Security

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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).

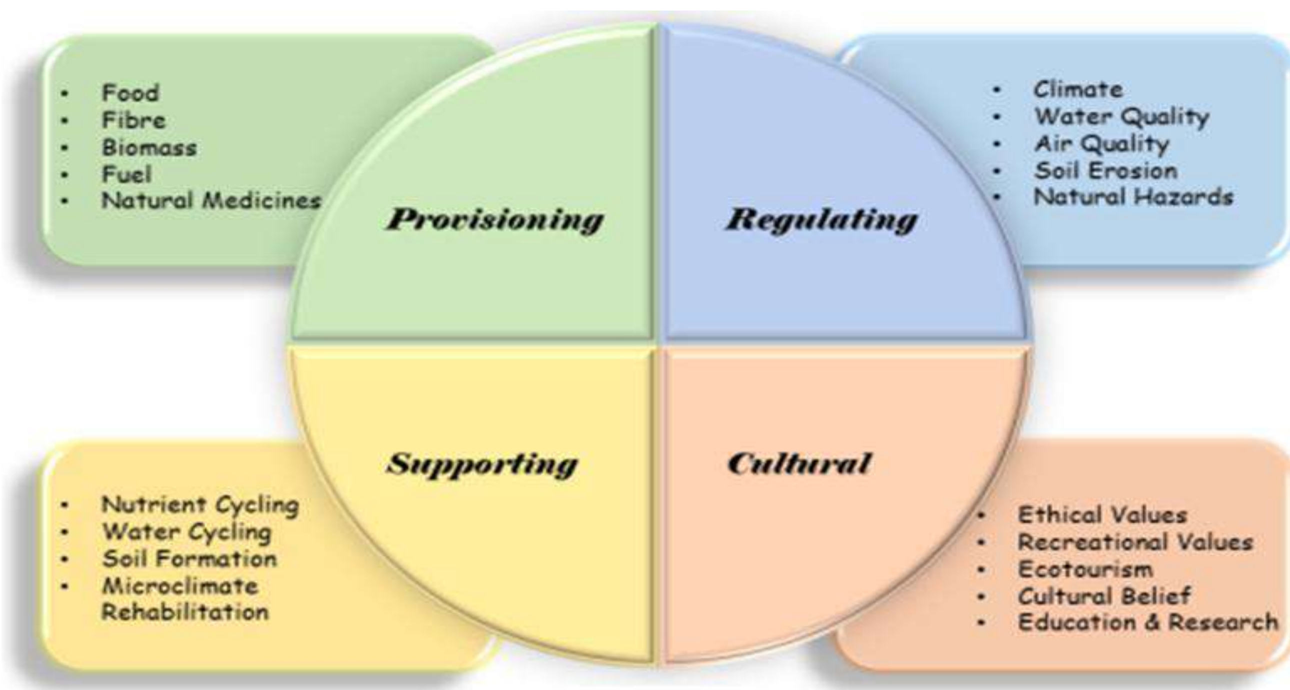

Figure 1. Different types of ecosystem services

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).

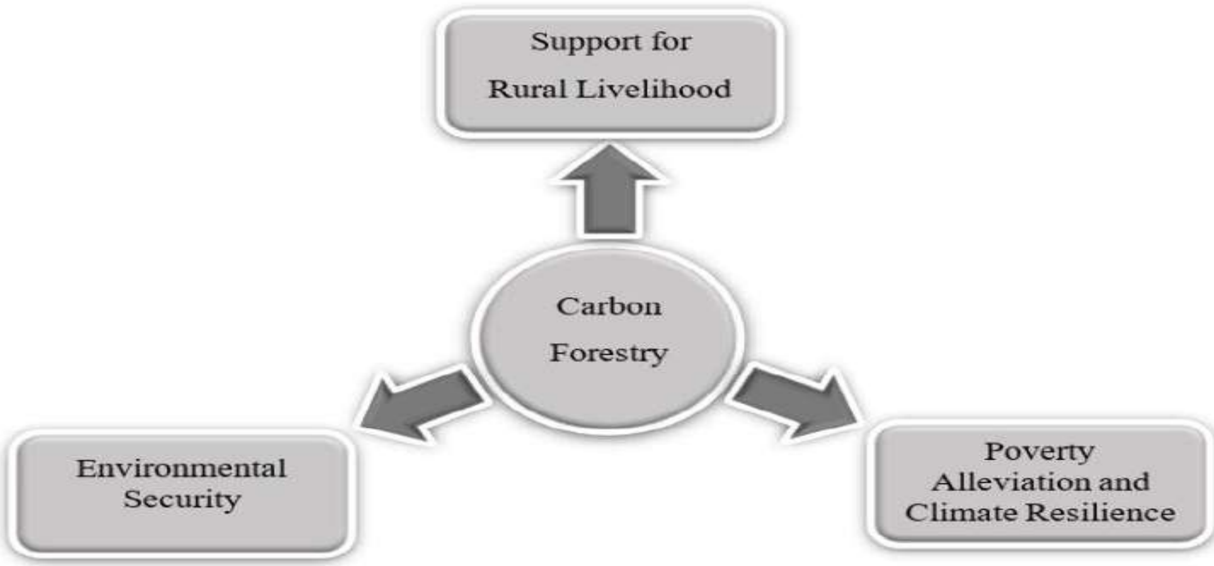

Figure 2. Linkage of carbon forestry and social livelihood

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.

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

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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.

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