Journal of Plant Development Sciences

Meerut, India

REVIEW ARTICLE

POTATO DRY ROT DISEASE: SYMPTOMS AND ETIOLOGY, PATHOGEN DIVERSITY, ASSOCIATED MYCOTOXINS AND THEIR IMPACT ON HUMAN AND ANIMAL HEALTH

Suroj Ahammed* and Bejoysekhar Datta

Mycology and Plant Pathology Research Laboratory, Department of Botany, University of Kalyani, Kalyani, Nadia, West Bengal, India, 741235.
Email: surojahammed4376@gmail.com

Received-01.02.2026, Revised-13.02.2026, Accepted-27.02.2026

Abstract: The world's potato crop is seriously threatened by *Fusarium* species that cause potato dry rot (PDR) disease. The crop stand is impacted by this soil- and seed-borne diseases because the pathogens inhibit potato sprouts development and cause severe tuber rots. Dry rot is indicated by sunken, wrinkled brown to black tissue areas with concentric rings on tubers. The pathogens infect potato tubers through the wounds. Although soil contaminated with *Fusarium* spp. is also a source of inoculum, the seed tuber is thought to be the primary source of inoculum. The diversity of the globally recognised, PDR causing 18 *Fusarium* species varies depending on the climate and geographic location. The pathogens produce different mycotoxins and the mycotoxins associated with PDR possess a serious threat to human and animal health when entered body through consumption of toxin contaminated food. This review provides a comprehensive overview of potato dry rot disease, covering its symptoms and etiology, pathogen diversity, mycotoxins associated with the disease and the impact of mycotoxins on human and animal health. The information detailed herein aims to improve the understanding about the current status and the significance of potato dry rot disease.

Keywords: *Fusarium* diversity, Mycotoxin toxicity, Post harvest disease, Potato tuber rot

INTRODUCTION

The potato (*Solanum tuberosum* L.), which comes in fourth place among food crops worldwide after rice, wheat, and maize, is a significant non-cereal crop for human consumption. Potato cultivation as a cash crop in areas with high rates of hunger and malnutrition, combined with their diverse distribution pattern, make potatoes a global crop for sustainable food availability (Haverkort *et al*., 2013).In addition to being a wealth of macronutrients like carbohydrates and dietary fiber and a great source of micronutrients like vitamins and minerals, potatoes are also a significant source of antioxidants for people's diets and contribute significantly to preserving food security in developing nations (Liu *et al*., 2022, FAOSTAT 2022).In 2023, India, the second-largest potato grower in the world, produced 59.74 million metric tons of potatoes. The nation's output has been increasing every day due to the expanding human population and their greater demand for food. However, biotic agents are the main barrier to the development of healthy seeds. The line of healthy potato seed development has significant biotic factor hurdles as a result of increased potato output to meet the growing population food demand. There are currently around 40 pathogens including bacteria, viruses, nematodes, fungi, and insects known to cause significant harm in various potato-growing regions and their infections pose a significant threat to the quality of potato tubers, which can lead to up to 22% of potato losses in the production system, either directly or indirectly(Kumar *et al*., 2020).

However, bacterial pathogens are the main causes of potato soft rots, potato dry rot is caused by the fungal pathogens belonging to the genus *Fusarium*. In contrast to soft rot, dry rot causes non-slimy lesions and causes the potato tuber to shrivel and shrink, exposing interior tissue and leaving a dark, depressed spot on the outside. During storage, fungal infections can spread up to 60% and potato sprout development is impeded, leading to losses of up to 25%(Wharton *et al*., 2007; Al-Mughrabi 2010). At least 18 species of *Fusarium* have been reported globally to be associated with the potato dr rot (PDR) disease and they produce diverse groups of mycotoxins which impart a serious threat to human and animal health when entered the body through food chain(Kumar *et al*., 2020;Xue *et al*., 2023).

Symptoms and etiology of potato dry rot disease:
Sunken tissue with a dry, leathery look and a wrinkled, dark appearance are the predominant signs of *Fusarium* spp. infection on potato tubers (Xue *et al*., 2023). Roots and tubers are the main parts of potato plants that are affected directly by dry rot

*Corresponding Author

pathogens. It is typical for tubers and roots to exhibit a pattern of shrivelling and shrinkage coupled with the formation of lesions on their exterior (Tiwari *et al*., 2020).After about a month of storage, the first signs of *Fusarium* dry rot on tubers manifest as shallow, little brown lesions at the wound sites. The periderm gradually sinks and may wrinkle in concentric rings as the underlying dead tissue desiccates, causing the lesions to expand in all directions (Bojanowski *et al*., 2013). The internal tissues also experience the brown or black decay at the same time. The pathogens enter the tubers mainly through the wounds, where internal tissue starts rotting that ultimately results in whitish, brick orange, brownish or blackish tissue. Necrotic lesions on the damaged roots of potato indicate the indirect influence of infection (Tiwari *et al*., 2020). When dry rot disease is severe, the potatoes may entirely decompose, giving them a mushy texture and an unpleasant smell. In order to stop potato dry rot from spreading further and to save financial losses, it is crucial to recognize and treat the condition (Xue *et al*., 2023).

Being hemi-biotrophs, the majority of *Fusarium* species live in soil as resistant spores or inside decaying plant tissues. In the field, soil and seed-borne inoculum may infect the plants, but storage is where most damage occurs and the seed tuber is thought to be the primary source of inoculum (Dean 1994, Bojanowski *et al*., 2013). Only when the potato skin is punctured can the pathogens infect the potato tuber, as they are incapable of doing so through the lenticels or in the absence of wounds. The pathogen gets entry into the tuber through wounds and penetrates through intercellular spaces; some may kill the host cells and grow in the intracellular region. While the pathogens are mesophilic in nature, some may survive below 5°C and cause dry rot during storage at low temperature (Bojanowski *et al*., 2013).

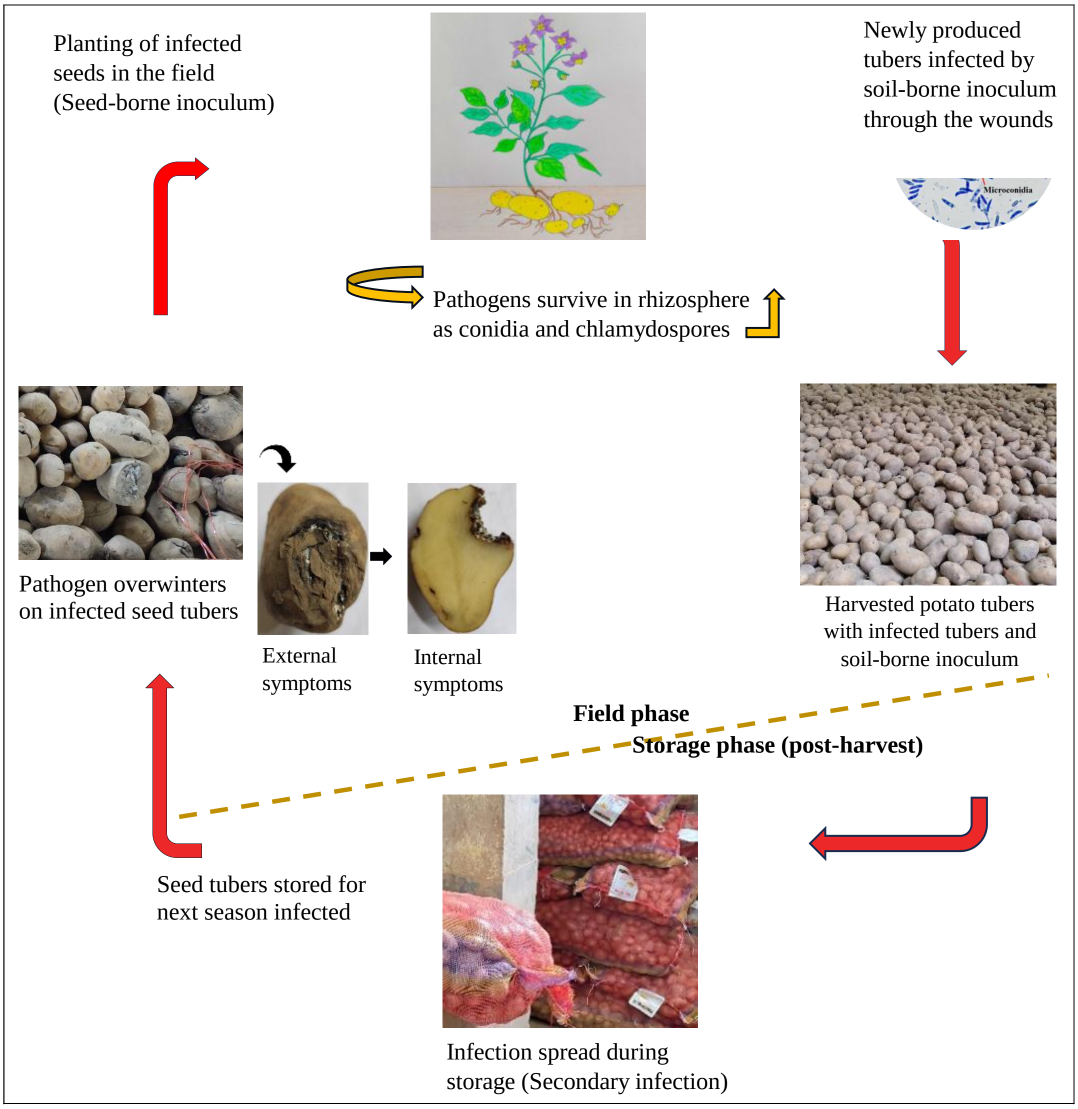

Figure 1. Disease cycle of potato dry rot disease consisting of field phase and post-harvest storage phase. Soil-borne inoculum (conidia and chlamydospores) infects the newly produced potato tubers. In post-harvest phase, inoculum from infected tubers infects the healthy tubers during storage and causes severe rot.

Diversity of *Fusarium* species causing potato dry rot:

One of the most destructive phytopathogenic fungus in the world is certainly *Fusarium* species which affects almost every crop that is farmed, including potatoes. There are at least 18 *Fusarium* species known to be responsible for potato dry rot (PDR) disease globally which include *F. oxysporum*, *F. sambucinum*, *F. avenaceum*, *F. graminearum*, *F. solani*, *F. acuminatum*, *F. proliferatum*, *F. equiseti*, *F. culmorum*, *F. crookwellense*, *F. coeruleum*, *F. incarnatum*, *F. sulphureum*. *F. semitectum*, *F. sporotrichioides*, *F. scirpi*, *F. vertical* and *F. tricinctum*. To find new species implicated in the disease, more surveys and sampling are required as this number is still not all-inclusive((Tiwari *et al*., 2020;Xue *et al*., 2023).

Based on geographic area and prevailing climatic conditions, *F. oxysporum*, *F. solani*, and *F. sambucinum* are the most common and damaging species of *Fusarium* responsible for potato dry rot (Stefańczyk *et al*., 2016). *F. sambucinum* and *F. coerulum* are the two most common fungi responsible for potato dry rot in the USA (Secor and Salas, 2001) and Great Britain (Peters *et al*., 2008) respectively. *F. avenaceum* and *F. culmorum* are minor rot-causing fungi. Still, according to a number of reports, *F. sulphureum* is the most common fungus in North America and Europe (Recep *et al*., 2009, Gachango *et al*., 2012). In South Africa the main fungi responsible for the dry rot in potato are *F. solani*and *F. oxysporum* (Theron and Holz, 1990). Iran's most common potato cultivars have been shown to be more prone to dry rot by *F. sulphureum* and *F. solani*. Fascinatingly, reports indicate that the predominant dry rot agent in North Dakota, Tunisia, and Canada is the cereal fungus *F. graminearum* (Daami-remadi *et al*., 2012; Tiwari *et al*., 2020). More recently, in our previous study, five fungal isolates of *Fusarium* (*F. oxysporum*, *F. sambucinum* and *F. avenaceum*) and a fungal isolate of *Geotrichum candidum* have been reported as the causal agent of potato dry rot in West Bengal state of India (Ahammed and Datta, 2025; Ahammed and Datta, 2026).

Mycotoxins associated with potato dry rot:

Mycotoxins produced by phytopathogenic fungi are secondary fungal metabolites that interfere with metabolism and cellular processes and ultimately to kill living host cells by rupturing membrane integrity. The host tissue may experience morphological, physiological, and metabolic changes as a result of these mycotoxins. The accumulation of several mycotoxins is linked to *Fusarium*-induced dry rot of potatoes. The mycotoxin fusaric acid inhibits the host tissue's peroxidase and polyphenol oxidase activities and decreases periderm growth by inhibiting steroid glycoalkaloids, which contributes to the start of potato dry rot disease (El-Hassan *et al*., 2007, Ismaiel and Papen brock 2015). Under the condition of suitable temperature and humidity, toxigenic fungi can produce several mycotoxins that could be harmful to human and animal health (Xue *et al*., 2023). These *Fusarium* mycotoxins, which fall into two categories—trichothecene and non-trichothecene—have been found in a variety of host plants infected by this pathogen. The trichothecenes are sesquiterpenes, which are responsible for phytotoxicity in host plants and mycotoxicosis in both humans and animals (Bojanowski *et al*., 2013; Nagaraja *et al*., 2016). More than 190 known trichothecenes have been identified till date. Based on variations in their chemical structures, trichothecenes are categorized into four groups: A, B, C, and D. The non-macrocyclic trichothecenes, produced by Fusarium species that infect potato and cereal crops, are mostly classified as type A (which contains diacetoxyscirpenol [DAS] and T-2 toxin) and type B (which includes nivalenol [NIV] and deoxynivalenol [DON]) (Delgado *et al*., 2010). As has been previously reported, a large number of *Fusarium* species that cause dry rot (*F. oxysporum, F. sambucinum, F. graminearum, F. coeruleum* and *F. equiseti*) produce trichothecenes NIV, T-2 toxin, DON and DAS in the tissues of rotting potato tubers (Bojanowski *et al*., 2013; Eranthodi *et al*., 2020).

The main non-trichothecene mycotoxins produced by *Fusarium* in dry rotted potato tubers arezearalenones (ZEA), beauvericin (BEA), fumonisins (FUM), sambutoxin (SAM), fusaric acids (FA),fusarin C (FUS), and enniatins (ENN)(Song *et al*., 2006;Bojanowski *et al*., 2013;Tiwari *et al*., 2020;Eranthodi *et al*., 2020;Hadjebar *et al*., 2024).Dry rotting potato tubers infected with *F. oxysporum* were shown to contain beauvericin (BEA) and enniatins (ENN), which have antibacterial, insecticidal, phytotoxic, and cytotoxic qualities (Song *et al*., 2006).Potato tubers infected with *F. sambucinum*, *F. solani*, and *F. oxysporum* showed contamination of Zearalenone (ZEA) and Fusarin C (FUS) (Golinski *et al*., 1998). When Potato tubers are dry rotted due to infection by *F. oxysporum*, *F. equiseti* and *F. sambucinum*, fumonisin (FUM) toxin accumulation has been found. Fusaric acid (FA) is produced in potato tubers infected with *F. oxysporum*, and there is a positive correlation between the incidence of dry rot and FA content (El-Hassan *et al*., 2007).In our recent study, potato dry rot causing *F. avenaceum* has reported for the first time to produce the trichothecene mycotoxin Deoxynivalenol (DON) and non-trichothecene mycotoxins like zearalenones (ZEA), sambutoxin (SAM), Fusaric acid (FA) and Fusarin C (FUS) (Ahammed and Datta, 2025).

Table 1. The major trichothecene and non-trichothecene mycotoxins produced by *Fusarium* species associated with potato dry rot disease

Toxins	Chemical formula	*Fusarium* species	References
Trichothecene toxins			
T-2 toxin	$C_{24}H_{34}O_9$	*F. oxysporum, F. equiseti,F.graminearum,F. sambucinum, F. sporotrichiodes,F. langsethiae*	El-Hassan *et al*., 2007; Eranthodi *et al*. 2020
HT-2 toxin	$C_{22}H_{32}O_8$	*F. coeruleum, F. sambucinum, F.sporotrichiodes, Fusarium langsethiae*	Desjardins and Gardner,1989
Nivalenol	$C_{15}H_{20}O_7$	*F. culmorum, F. equiseti, F. graminearum, F. sambucinum,F. crookwellense,F. sporotrichiodes*	Nielsen and Thrane, 2001; Delgado *et al*., 2010; Eranthodi *et al*., 2020
Deoxynivalenol	$C_{15}H_{20}O_6$	*F. culmorum, F. coeruleum,F.sambucinum, F. graminearum, F. oxysporum,F.sporotrichiodes, F. equiseti,F. avenaceum*	Delgado *et al*., 2010; Eranthodi *et al*. 2020; Ahammed and Datta, 2025
3-acetyldeoxynivalenol	$C_{17}H_{22}O_7$		
15-acetyldeoxynivalenol	$C_{17}H_{22}O_7$		
Neosolaniol	$C_{19}H_{26}O_8$	*F. sambucinum, F. sporotrichiodes*	Nielsen and Thrane, 2001
Fusarenone	$C_{17}H_{22}O_8$	*F. culmorum, F. equiseti, F. graminearum,*	Nielsen and Thrane, 2001
4-acetyl-monoacetoxyscirpenol, 15-acetyl-monoacetoxyscirpenol Diacetoxyscirpenol	$C_{17}H_{24}O_6$ $C_{17}H_{24}O_6$ $C_{19}H_{26}O_7$	*F. equiseti, F. sambucinum F. sulphureum, F. solani*	Nielsen and Thrane, 2001; El-Hassan *et al*., 2007; Xue *et al*., 2013; Eranthodi *et al*., 2020
Non-trichothecenetoxins			
Beauvericin	$C_{45}H_{57}N_3O_9$	*F. sambucinum, F. equiseti, F. oxysporum,F. acuminatum, F. avenaceum*	Song *et al*., 2006
Enniatins	$C_{33}H_{57}N_3O_9$	*F. acuminatum, F. avenaceum, F. oxysporum, F. sambucinum, F. scirpi*	Song *et al*., 2006
Zearalenones	$C_{18}H_{22}O_5$	*F. crookwellense, F. equiseti,F. solani,F. graminearum, F. oxysporum, F. sambucinum, F. sporotrichiodes,F. avenaceum*	Golinski *et al*., 1998; El-Hassan *et al*., 2007; Alwan *et al*., 2020; Ahammed and Datta, 2025
Sambutoxin	$C_{28}H_{39}NO_4$	*F. sambucinum, F. oxysporum,F. avenaceum*	Kim and Lee, 1994; Ahammed and Datta, 2025
Fumonisin	$C_{34}H_{59}NO_{15}$	*F. sambucinum, F. equiseti, F. oxysporum*	El-Hassan *et al*., 2007
Fusaric acid	$C_{10}H_{13}NO_2$	*F. sambucinum, F. crookwellense,F. solani,F. oxysporum,F. avenaceum*	Venter *et al*., 1998; El-Hassan *et al*., 2007; Ahammed and Datta, 2025
Fusarin C	$C_{23}H_{29}NO_7$	*F. sambucinum,F. sulphureum, F. solani,F. crookwellense,F. oxysporum,F. avenaceum*	Golinski *et al*., 1998; Stefańczyk *et al*., 2016; Ahammed and Datta, 2025

Impact of mycotoxins on human and animal health:

Mycotoxins build up on distant, seemingly healthy tissues in addition to the decaying tissues of the infected potato tubers and these mycotoxins could be harmful to human and animal health. DON is the most common mycotoxin found in the rotting tissues of potato tubers. Since DON is enzymatically transformed into NIV in the rotten potato tissue, it is typically found in conjunction with NIV (Delgado *et al*., 2010). While trichothecene mycotoxin DON, commonly called vomitoxin, is a strong protein synthesis inhibitor that suppresses the immune system and results in dysphagia. Ingestion of DON mycotoxin can result in both immediate and long-term damage. Abdominal pain, intestinal damage, nausea, dizziness, headache, anorexia, diarrhea, increased salivation, vomiting, and malaise are examples of acute symptoms. Anorexia, weight loss, and changes in dietary efficacy are the most frequent consequences of long-term DON exposure. It causes epithelial cell cycle arrest at G_2/M and G_0/G_1 phase, micronucleus induction, DNA damage (Kamle *et al*., 2022). Mycotoxin NIV has cytotoxic and immunotoxic effects, destroys thymus and bone marrow cells, and lowers peripheral blood lymphocyte counts by apoptosis (Kumar *et al.*, 2022). T-2/HT-2 toxin produces oxidative damage, aberrant immunoglobulin alterations, mitochondrial malfunction, and teratogenic, cytotoxic, and hematotoxic effects (Meneely *et al*., 2023). Zearalenone inhibits the synthesis of follicle stimulating hormones, suppresses ovarian follicle maturation, and results in reproductive abnormalities by competitively binding to estrogen receptors. Through the G protein-coupled estrogenic receptor, a low dose of zearalenone increased the proliferation of colon cancer cells (Lo *et al*., 2021). Sambutoxin has hematotoxic effects, causes apoptosis and cell cycle halt, and alters mitochondrial respiration

(Kim*et al*.,1994). Fusarin C, a polyketide mycotoxin generated by PDR pathogens, has a mutagenic effect and disrupts mammalian chromosomes. Due to its carcinogenic effects, Fusarin Cstimulates Breast cancer *in-vitro* and is associated with esophageal cancer (Sondergaard *et al*., 2011). Fumonisin is a polyketide mycotoxin that causes esophageal carcinoma, kidney and liver tumors, neurotoxic, hepatotoxic, and immunotoxic effects, deregulates calcium homeostasis, and interferes with sphingolipid metabolism (Kamle *et al*., 2019).

CONCLUSION

Fusarium dry rot is one of the most damaging forms of potato decay that lowers tuber quality, causes financial losses, and contaminates tubers with mycotoxin. There are 18 species of *Fusarium* that cause potato dry rot worldwide, and the genetic diversity varies depending on the geographical regions and climatic variations. The frequency and aggressiveness of *Fusarium* strains that cause dry rot in a location-specific manner are also influenced by the dominant cultivars and environmental conditions. The mycotoxins associated with the potato dry rot impart a serious threat to human and animal health when entered the body through food chain.

ACKNOWLEDGEMENT

The work has been supported by funds received from University of Kalyani and UGC, Govt. of India.

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Journal of Plant Development Sciences
Meerut, India

RESEARCH ARTICLE

PHYTOCHEMICAL STUDIES ON TRIBALLY USED AQUATIC MEDICINAL PLANTS OF LALBAGH BLOCK OF MURSHIDABAD DISTRICT, WEST BENGAL, INDIA

Souhardya Ray[1], Sutibra Narayan Mondal[1], Mithun Biswas[1] and Asim Mandal[2]*

[1]Department of Botany, Murshidabad University, West Bengal, India
[2]Department of Botany, Krishnath College, Murshidabad, West Bengal, India
Email: asimbotvu@yahoo.com

Received-22.01.2026, Revised-09.02.2026, Accepted-26.02.2026

Abstract: Since ancient times, plants have been utilized to treat a wide range of ailments. Conventional medical practices, such as Homeopathy, Ayurveda, and Unani, utilize the understanding of ethnomedicinal plants to address human health problems. Among tribal communities, these plants continue to be used for various traditional healthcare practices. Plants possess a multitude of bioactive chemicals that serve as the foundation for medical care; known as Secondary metabolites. The present study deals with the phytochemical screening and ethnomedicinal documentation of aquatic plants used by the tribal people of Lalbagh block of Murshidabad district. Fourteen aquatic and semi-aquatic plant species belonging to different families have been documented through field surveys and interviews, highlighting their medicinal importance. Each species then subjected to phytochemical screening using aqueous and organic solvent extracts to detect the different secondary metabolites. Results confirmed the presence of alkaloids, flavonoids, tannins, saponins, terpenoids, phenol etc. These secondary metabolites are associated with specific pharmacological activities that validate the indigenous therapeutic claims. This study aims towards detailed documentation of tribally used ethnomedicinally important aquatic plants with their potential reservoirs of bioactive compounds for future drug development and sustainable healthcare approaches.

Keywords: Phytochemical screening, Secondary metabolites, Tribal ethnomedicinal profiles, Murshidabad

INTRODUCTION

The present study aims to document and evaluate the phytochemical composition of aquatic and semi-aquatic medicinal plants traditionally utilized by the tribal communities of the Lalbagh block of Murshidabad district, West Bengal. Medicinal plants have been used since ancient times as a primary source of healthcare across different cultures, owing to their diverse bioactive constituents known as secondary metabolites. Aquatic and semi-aquatic plants, although less explored than terrestrial plants, represent an important group of medicinal flora with immense pharmacological potential. These plants thrive under unique ecological conditions, often resulting in the synthesis of distinctive secondary metabolites with antioxidant, antimicrobial, anti-inflammatory, and neuroprotective properties (Arya *et al*., 2022).
Ethnobotanical research conducted across different regions of India indicates that indigenous and tribal communities possess extensive and well-structured traditional knowledge related to the use of medicinal plants, including aquatic and semi-aquatic species, for treating a wide range of health-related issues. This knowledge system, which is largely transmitted verbally from one generation to the next, plays a vital role in primary healthcare practices and reflects long-term empirical observations of plant efficacy. Such indigenous wisdom forms a crucial foundation for contemporary ethnopharmacological research, aiding in the scientific validation of traditional remedies and the identification of potential bioactive compounds (Sharma, Thakur, & Uniyal, 2019). Recent reviews highlight that aquatic and semi-aquatic medicinal plants are rich sources of alkaloids, flavonoids, tannins, saponins, terpenoids, glycosides, phenols, and steroids, which contribute significantly to their therapeutic efficacy (Ochatt *et al.*, 2022). These compounds play crucial roles in plant defense and exhibit strong biological activities beneficial to human health. Few Studies focusing on hydrophytes have demonstrated that phenolic compounds and flavonoids are among the most dominant metabolites, imparting antioxidant, antimicrobial, antiparasitic, and anticancer activities (Alharthi *et al.*, 2024). This highlights the pharmaceutical relevance of wetland plants and supports their traditional medicinal usage. In India, wetlands serve as biodiversity-rich ecosystems supporting numerous medicinal aquatic plants. Ethnobotanical surveys conducted in different regions of the country have documented extensive use of aquatic macrophytes by tribal communities for traditional healthcare practices (Behera, 2006).

*Corresponding Author

However, scientific validation of these medicinal claims through phytochemical screening remains inadequate for many species.

Comparative phytochemical studies have clearly demonstrated that solvent polarity plays a crucial role in the extraction of secondary metabolites from plant materials. Organic solvents such as methanol and ethanol are generally more efficient than aqueous solvents in extracting a wider range of bioactive compounds due to their ability to dissolve both polar and moderately non-polar phytochemicals. Such solvent-based evaluations are therefore essential for understanding metabolite solubility patterns and optimizing extraction efficiency in phytochemical investigations (Tiwari et al., 2011). Systematic ethnobotanical studies from West Bengal indicate that aquatic and semi-aquatic medicinal plants continue to be widely used in rural and tribal healthcare systems, yet many remain unexplored scientifically. Documentation efforts in different districts have recorded extensive traditional uses of wetland and local flora for treating diverse ailments, emphasizing the need for phytochemical and pharmacological validation of these species (Chakraborty, Mondal, & Mukherjee, 2016).

Statistical evaluation will further assess the efficiency of different solvents in extracting these compounds and highlight metabolite richness across species (Kumar & Bhat, 2022). By correlating ethnomedicinal claims with laboratory-based phytochemical profiles, the study intends to identify potential candidate plants for pharmacological exploration, drug discovery, and sustainable healthcare practices (WHO, 2013). Ultimately, this research underscores the importance of conserving indigenous medicinal plant resources and promoting their sustainable use in the context of biodiversity preservation and traditional knowledge systems, thereby contributing to both scientific advancement and community-based healthcare resilience.

METHODOLOGY

The present study deals with the ethnobotanical knowledge related to medicinal uses of aquatic and semi aquatic plants used by tribal as well as local people of Lalbagh block of Murshidabad district (24.17590^o N, 88.28020^o E), West Bengal. The district Murshidabad is one of the important districts in West Bengal that is full of rivers and wetlands. Generally, two types of interviews were conducted- firstly, of individuals and secondly of groups. Of individuals, people were selected randomly from the knowledgeable and for groups more than one person is approached. They talk about the plants and their local collection side as well. Plants were then collected and identified with the help of different Floras and standard literatures. For every plant species, the appropriate morphology and other important traits were meticulously recorded. A documentation table was created to store the detailed knowledge of tribal folk medicine of Lalbagh block of Murshidabad District showing the plants scientific name as well as local name with their medicinal uses. Which parts of the plants and how those parts are used are also documented.

To check the medicinal properties of those plants, phytochemical screening of secondary metabolites has been performed. Firstly, fresh leaves are collected from each plant sample and crushed thoroughly using a mortar pestle with aqueous, methanol &ethanol as the solvent. The obtained crude extracts then taken into centrifuge tubes and centrifuged for 12-15 minutes. Supernatant is taken and filtration was done using filter paper. Lastly, the final filtered supernatants are taken in the fresh test tubes and labeled properly for various qualitative phytochemical tests, (Ochatt *et al.,* 2022).

Qualitative Test

A. **Test for Alkaloids:** 2ml 1% HCl is added to the crude extract. Then the mixture is heated and then Mayer’s reagent and Wagner’s reagent are added and if precipitate is formed then it shows the presence of alkaloids. (Mandal *et al.,* 2023)

B. **Test for Flavonoids:** Alkaline reagent test is performed; 1 ml of crude extract is taken to it 3 ml of 2% NaOH solution is added. Dark yellow is developed and then if a few drops of diluted acid are added the color disappears. This confirms the presence of flavonoids in the sample. (Mandal *et al.,* 2023)

C. **Test for Tannins:** 3 ml of the crude extract is taken obtained from the plant samples and to it, 1 ml of distilled water is added to it. To this mixture of the solution, 1ml of 5% Ferric chloride solution is added. If black is formed, then it indicates the presence of tannins. (Mandal *et al.*, 2023)

D. **Test for Saponins:** 1 ml of the crude extract and 5 ml of distilled water was taken and shaken vigorously; the constant foam formation indicated the presence of saponin. (Mandal et al., 2023)

E. **Test for Terpenoids:**1 ml of the crude extract was taken, and 2 ml of conc. sulfuric acid (H_2SO_4) was added to it. If reddish-brown coloration at the interface appeared, indicates terpenoids.

F. **Test for Glycosides:** Keller-Kilani test, 1 ml of the crude extract was taken and mixed with 2ml of Glacial acetic acid. 1 ml of 2% Ferric chloride solution is used. Then to the mixture 2 ml of conc. H_2SO_4 is added. A brown ring is formed at the interface which gives a positive result for the Glycosides. (Mandal *et al*., 2023)

G. **Test for Phenols:** 2 ml of alcohol and 1 ml of Ferric chloride solution is added to 1 ml of crude extract. If blue, green, or black color is developed, it shows the presence of phenols in the sample. (Mandal *et al.*, 2023)

RESULTS AND DISCUSSIONS

The survey conducted in the wetland and adjoining rural areas of the Lalbagh block, Murshidabad district, revealed a rich diversity of aquatic and semi-aquatic medicinal plants traditionally used by local and tribal communities for primary healthcare. Information regarding vernacular names, plant parts used, modes of preparation, and therapeutic applications was systematically documented through field observations and interactions with traditional healers and elderly informants. A total of 14 aquatic medicinal plant species belonging to 13 families were recorded, reflecting the strong dependence of indigenous communities on wetland flora for treating a wide range of ailments.

These plants are primarily utilized in the form of fresh pastes, decoctions, infusions, indicating simple yet effective traditional processing methods (Tomar, 2022). Leaves and whole plants were the most frequently used parts, which may be attributed to their easy availability and higher concentration of bioactive compounds. The recorded medicinal uses ranged from treatment of skin disorders, wounds, and inflammation to neurological, digestive, and metabolic conditions. Such medicinal practices are consistent with earlier reports from wetland-rich regions of eastern India, highlighting the therapeutic significance of aquatic plant resources.

Based on documented information on medicinally important plants, subsequent phytochemical evaluation and comparative analysis of secondary metabolites are conducted. The list of traditionally used aquatic medicinal plants recorded from the study area, along with their botanical identity, family, parts used, method of use, and medicinal importance, is presented in Table 1.

Table 1: Shows the list of tribally used aquatic medicinal plants of Lalbagh block of Murshidabad district

Sl. No	Common Name	Botanical Name	Family	Parts Used	Method Used	Medicinal Importance
1	**Thankuni**	*Centella asiatica* (L.) Urb.	Apiaceae	Leaves, whole plant	Crushed or boiled to make herbal tea or paste	Memory enhancement, wound healing, skin issues
2	**Brahmi Shak**	*Bacopa monnieri* (L.) Wettst.	Plantaginaceae	Whole plant	Made into decoction or paste for oral use	Nervine tonic, epilepsy, anti-anxiety
3	**Bhringraj**	*Eclipta prostrata* (L.) L.	Asteraceae	Leaves, whole plant	Leaf juice applied topically or taken orally	Liver tonic, hair growth promoter, skin problems
4	**Kolmi Shak**	*Ipomoea aquatica*Forssk.	Convolvulaceae	Stems and leaves	Cooked as vegetable, leaf juice used	Anti-inflammatory, detoxification, jaundice remedy
5	**Sushni Shak**	*Marsilea quadrifolia* L.	Marsileaceae	Leaves	Boiled or juiced, sometimes dried	Anticonvulsant, febrifuge, urinary relief
6	**Water Lily**	*Nymphaea nouchali* Burm.f.	Nymphaeaceae	Flowers, roots	Flower extracts used in decoctions	Cooling agent, astringent, promotes fertility
7	**Lotus**	*Nelumbo nucifera*Gaertn.	Nelumbonaceae	Flowers, seeds, rhizomes	Seeds eaten, petals used in infusions	Cardiac tonic, anti-diarrheal, wound healing
8	**Water Hyacinth**	*Eichhornia crassipes* (Mart.) Solms	Pontederiaceae	Leaves, roots	Crushed into poultice or paste	Skin diseases, inflammation (used cautiously)
9	**Water Lettuce**	*Pistia stratiotes* L.	Araceae	Whole plant	Crushed for topical use	Rheumatism, skin disorders (folk application)

Sl. No	Common Name	Botanical Name	Family	Parts Used	Method Used	Medicinal Importance
10	**Arrowhead**	*Sagittaria trifolia* L.	Alismataceae	Tuber, leaves	Tubers boiled or ground for pastes	Antibacterial, healing wounds, edible
11	**Rice Paddy Herb**	*Limnophila indica* (L.) Druce	Plantaginaceae	Whole plant	Used as infusion or in fresh paste form	Cough suppressant, expectorant, used in fever & indigestion
12	**Water Fern**	*Salvinia molesta* D.S. Mitch.	Salviniaceae	Whole plant	Dried or used in aqueous extracts	Antioxidant, anti-inflammatory, reported antimicrobial
13	**Water Smartweed**	*Polygonum glabrum* Willd.	Polygonaceae	Leaves, stem	Crushed paste or decoction	Antimicrobial, wound healing, anti-inflammatory
14	**Matsyaakshi**	*Alternanthera sessilis* (L.) R.Br. ex DC.	Amaranthaceae	Whole plant	Eaten raw/cooked, used in infusions	Improves eyesight, skin ailments, blood purifier

To validate the ethnomedicinal relevance of the recorded aquatic plant species, a preliminary qualitative phytochemical screening was carried out to detect the presence of major secondary metabolites responsible for therapeutic activity. Extracts of each plant species were prepared using three solvents of varying polarity—aqueous, ethanol, and methanol—in order to assess solvent efficiency and metabolite solubility. The use of multiple solvent systems is essential, as different classes of phytochemicals exhibit differential extractability depending on solvent polarity.

The screening focused on seven important groups of secondary metabolites, namely alkaloids, flavonoids, tannins, saponins, terpenoids, glycosides, and phenols, which are widely reported for their pharmacological properties such as antioxidant, antimicrobial, anti-inflammatory, and neuroprotective activities. Qualitative tests were performed following standard phytochemical protocols, and the results were recorded based on the intensity of colour development or precipitate formation, categorized as present (+), weakly present (±), or absent (−).

The comparative phytochemical profiles obtained across different solvent extracts provide insights into the metabolite richness of individual species and highlight the superiority of alcoholic solvents over aqueous extracts in extracting a broader spectrum of bioactive compounds. The detailed qualitative phytochemical screening results of the 14 aquatic medicinal plants at different solvent fronts are presented in Table 2.

Table 2: Shows Phytochemical Screening of Secondary Metabolites at Different Solvent Fronts

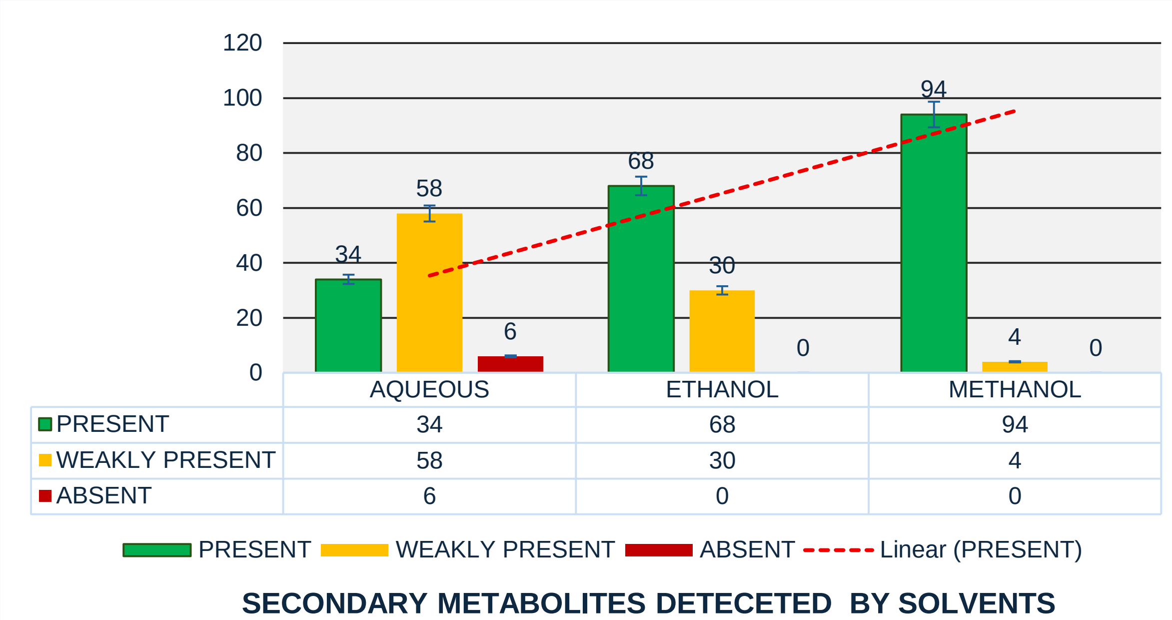
SL NO	BOTANICALNAME	SOLVENT	A	B	C	D	E	F	G
1	*Centella asiatica*	Aqueous	+	+	+	+	±	+	+
		Ethanol	+	+	+	±	+	+	+
		Methanol	+	+	+	+	+	+	+
2	*Bacopa monnieri*	Aqueous	±	+	+	+	±	+	+
		Ethanol	+	+	+	±	+	+	+
		Methanol	+	+	+	+	+	+	+
3	*Eclipta prostrata*	Aqueous	+	±	+	+	±	+	+
		Ethanol	+	+	+	±	+	+	+
		Methanol	+	+	+	+	+	+	+
4	*Ipomoea aquatica*	Aqueous	±	+	±	+	±	±	±

SL NO	BOTANICALNAME	SOLVENT	A	B	C	D	E	F	G
		Ethanol	+	+	+	±	±	+	+
		Methanol	+	+	+	+	+	+	+
5	*Marsilea quadrifolia*	Aqueous	±	±	+	+	±	-	±
		Ethanol	+	+	+	±	±	±	+
		Methanol	+	+	+	+	+	+	+
6	*Nymphaea nouchali*	Aqueous	±	+	+	+	±	±	±
		Ethanol	+	+	+	±	±	+	+
		Methanol	+	+	+	+	+	+	+
7	*Nelumbo nucifera*	Aqueous	+	±	+	±	±	±	±
		Ethanol	+	+	+	±	+	+	+
		Methanol	+	+	+	+	+	+	+
8	*Eichhornia crassipes*	Aqueous	±	±	±	±	-	-	±
		Ethanol	+	+	+	±	±	±	+
		Methanol	+	+	+	+	+	+	+
9	*Pistia stratiotes*	Aqueous	-	±	±	±	±	-	±
		Ethanol	±	+	+	±	±	±	+
		Methanol	+	+	+	+	+	±	+
10	*Sagittaria trifolia*	Aqueous	±	±	±	±	±	±	±
		Ethanol	+	+	+	±	±	±	+
		Methanol	+	+	+	+	+	+	+
11	*Limnophila indica*	Aqueous	±	+	+	±	±	+	+
		Ethanol	+	+	+	±	+	+	+
		Methanol	+	+	+	+	+	+	+
12	*Salvinia molesta*	Aqueous	±	±	+	±	±	±	±
		Ethanol	±	+	+	±	+	±	+
		Methanol	+	+	+	±	+	±	+
13	*Polygonum glabrum*	Aqueous	±	+	+	±	±	±	+
		Ethanol	+	+	+	±	+	+	+
		Methanol	+	+	+	+	+	+	+
14	*Alternanthera sessilis*	Aqueous	±	±	±	+	±	-	±
		Ethanol	±	+	+	±	+	+	+
		Methanol	+	+	+	+	+	+	+

Legends: A: Alkaloids, **B:** Flavonoids, **C:** Tannins, **D:** Saponins, **E:** Terpenoids, **F:** Glycosides, **G:** Phenols. **(+):** Present, **(-):** Absent, **(±):** Weakly Present

To further elucidate the comparative efficiency of different solvent systems in extracting secondary metabolites, the qualitative phytochemical screening results were consolidated and expressed as total counts of metabolites detected under each solvent category. Summarization of the results into present, weakly present, and absent classes allows a clearer comparison of extraction performance among aqueous, ethanolic, and methanolic solvents. This solvent-wise quantification highlights overall trends in metabolite recovery and provides a visual and numerical basis for evaluating solvent polarity in relation to phytochemical solubility. Such comparative assessment is essential for identifying the most suitable solvent system for comprehensive phytochemical investigation of aquatic medicinal plants. The total number of secondary metabolites detected by each solvent system, along with their distribution pattern, is presented in Table 3 and illustrated graphically for better interpretation.

Table 3: Total number of secondary metabolites detected by solvents



To gain a comprehensive understanding of the distribution and prevalence of individual secondary metabolites across all studied aquatic medicinal plants, a frequency-based analysis was carried out. While solvent-wise screening highlights extraction efficiency, frequency analysis allows assessment of how commonly each class of secondary metabolite occurs irrespective of plant species or solvent system. This approach provides valuable insight into the dominant and least abundant phytochemical groups present in the flora investigated.

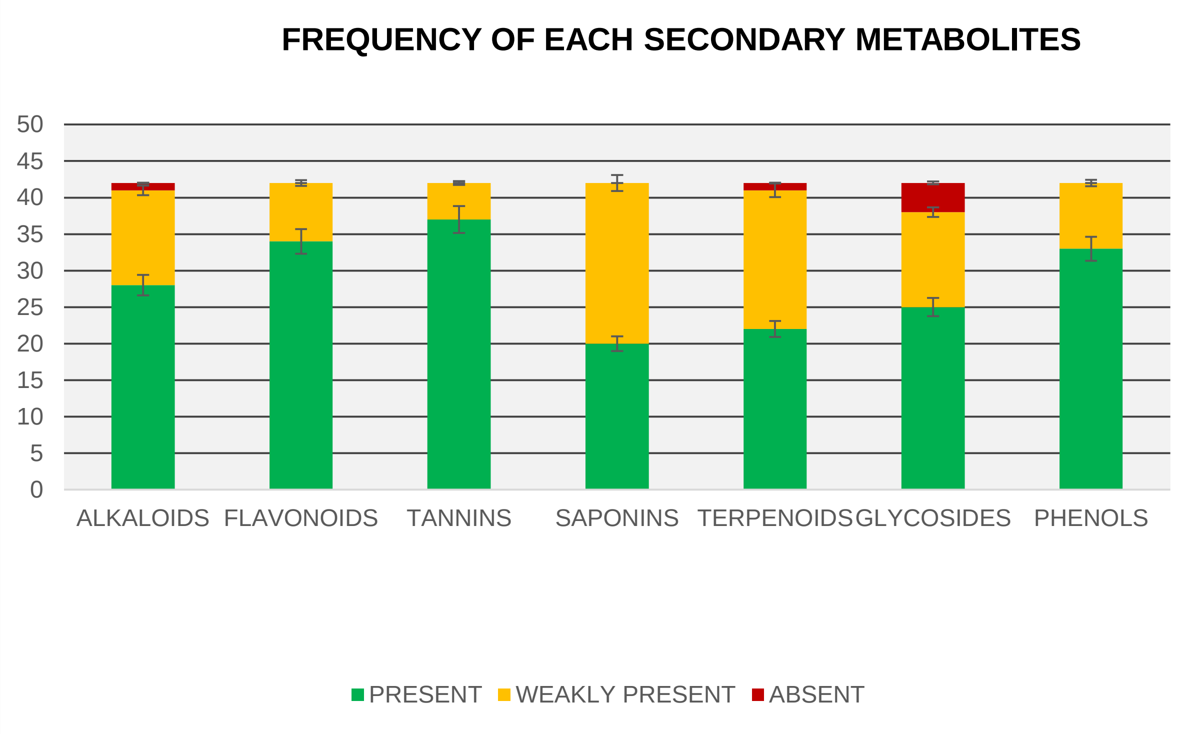
The frequency of each secondary metabolite was determined by compiling the qualitative screening results obtained from all plant–solvent combinations and categorizing them as present, weakly present, or absent. Such an analysis helps to identify metabolite groups that are widely distributed and potentially responsible for the broad therapeutic applications reported in ethnomedicinal practices. Moreover, it facilitates comparison among different classes of compounds in terms of consistency and intensity of occurrence.

The summarized frequency distribution of alkaloids, flavonoids, tannins, saponins, terpenoids, glycosides, phenols, and steroids across all plant species and solvent extracts is presented in Table 4 (A)&4(B).

Table 4 (A): Frequency of each secondary metabolites across all plants & solvents

CODE	NAME OF THE SECONDARY METABOLITES	TOTAL PRESENT	TOTAL WEAKLY-PRESENT	TOTAL ABSENT
A	ALKALOIDS	28	13	01
B	FLAVONOIDS	34	08	00
C	TANNINS	37	05	00
D	SAPONINS	20	22	00
E	TERPENOIDS	22	19	01
F	GLYCOSIDES	25	13	04
G	PHENOLS	33	09	00

Table 4 (B): Frequency of each secondary metabolites across all plants & solvents



To compare the relative phytochemical richness of the investigated aquatic medicinal plants, a plant-wise quantitative assessment was performed based on the total number of positive (+) reactions obtained during qualitative phytochemical screening. The total '+' count represents the cumulative presence of secondary metabolites detected across all solvent extracts and metabolite classes for each plant species. This approach enables identification of species by exhibiting a higher diversity of bioactive constituents.

Plant-wise comparison of metabolite occurrence is important for prioritizing species with greater therapeutic potential and for selecting suitable candidates for further quantitative, pharmacological, and bioactivity-guided studies. Species showing higher total '+' counts are considered metabolite-rich and may contribute significantly to the ethnomedicinal efficacy reported by local communities. The plant-wise distribution of total positive phytochemical reactions is presented in the following table 5(A)& 5(B).

Table 5 (A): Metabolites richness per plant

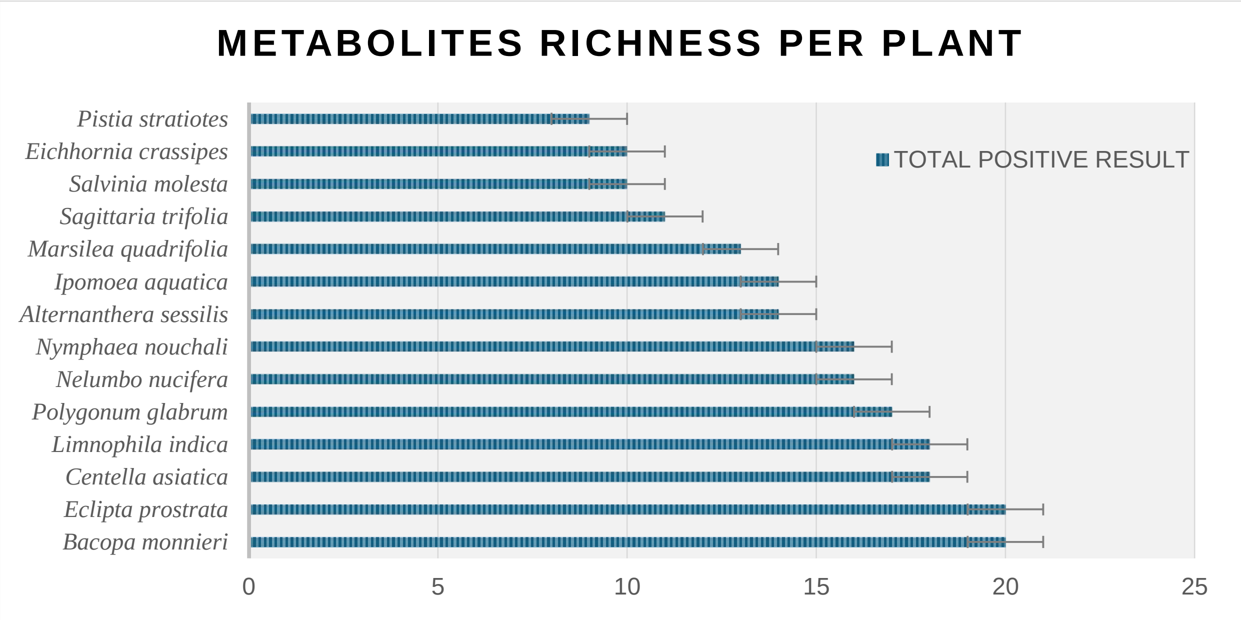


Table 5 (B): Metabolites richness per plant

SL NO	NAME OF THE PLANT	TOTAL '+' COUNTS
1	*Bacopa monnieri*	20
2	*Eclipta prostrata*	20
3	*Centella asiatica*	18
4	*Limnophila indica*	18
5	*Polygonum glabrum*	17
6	*Nelumbo nucifera*	16
7	*Nymphaea nouchali*	16
8	*Alternanthera sessilis*	14
9	*Ipomoea aquatica*	14
10	*Marsilea quadrifolia*	13
11	*Sagittaria trifolia*	11
12	*Salvinia molesta*	10
13	*Eichhornia crassipes*	10
14	*Pistia stratiotes*	09

CONCLUSIONS

The present investigation provides a comprehensive account of tribally used aquatic and semi-aquatic medicinal plants from the Lalbagh block of Murshidabad district, West Bengal, integrating ethnomedicinal knowledge with preliminary phytochemical validation. A total of fourteen aquatic plant species belonging to thirteen families were documented through systematic field surveys, reflecting the continued reliance of indigenous and local communities on wetland flora for primary healthcare. The medicinal uses record ranging from treatment of neurological disorders, skin ailments, digestive problems, inflammation, and wound healing—highlight the therapeutic significance of these plants and the depth of traditional knowledge preserved among tribal communities.

Qualitative phytochemical screening revealed the widespread occurrence of major secondary metabolites such as alkaloids, flavonoids, tannins, saponins, terpenoids, glycosides, and phenols across the investigated species. The presence of these bioactive compounds provides scientific support for many of the traditional medicinal claims documented during the ethnobotanical survey. Among the different solvent systems employed, methanolic extracts consistently showed superior efficiency in extracting a broader spectrum of secondary metabolites compared to ethanolic and aqueous extracts. This observation underscores the importance of solvent polarity in phytochemical investigations and supports the preferential use of organic solvents for comprehensive metabolite profiling.

Plant-wise comparative analysis indicated that *Bacopa monnieri*, *Eclipta prostrata*, *Centella asiatica*, *Limnophila indica*, and *Polygonum glabrum* exhibited higher metabolite richness, suggesting their potential as promising candidates for further pharmacological and bioactivity-guided studies. The dominance of phenols, flavonoids, and tannins across most species highlights the antioxidant and anti-inflammatory potential of aquatic medicinal plants, which may play a key role in their therapeutic efficacy. Furthermore, the frequent use of leaves and whole plants by tribal communities aligns with the higher concentration of secondary metabolites typically found in these plant parts.

Overall, the findings of this study emphasize that aquatic and semi-aquatic plants of the wetland ecosystems of Murshidabad constitute an important yet underexplored reservoir of medicinally valuable bioactive compounds. The correlation between traditional ethnomedicinal knowledge and phytochemical evidence reinforces the relevance of indigenous healthcare practices and validates their scientific basis. However, as the present study is limited to qualitative screening, further investigations involving quantitative phytochemical estimation, in vitro and in vivo pharmacological assays, toxicity evaluation, and compound isolation are necessary to fully elucidate the therapeutic potential of these species.

In conclusion, this study not only contributes valuable baseline data on ethnomedicinally important aquatic plants of eastern India but also highlights the need for conservation of wetland ecosystems and preservation of traditional knowledge systems. Sustainable utilization and scientific exploration of these aquatic medicinal plants may play a crucial role in future drug discovery programs and community-based healthcare strategies.

ACKNOWLEDGEMENTS

We sincerely thank everyone who offered invaluable advice and practical support, especially our esteemed Dr. Dola Boral, Head of the Department, Department of Botany, Murshidabad University, for her unwavering support throughout this study. The authors thank Prof. Biplab Bandyopadhyay and Dr. Sandip More for their support and guidance. We also thank our laboratory attendants Sri Narayan Saha, Sri

Raju Rakshit, and Sri Ramesh Mandal, Department of Botany, Murshidabad University, for their help and support during this study. We are grateful to esteemed Vice-Chancellor and Registrar of Murshidabad University for giving us the opportunity to learn and complete this valuable work. We also express our heartfelt gratitude to the local tribal communities and traditional knowledge holders and practitioners who generously shared their ethnobotanical knowledge and cooperated during field investigations. Their traditional wisdom and support greatly contributed to the successful completion of this study.

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Journal of Plant Development Sciences
Meerut, India

RESEARCH ARTICLE

MEMECYLON MATHEWDANII (MELASTOMATACEAE), A NEW SPECIES FROM KERALA, INDIA

Santhosh Kumar E.S.*, Shareef S.M., Anusha P.P. and Rejitha Joseph

Jawaharlal Nehru Tropical Botanic Garden and Research Institute (JNTBGRI), Palode, Karimancode P.O., Thiruvananthapuram-695562, Kerala, INDIA
Email: santhoshkumares@gmail.com

Received-20.01.2026, Revised-11.02.2026, Accepted-27.02.2026

Abstract: A new species of the genus *Memecylon* from Kerala, SW India, *viz. Memecylon mathewdanii* E.S.S.Kumar, Shareef, Anusha & Rejitha is described and illustrated. A detailed taxonomic description, accompanied by photographs, notes on its ecology, and a comparative table distinguishing it from closely related species.

Keywords: *Memecylon*, Kerala, Southwest India, Endemic, Taxonomy

INTRODUCTION

The genus *Memecylon* Linnaeus belongs to the family Melastomataceae with more than 405 species of small trees and shrub distributed in the Old-World tropics (POWO, 2026). In India, the genus is represented by 59 species and seven varieties, of which 15 endemics to southern Western Ghats (Clarke, 1879; Gamble, 1915; Radh & Nampy, 2019; Shrotri *et al.*, 2025). In the present paper, we describe a new species of *Memecylon* based on several recent collections from Kerala. This species has often been misidentified as *Memecylon umbellatum* Burm.f., *M. edule* Roxb., or even *M. molestum* C.B. Clarke (Fig.2.D) [= *M. umbellatum* var. *molestum* (C.B. Clarke) M. Das] in a few recent treatises (Sivu, 2012; Das, 2017, 2020; Bharathi *et al.*, 2016). However, it is readily distinguishable from these taxa by a suite of consistent morphological characters (Table 1). Accordingly, it is here described as a species new to science. The description is supplemented with analytical photographs of the living plant, along with detailed notes on its habitat and phenology, to facilitate accurate identification in the field and herbarium.

MATERIALS AND METHODS

This work has resulted from the *ex-situ* conservation of endemic and threatened plants of the Western Ghats. The description and photographs were taken by examining living and herbarium specimens collected during the field surveys. All relevant literature, including protologues of all described species of *Memecylon* was examined. The relevant types and other specimens deposited in BM, C, CAL, K, L, MH, TBGT (herbaria codes according to Thiers 2020+) were examined for this study. The specimens kept at BM, C, K and L were examined through high resolution images accessed at https://jstor.org and https://www.gbif.org. The description was prepared based on fresh collection examined under a Wild M3Z stereo microscope. The colour of the vegetative and floral parts were examined using Methuen Handbook of Colour (Kornerup & Wanscher, 1961).

TAXONOMY

Memecylon mathewdanii E.S.S.Kumar, Shareef, Anusha & Rejitha, *sp. nov*. (Figure 1)

Diagnosis:—*Memecylon mathewdanii* is allied to *M. edule* and *M. umbellatum*, but differs mainly in its large spreading shrubby habit, shortly acuminate leaf apices, greyish-green drying leaves, relatively shorter petioles, simple umbellate lateral inflorescences lacking secondary and tertiary axes, a pale pinkish-blue calyx tube, and ovoid-ellipsoid fruits that are yellow when young, turning blackish-purple when ripe.

Type: —INDIA, Kerala State, Thiruvananthapuram district, Mannanthala, 100 m, 12 March 2025, *E. S. Santhosh Kumar 92474* (holotype:TBGT; isotypes: CAL, MH).

Description: —Large spreading shrubs, 2–3 m high; bark greyish- brown, shallowly fissured; young shoots quadrangular; branchlets terete, greyish-brown. Leaves opposite, 3.5–8 × 2.2–4.5 cm, ovate to ovate-elliptic, cuneate at base, shortly acuminate and obtuse or emarginate at the very apex; mid vein sulcate above, raised below, lateral nerves 4–5 pairs, faint but visible, coriaceous, drying greyish green above, absinthe green beneath; foliar sclereid

*Corresponding Author

filiform; petiole 2–5 mm long, slender. Inflorescence lateral, 5–12 flowered umbellate cyme; peduncle 2–3 mm long, terete; pedicels 3–4 mm long, terete, slender, pinkish–white; bracts ovate, 1mm long. Flower buds obtuse to rounded at apex with exposed petals, expanded flowers 6 mm across, pale blue. Calyx campanulate, 4 mm across, shallowly 4-lobed, pale blue, papillate on the outer surface; lobes broadly triangular, pinkish. Petals 4, to 2.5 mm across, suborbicular, rounded at the apex, laterally awned, clawed at base, margin irregularly gnawed, pale blue. Disc smooth or shallowly striate. Stamens 8, equal; filaments slender, 6–8 mm long; anthers 1 mm long, connective with a gland. Ovary unilocular, placentation free central; ovules 10; style subulate, 9–12 mm long; stigma simple. Fruit a berry, ovoid-ellipsoid, 5–8 × 3.5–5 mm, yellow turn blackish purple when ripe with a smooth surface and a crown formed by persistent hypantho-calyx. Seeds 1-per fruit, ovoid.

Phenology: —Flowering and fruiting occur during March-June.

Distribution: — It is so far known only from Kerala state (Thiruvananthapuram and Malappuram districts).

Etymology: —This new species is named in honour of Dr Mathew Dan, Senior Principal Scientist (Retd.), JNTBGRI for his contribution to the field of Systematic Botany.

Additional Specimens Examined: —INDIA, Kerala state, Malappuram district, Calicut University campus, 27.05.2015, *Moumita Das Das, Satheesh K.T. & Mini V. 30890* (CAL); Thiruvananthapuram district, Mannanthala, 100 m, 26 May 2024, *E. S. Santhosh Kumar 96347* (TBGT).

Table 1. Diagnostic morphological characters of *Memecylon mathewdanii sp.nov*. and related species

Characters	***Memecylon edule*** (Fig.2. A& B)	***M.umbellatum*** (Fig.2. C)	***M.mathewdanii*** (Fig.1.)
Habit	Shrubs or trees, 3–15 m high.	Large shrubs or small trees, 3–5 m high	Large spreading shrubs, 2–2.5 m high
Branchlets	Terete or subterete	Terete to subquandrangular	Terete
Leaves	Ovate-elliptic or elliptic, 4–7 × 2–3.5 cm	Elliptic or elliptic-ovate, obovate or suborbicular, 2.5–8 ×1.2–4.5 cm	Ovate or ovate-elliptic, 3.5–8 × 2.2–4.5 cm
Leaf apices	Obtuse or slightly caudate at apex	Obtuse-rounded or notched at apex	Shortly acuminate and obtuse or emarginate at the very apex
Drying colour of leaves	Greenish to dark blackish-brown	Yellowish green	Greyish green
Petioles	4–8 mm long	4–6 mm long	2–4 mm long
Inflorescence	Axillary or lateral	Axillary or lateral	Lateral
Peduncle	Primary axes 4–9 (–20) mm long; secondary axes 2–7 mm long; tertiary axes 4.3 mm long	Primary axes up to 10 mm long; secondary axis 2–6 mm long	Primary axis up to 2 mm long; secondary and tertiary axes absent
Pedicel	1.5–2 mm long	2–5 mm long	3–4 mm long
Hypanthocalyx	Campanulate, 2 mm wide truncate to shallowly 4 lobed	Campanulate, 4 mm wide shallowly 4 lobed	Campanulate, 4 mm wide shallowly 4 lobed, pappillate
Calyx tube	Greenish-white	Pale blue	Pale-Pinkish blue
Petals	Ovate-deltoid, 1–2.5×1–1.75 mm, usually truncate with a claw, apex acute	Sub orbicular to 2.5 mm across.	Sub orbicular, clawed at base, apex rounded.
Filaments anther-connective	2–3 mm long (in bud), ‘e’ shaped, 1–1.75 x 0.5 mm, white or pale yellow	6–8 mm	8 mm long, anther 1 mm long.
Style	1.25 mm (bud), 6 mm long	9–12 mm long	11 mm long
Fruit	Globose, 7×8 mm in diameter, yellowish-green turning bluish-black. Persistent calyx crown raised, nearly truncate.	Globose, 7 mm diameter. Yellowish green to bluish black	Ovoid-ellipsoid, 5–8 × 3.5–5 mm in diameter. yellow turn blackish purple when mature

Note: — *Memecylon mathewdanii* was once a fairly common species, predominantly occurring in wastelands and along road cut walls bordering state highways of southern Kerala. However, in recent years, a significant proportion of these habitats has been lost due to road widening and various forms of habitat alteration associated with developmental activities. As a result, the species has experienced a noticeable decline in its natural populations. It is typically found in association with species such as *Osbeckia aspera* (Meerb. ex Walp.) Blume, *Osbeckia virgata* D.Don, *Memecylon umbellatum* Burm.f., *Canthium coromandelicum* (Burm.f.) Alston, and *Getonia floribunda* Roxb., among others.

Memecylon mathewdanii is also misidentified as M. molestum, which is otherwise a medium sized evergreen tree reaching 30-40 ft height with strong wood usually seen in the shola forests of Kerala state. Many of the local floristic treatises wrongly attributed *M.mathewdanii* as *M.molestum*, *M.umbellatum* or *M.edule*. These species can easily be distinguished based on the following keys:

Key to the species of *Memecylon* closely allied to *M.mathewdanii*:-

1.Medium to large sized trees . ……………..………………………….*M.molestum*

1.Shrubs to small trees ………………………..……..…………………2

2.Inflorescence strictly lateral; flowers in simple umbels ………………………….….…*M. mathewdanii*

2. Inflorescence mostly axillary, very rarely lateral; flowers in branched umbels …………………………………………….………3

3. Leaf apices obtuse or slightly caudate; drying leaves greenish to dark blackish brown; petals ovate-deltoid …………………………………..……..*M. edule*

3. Leaf apices obtuse-rounded or notched; drying leaves yellowish green; petals suborbicular …..………………………………….*M.umbellatum*

Figure 1. ***Memecylon mathewdanii***, *sp. nov*. : **A.** Habit; **B.** Bark; **C.** Flowering twig; **D.** Inflorescence; **E.** Inflorescence (Bud stage); **F.** A single flower; **G.** L.S. of calyx showing style; **H.** A stamen; **I.** L.S. of calyx showing ovules; **J & K.** Fruits.

Figure 2. A. Illustration of *Memecylon edule* Roxb.; **B.** Lectotype of *Memecylon edule* Roxb. (Left top specimen Wall Cat. 4107A; K001038141© Board of Trustees, RBG Kew); **C.** Lectotype of *Memecylon umbellatum* Burm.f. (BM000621285 ©Natural History Museum, reproduced with permission); **D.** Type of *Memecylon molestum* Cogn. (K004414598 © Board of Trustees, RBG Kew).

ACKNOWLEDGEMENTS

The authors are grateful to the Director of the Jawaharlal Nehru Tropical Botanic Garden and Research Institute for providing research facilities, and to the Kerala State Council for Science, Technology and Environment for financial support. They also thank the officials of the Kerala Forest

Department for granting permission to conduct field explorations in forest areas. The authors further express their sincere thanks to the Board of Trustees of the Royal Botanic Gardens, Kew and to the authorities of the Natural History Museum, London for permitting the use of herbarium images in this manuscript.

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Journal of
Plant Development Sciences
Meerut, India

RESEARCH ARTICLE

SEASONAL OCCURRENCE OF MAJOR SUCKING INSECT-PESTS AND THEIR NATURAL ENEMIES ON OKRA (*ABELMOSCHUS ESCULENTUS* L. MOENCH) DURING SUMMER

Fanendra Kumar[1], G.P. Painkra[2]*, K.L. Painkra[3] and P.K. Bhagat[3]

[1]Department of Entomology, Indira Gandhi Krishi Vishwavidyalaya, Raipur,,Raj Mohini Devi College of Agriculture and Research Station, Ambikapur (C.G.) India
[2]Department of Entomology,Indira Gandhi Krishi Vishwavidyalaya, Raipur, College of Agriculture and Research Station, Shankargarh, Distt- Balrampur -Ramanujganj (C.G.) India
[3]Department of Entomology, Indira Gandhi Krishi Vishwavidyalaya, Raipur,Raj Mohini Devi College of Agriculture and Research Station, Ambikapur (C.G.) India
Email: fanendrasahu2000@gmail.com

Received-14.01.2026, Revised-06.02.2026, Accepted-24.02.2026

Abstract: The present study was investigated the seasonal occurrence of major sucking insect- pests of okra (*Abelmoschus esculentus* L. Moench) and their natural enemies during the summer. Field observations were recorded from seedling stage to crop maturity on leafhopper, whitefly, and aphid populations, along with associated natural enemies, and were correlated with weather parameters. Pest populations appeared soon after crop establishment and peaked during the mid-season, with leafhopper being the most predominant pest. Natural enemy activity closely followed pest population trends, while temperature and relative humidity significantly influenced population fluctuations. The findings highlight the importance of understanding seasonal pest dynamics for developing effective and eco-friendly Integrated Pest Management strategies.

Keywords: Aphid, Coccinellids, Leafhopper, Okra, Whitefly

INTRODUCTION

Okra (*Abelmoschus esculentus* L. Moench), commonly known as bhindi or lady's finger due to the characteristic shape of its pods, is an important vegetable crop widely cultivated in tropical and subtropical regions of the world. In India, okra is grown extensively during the kharif and summer seasons. It is cultivated throughout the country, with major contributions from states such as Andhra Pradesh, West Bengal, Bihar, Gujarat, Odisha, Jharkhand, Maharashtra, Madhya Pradesh, Chhattisgarh, Assam, Uttar Pradesh, and Haryana. The crop occupies an area of about 532.66 thousand hectares with an annual production of approximately 6,513 thousand metric tonnes. In Maharashtra alone, okra is cultivated over an area of 8.91 thousand hectares, producing nearly 139.28 thousand tonnes annually (Anonymous, 2021).

Okra is attacked by several insect pests that cause significant yield losses. The major pests include shoot and fruit borers, *Earias insulana* (Boisd.) and *Earias vittella* (Boisd.); leafhopper, *Amrasca biguttula biguttula* (Ishida); leaf roller, *Sylepta derogata* (Fab.); whitefly, *Bemisia tabaci* (Genn.); aphid, *Aphis gossypii* (Glover); and red spider mite, *Tetranychus cinnabarinus* (Boisd.). Among these, sucking pests such as leafhoppers, whiteflies, and aphids pose a major threat to okra production. The leafhopper (*A. biguttula biguttula*) is considered one of the most destructive pests, as it feeds on the sap from the undersurface of leaves, leading to leaf margin curling, chlorosis, and ultimately substantial reduction in yield.

Effective management of insect pests at the appropriate stage of crop growth is essential to ensure higher yield and better-quality produce. Although the use of chemical insecticides has contributed significantly to increased agricultural productivity, their indiscriminate and excessive use has resulted in several adverse effects, including the development of insecticide resistance, pest resurgence, secondary pest outbreaks, and accumulation of pesticide residues in the environment. Insecticide resistance has emerged as a major challenge in modern pest management, often leading to unexpected and severe crop losses.

Under the present scenario of climate change, insect pest dynamics are undergoing significant alterations due to variations in abiotic factors. Therefore, understanding the relationship between insect pest populations, their natural enemies, and prevailing weather parameters is crucial for predicting pest outbreaks and developing effective management strategies. Despite their importance, natural enemies

*Corresponding Author

have received relatively limited attention as biological control agents, highlighting the need for further research in this area.

MATERIALS AND METHODS

The experiment was conducted during summer at research-cum-Instructional farm of Raj Mohini Devi College of Agriculture and Research Station, Ajirma, Ambikapur, District, Surguja (C.G.). The observations of leafhoppers, aphids, and whiteflies were recorded on a per-plot basis. For each observation, five plants were randomly selected from each plot, and three leaves (one each from the bottom, middle, and top) of each plant were examined visually to assess pest infestation levels.

The seasonal occurrence of sucking insect-pests population was recorded weekly on five randomly selected plants per plot from their appearance until harvest. Populations of sucking pests (leafhopper, whitefly, and aphids) were counted. The population of natural enemies ware also recorded from the same plants. Weekly pooled meteorological data (temperature, rainfall, morning and evening relative humidity) from RMD CARS, Ambikapur (C.G.) were correlated with pest incidence.

RESULTS AND DISCUSSION

Seasonal occurrence of aphids

The okra crop was sown during the March and recorded aphid populations ranging from 4.42 to 18.51 aphids per three leaves from five selected plants throughout the summer season. The initial presence of aphids was observed in the 12th Standard Meteorological Week (SMW), approximately 15 days after sowing, with a population of 4.42 aphids per three leaves per plant. The population gradually increased, reaching a peak of 18.91 aphids per three leaves per plant in the 17th SMW, corresponding to the last week of April. Interestingly, the aphid population remained relatively stable at 18.51 aphids per three leaves per plants until the end of the cropping season.

The present findings are consistent with those of Parasai and Shastry (2009), who observed the highest incidence of aphid populations during the first week of September, corresponding to the 37th SMW. Similarly, the results align with the observations of Thara *et al.* (2019), who reported a gradual increase in aphid population, reaching its peak during the second week of October.

Seasonal occurrence of leafhopper

During the summer season, leafhopper infestation on okra began in the 12th SMW with a population of 7.56 leafhoppers per five leaves per plant. The population gradually increased, reaching 18.10 leafhoppers per five leaves per plant in the 17th SMW, followed by a temporary decline. However, it rose again and peaked in the 26th SMW, corresponding to the last week of June, with 21.45 leafhoppers per five leaves per plant. Throughout the season, the leafhopper population ranged from 7.56 to 21.45 leafhoppers per five leaves.

Similar observations were reported by Mahmood *et al*. (1990), who noted that leafhoppers began emerging in June and remained active until the end of the cropping season. These findings are also supported by Hegde *et al*. (2004), who recorded peak populations during August to September. The present results are further in agreement with those of Potai and Chandrakar (2018), who reported that the major activity period of leafhoppers occurred between August and October, with a distinct peak during the 38th SMW. Likewise, Thara *et al*. (2019) observed that leafhopper incidence began in the second week after sowing and peaked in the fourth week of September, corresponding to the 39th SMW.

Seasonal occurrence of whitefly

During the summer, whitefly infestation on the okra crop was observed throughout the growing season. The initial infestation appeared in the second week of March, corresponding to the 11th SMW, with a mean population of 5.52 whiteflies per five leaves per plant. The population ranged from 5.52 to 10.67 whiteflies per five leaves per plant. The highest infestation was recorded in the 18th SMW, with a peak population of 10.67 whiteflies per five leaves per plant. Thereafter, a gradual decline in the population was observed.

The present findings are broadly in agreement with those of earlier researchers. Yadav and Singh (2013) and Aarwe *et al*. (2016) reported that the whitefly population peaked in August, during the 34th SMW. These results are also supported by Potai and Chandrakar (2018), who observed the initial appearance of the pest in the second week of August, with peak population levels recorded in the third week of September, corresponding to the 38th SMW.

Seasonal occurrence of coccinellids

During the summer season, predatory coccinellids were observed throughout the cropping period, co-existing with various pest species. The initial population was recorded in the 13th SMW (last week of March) at 1.82 coccinellids per five leaves per plant. Over the season, the population fluctuated between 1.82 and 4.51 coccinellids per five leaves per plant. The highest activity was recorded in the 22nd SMW, with a peak population of 4.51 coccinellids per five leaves.

The findings of Purohit *et al*. (2006) and Singh *et al.* (2013) also support the present results, as they recorded peak coccinellid activity during the first week of September and the second week of October, respectively. Similarly, the present observations are in agree with those of Gaikwad *et al*. (2020), who reported the initial appearance of coccinellids during the 31st SMW, followed by a gradual increase in population in the subsequent weeks.

Table 1. Seasonal occurrence of sucking insect-pests and natural enemies on okra during summer.

SMW	Weather parameters					Population of sucking pests/plant			Population of natural enemies/plant
	Max. T. (°C)	Min. T. (°C)	RH-I (%)	RH-II (%)	Rainfall (mm)	Aphids	Leafhoppers	Whitefly	Coccinellids (Grubs/ Adults)
10	31.1	11.00	79.7	47.9	0.00	0.00	0.00	0.00	0.00
11	34.3	14.3	50.3	34.0	0.00	0.00	0.00	5.52	0.00
12	31.4	15.8	98.3	94.1	0.00	4.42	7.56	5.30	0.00
13	35.9	15.4	69.1	43.9	0.00	8.50	15.10	5.87	1.82
14	38.6	23.4	72.0	41.6	0.00	9.30	13.50	4.50	2.56
15	36.3	22.1	72.1	43.3	5.10	8.93	18.30	5.83	2.79
16	27.4	22.3	95	89.3	0.00	15.63	16.3	5.23	4.23
17	37.2	22.3	79.1	33.7	0.00	18.91	20.11	7.62	4.50
18	34.1	23.6	77.0	45.4	4.10	16.24	17.36	8.33	3.14
19	36.8	27.2	71.7	38.0	1.30	13.65	15.85	7.50	3.99
20	39.4	27.9	77.7	36.4	0.20	10.17	14.67	9.30	3.90
21	32.9	26.3	80.6	59.1	11.4	11.42	14.21	2.30	3.64
22	34.4	21.2	67.2	64.2	4.70	14.61	17.93	8.89	3.49
23	36.8	26.3	84.1	75.3	3.40	17.39	19.6	5.45	4.51
24	36.2	28.1	81.0	64.4	0.10	15.47	18.61	7.82	3.45
25	26.0	22.0	94.7	75.6	16.4	11.50	18.46	6.30	3.98
26	28.1	20.1	93.6	84.6	0.00	18.51	21.45	8.00	2.37

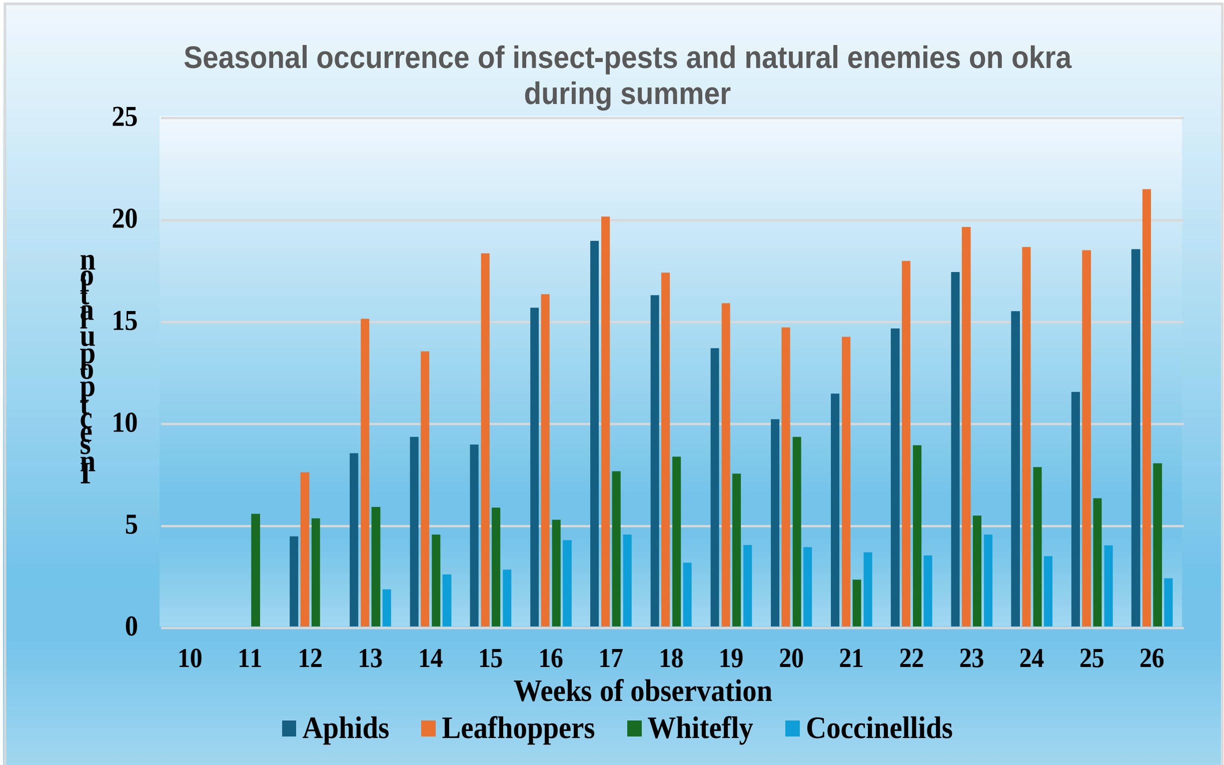

Fig. 1 Correlation of insect-pests and natural enemies with weather parameters during summer.

Correlation of insect-pest and natural enemies with weather parameters during summer.

Correlation coefficients between various weather parameters with the population of sucking pests viz., aphids, leafhoppers and whitefly and their natural enemies i.e., Coccinellids presented in Table 2.

Table 2. Correlationof insect-pests andnatural enemies with weather parameters during summer.

Weather parameters	Correlationcoefficientvalue			
	Aphid	**Leafhopper**	**Whitefly**	**Coccinellid**
Max.Temperature	0.425*	0.265	0.456*	0.160
Min.Temperature	-0.586**	-0.548*	-0.276	-0.209
MorningRH	-0.028	0.339	0.165	0.212
EveningRH	-0.575**	-0.213	-0.182	-0.026
Rain fall	-0.104	-0.056	0.114	-0.338

*5%level of significance df 15=0.412, **1% level of significance df 15=0.558

Correlation study investigated the relationship between maximum temperature and various insect populations. The positive correlation was observed between maximum temperature, leafhopper and Coccinellid. However, these correlations were not statistically significant, with correlation coefficients of 0.265 and 0.160 respectively. In contrast, a significant positive correlation (coefficient 0.425* and 0.456*) was observed between maximum temperature, aphid and whitefly populations.

Minimum temperature showed negative significant correlation with the aphid (-0.586**), leafhopper (-0.548*) population. In contrast, a non-significant and negative correlation was observed between min. temperature and whitefly (-0.276) and Coccinellid (-0.209) population.

The aphid population correlated negatively and non-significant with the morning relative humidity with correlation coefficient value -0.003. In contrast a positively non-significant correlation was observed between morning RH and leafhopper (0.035), whitefly (0.235) and coccinellid (0.075) population.

The negative correlation was recorded between evening relative humidity the Aphid and leafhopper which was negatively significant with correlation coefficient value (-0.609**) and (-0.472*) respectively. And negatively non-significant correlation observed between evening RH and whitely (-0.286) and coccinellid (-0.185) population.

As regards rainfall positive non-significant correlation showed with the whitefly with correlation coefficient value (0.114). Whereas aphid, leafhopper and coccinellid with correlation coefficient value (-0.105), (-0.005) and (-0.109) respectively showed negative non- significant correlation with rainfall.

The correlation studies between pests, natural enemies and major weather parameters during summer season revealed that there was a negative correlation between aphid and minimum temperature, morning relative humidity, evening relative humidity and rainfall, while positive correlation with maximum temperature. Investigations by Dhandge *et al.* (2018) revealed that aphid population showed positive correlation with maximum temperature while, negative correlation with morning and evening relative humidity. Potai and Chandrakar (2018) reported negative correlation between aphid and minimum temperature in confirmation with the present findings. Another finding by Badotiya *et al.* (2023) revealed that pest population showed negative correlation between aphid and rainfall.

There was a positive correlation between leafhopper and maximum temperature. Whereas leafhopper showed negative correlation with minimum temperature, morning and evening RH and rainfall. The present findings are in close agreement with Ratanpara *et al.*, (1994) reported that minimum temperature showed negative correlation with leafhoppers. Other findings by Dhandge *et al.* (2018) revealed that pest population showed positive correlation with maximum temperature while, negative correlation with evening relative humidity.

Investigations revealed the positive correlation between whitefly and maximum temperature, minimum temperature, morning RH, evening RH and rainfall. Reports of Purohit *et al.* (2006) stated positive correlation of whitefly with all the abiotic factors. These results are in confirmation with the findings of Yadav and Singh (2013) who revealed positive correlation between whitefly and maximum temperature.

The present study revealed that there was a positive correlation between coccinellid and maximum temperature, minimum temperature, morning RH, evening RH and rainfall. Reports of Purohit *et al.* (2006) stated correlation between coccinellid and minimum temperature and rainfall in confirmation with the present findings. These findings are similar with reports by Dhaka and Pareek (2007) who revealed correlation between Coccinellid and evening relative humidity. Potai and Chandrakar (2018) reported positive correlation between aphid and morning relative humidity in confirmation with the present findings.

CONCLUSION

During the summer of 2025, major sucking insect pests of okra, namely aphids, leafhoppers, and whiteflies and natural enemy were observed throughout the crop growth period. Aphids appeared in the third week of March and peaked in the last week of April, while leafhoppers persisted throughout the season with maximum abundance in late June. Whiteflies showed moderate fluctuations, attaining peak activity in mid-May. Coccinellids, the predominant natural predators, appeared from late March and reached their highest population in mid-June. Correlation analysis indicated that aphid and leafhopper populations were positively influenced by maximum temperature but negatively affected by minimum temperature, relative humidity, and rainfall. Whitefly incidence was also positively correlated with maximum temperature. In contrast, coccinellid populations showed positive associations with temperature, morning relative humidity, and rainfall, but a negative correlation with evening relative humidity.

ACKNOWLEDGEMENTS

The first author expresses his heartfelt gratitude to Major Advisor, Head of Section (Entomology), all the Advisory member, Staff members, Dean, RMD CARS Ambikapur and Head of Department (Entomology), COA Raipur for their excellent guidance, suggestions and regular encouragement during the course of investigation.

Fig.1. *Amrasca biguttula biguttula*

Fig. 2. *Bemisia tabaci*

Fig.3. *Aphis gossypii*

Fig. 4. *Coccinella septempunctata*

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Journal of Plant Development Sciences

Meerut, India

RESEARCH ARTICLE

PROSPECTS OF *ACROCARPUS FRAXINIFOLIUS* AS AN ALTERNATIVE RAW MATERIAL FOR THE PULP AND PAPER INDUSTRY

Vennila S[1]*, S. Manivasakan[2] C. Cinthia Fernandaz[3] and S. Kala[4]

[1]*Deptt. of Forestry, Agricultural College and Research Institute, TNAU, Tiruvanamalai - 606 753, Tamil Nadu*
[2]*Deptt. of Forestry, ICAR KVK, TNAU, Ooty - 643002, Tamil Nadu*
[3]*Deptt. of Agrl. Extension, Tamil Nadu Agricultural University, Coimbatore*
[4]*ICAR-Indian Institute of Soil & water conservation Research Centre, Kota - 324 002, Rajasthan*
Email: vennila.s@tnau.ac.in

Received-25.01.2026, Revised-10.02.2026, Accepted-24.02.2026

Abstract: The growing demand for pulp and paper products has intensified the need to identify alternative and sustainable raw materials for the industry. *Acrocarpus fraxinifolius* Wight & Arn., a fast-growing multipurpose tree species native to tropical Asia, has gained attention for its potential as a pulpwood resource. The present study evaluates the prospects of *Acrocarpus fraxinifolius* as an alternative raw material for the pulp and paper industry by examining its physical and chemical characteristics. The results indicated that the species possesses moderate moisture content, satisfactory bulk and basic density, and a high proportion of acceptable chip fraction suitable for pulping operations. Chemical analysis revealed appreciable holocellulose content and comparatively lower lignin and extractives, which are favorable attributes for pulp production and paper quality. These characteristics are comparable with commonly used pulpwood species such as *Eucalyptus* and *Casuarina*. The findings suggest that *Acrocarpus fraxinifolius* can serve as a promising supplementary raw material for the pulp and paper industry. Its fast growth, adaptability to tropical conditions, and favorable wood properties further enhance its suitability for plantation-based pulpwood production. Adoption of this species could contribute to diversification of pulpwood resources and sustainable raw material supply for the paper industry.

Keywords: *Acrocarpus fraxinifolius,* Indigenous species, Pulp, Paper

INTRODUCTION

The pulp and paper industry is one of the major forest-based sectors worldwide, relying heavily on lignocellulosic raw materials for the production of paper, paperboard, and related products. Traditionally, the industry depends on a limited number of fast-growing tree species such as *Eucalyptus camaldulensis*, *Casuarina equisetifolia,* and *Populus deltoides* for pulp production due to their favorable fiber characteristics, rapid growth, and adaptability to plantation forestry. However, increasing demand for paper products, combined with pressure on natural forests and limited availability of conventional pulpwood species, has necessitated the exploration of alternative fast-growing tree species suitable for pulp and paper manufacturing.

In recent years, considerable attention has been given to identifying non-traditional species that can supplement the raw material requirements of the pulp and paper industry. Among these, *Acrocarpus fraxinifolius* has emerged as a promising multiutility tree species. This species, commonly known as pink cedar, is a fast-growing deciduous tree belonging to the family Fabaceae and is widely distributed in tropical and subtropical regions of Asia, including India, China, Myanmar, Indonesia, and Vietnam. The species is known for its rapid growth, straight bole and ability to adapt to a wide range of climatic and soil conditions, making it suitable for plantation forestry and agroforestry systems.

The wood of *A. fraxinifolius* is moderately dense and possesses desirable anatomical and chemical properties that may make it suitable for pulp and paper production. Fast growth rate, relatively short rotation period and good biomass yield further enhance its potential as an alternative pulpwood resource. In addition, the species is often cultivated for shade, timber and ornamental purposes, and its inclusion in agroforestry systems provides multiple ecological and economic benefits. Despite these advantages, systematic evaluation of its physical properties, fiber characteristics and pulping suitability remains limited.

With the increasing emphasis on sustainable raw material supply and efficient utilization of forest resources, assessing the suitability of new species for industrial applications has become essential. Therefore, the present study aims to evaluate the prospects of *Acrocarpus fraxinifolius* as an alternative raw material for the pulp and paper

*Corresponding Author

industry by examining its key physical properties and chip characteristics in comparison with commonly used pulpwood species. The findings of this study are expected to provide useful insights into the potential utilization of this species in the pulp and paper sector and contribute to the diversification of raw material resources for sustainable industrial development.

MATERIALS AND METHODS

The investigations were carried out in the laboratory of Forest College and Research Institute, Mettupalayam., A billet of *Acrocarpus fraxinifolius* measuring one meter length and 50-60 cm girth was collected, debarked and chipped separately and screened. The screened chips were used for pulping experiments. Some chips were converted into dust for proximate chemical analysis. Based on the initial screening study in the laboratory, the wood samples were subjected to analysis of physical and chemical properties. The pulping experiments were also carried out to find out its suitability for papermaking.

Physical properties for pulpwood

The bulk density and basic density were determined using the displacement method (Haygreen and Bowyer, 1982). Moisture content of wood chips was determined after drying it at 100 + 5 ºC for 48 h. The billets collected across the age gradation were chipped in pilot chipper and air-dried for 24 hours. The wood chips were passed through different sieves (50 mm, 10 mm, 5 mm and 2 mm) as per TAPPI methods (TAPPI, 1980) for Chips classification.

Chemical properties for pulpwood

The billets of individual tree species were chipped in pilot chipper; air-dried and converted into wood meal in a laboratory pulp disintegrator. The wood dust of sample was prepared using Wiley mill and the wood dust passing through 40 mesh but retained over 60 mesh was subjected to analysis for moisture, ash, hot water soluble, one per cent NaOH soluble, AB extractive, Acid insoluble lignin, pentosans, hollocellulose as per TAPPI methods (TAPPI, 1980).

Strength properties for pulpwood

30 g (dry weight) pulp was taken and diluted to 1.5 per cent (w/v) with water. This pulp slurry was thoroughly mixed. It was further diluted to 1.0 per cent and kept for 30 min. The measured volume of this was transferred in the sheet form in order to make 60 gsm sheets. These hand sheets were prepared according to TAPPI standard T 205 om-88. By couching, the sheet was removed from the wire with the help of absorbent blotters. These sheets were pressed between the blotters at 0.27 mpa to increase the dryness and to consolidate the sheet and then these sheets were dried at 27 ± 1ºC and 65 per cent ± 2 RH for 24 hrs. The dried sheets were air dried and were again conditioned at 27 ± 1ºC and 65 per cent ± 2 RH for four hours before testing. The tensile strength, bursting strength, tensile energy absorption and elongation of paper sheets were measured according to TAPPI standard T 494 om-88 (TAPPI, 1980).

RESULTS AND DISCUSSION

Physical properties of wood

The physical properties of wood, particularly basic density, bulk density, and moisture content, are very important in determining the quality and suitability of wood for various applications. Among these, moisture content plays a crucial role in influencing the performance of wood. Changes in moisture content directly affect the dimensional stability of wood, causing it to shrink or swell as it loses or absorbs moisture. Therefore, understanding the relationship between moisture content and dimensional stability is essential when utilizing forest products. Generally, wood that undergoes rapid moisture fluctuations is not preferred for practical applications because such changes can adversely affect its physical and mechanical properties, leading to deformation, cracking, or reduced strength.

Moisture Content

The moisture content of the different wood species analyzed ranged from 8.67% to 9.76%. Among the species studied, *Eucalyptus camaldulensis* recorded the highest moisture content (9.76%), indicating a relatively greater capacity to retain water compared to the other species. In contrast, *Casuarina equisetifolia* showed the lowest moisture content (8.67%), suggesting a comparatively drier wood composition. *Acrocarpus fraxinifolius* exhibited a moderate moisture content (8.9%), falling between the values observed for the other two species. The variation in moisture content among these species is important because moisture significantly influences the physical characteristics, dimensional stability, and mechanical performance of wood. Differences in moisture levels may affect the suitability of these species for various industrial applications such as timber, pulp, and other wood-based products, as wood with lower moisture content generally provides better stability and reduced shrinkage during processing and utilization (Haygreen and Bowyer, 1982; Tsoumis, 1991; Glass and Zelinka, 2010).

Bulk Density

The bulk density of the wood chips, measured on an oven-dry basis, exhibited a range from 191 to 270 kg m^{-3}. Among the species analyzed, Eucalyptus camaldulensis demonstrated the highest bulk density at 270 kg m^{-3}, suggesting that its wood chips are more compact and potentially denser than those of other species. In contrast, *Casuarina equisetifolia* recorded the lowest bulk density at 191 kg m^{-3}, indicating a less compact structure. *Acrocarpus fraxinifolius* fell in between these two extremes, with a bulk density of 230 kg m^{-3}, reflecting a moderate level of compactness in its wood chips. This variation in bulk density among the different species highlights the importance of species selection in applications where wood chip density may influence performance and usability (Bajpai, 2018).

Basic density

The basic density measured on an oven-dry basis for both *Acrocarpus fraxinifolius* and *Eucalyptus camaldulensis* was found to be quite similar, with both species exhibiting a density of 510 kg m^{-3}. In contrast, *Casuarina equisetifolia* demonstrated a notably lower basic density, recorded at 435 kg m^{-3}. This variation in density among the species may have implications for their respective uses in various applications, such as construction and furniture making, where density can influence strength, durability, and overall performance of the wood (Haygreen and Bowyer, 1982; Tsoumis, 1991; Zobel and Van Buijtenen, 1989). Understanding these differences is crucial for selecting the appropriate species for specific purposes in forestry and wood industry practices.

Chips classification

The analysis of chip size distribution indicated no presence of oversized chips (>45 mm**)** among the species evaluated, demonstrating the efficiency of the chipping process and the suitability of the raw material for industrial pulping operations. Proper chip size distribution is essential in the pulp and paper industry because it ensures uniform cooking during the pulping process and improves fiber quality. In the present study, the majority of the chips produced were within the acceptable chip size fraction (>7 mm). Among the species examined, Eucalyptus camaldulensis recorded the highest proportion of acceptable chips (82.8%), followed by *Casuarina equisetifolia* with 81.5%, and *Acrocarpus fraxinifolius* with 80.5%. A higher proportion of acceptable chip size is desirable as it contributes to uniform chemical penetration and efficient pulping performance.

The proportion of pin chips (3–7 mm) ranged from 12.4% to 14.9%, with *Acrocarpus fraxinifolius* showing a slightly higher percentage compared to the other species. Pin chips are generally less desirable because they tend to overcook during the pulping process, potentially affecting pulp yield and fiber quality. However, the observed levels remain within acceptable limits for industrial operations. The dust fraction (<3 mm) was minimal across all species, ranging between 0.4% and 0.5%, indicating good chip quality and minimal material loss during processing. Excessive dust and fines are typically undesirable because they may lead to chemical overconsumption, reduced pulp quality, and operational inefficiencies in digesters.

Overall, the chip size distribution observed in the present study reflects an efficient chipping process and indicates that all three species can produce chips of suitable quality for pulping operations. Proper chip size distribution is widely recognized as a critical factor influencing digester efficiency, pulp yield, and fiber quality, making it an important parameter in evaluating the suitability of wood species as raw materials for the pulp and paper industry (Bajpai, 2018; Gullichsen and Fogelholm, 2000; Sixta, 2019).

The assessment of three tree species highlights the strengths of each in terms of moisture content, density, and chip quality for industrial applications. *Acrocarpus fraxinifolius* is noted for its moderate moisture content and density, along with a commendable percentage of acceptable chips, making it a viable option for pulp and paper production. Eucalyptus camaldulensis is distinguished by its high bulk density and the greatest proportion of acceptable chip fraction, positioning it as particularly beneficial for industrial uses. Meanwhile, *Casuarina equisetifolia*, despite having a lower density, offers chip quality that is on par with the other species. Overall, all three species exhibit a strong potential for yielding over 80% acceptable chips and generating minimal dust, indicating their suitability as high-quality raw materials for industrial processing.

Chemical Properties of industrial wood species

The chemical composition of wood plays a crucial role in determining its suitability for industrial applications such as pulp and paper manufacturing, bioenergy production, and other wood-based industries. The major chemical constituents of wood include cellulose, hemicellulose (pentosans), lignin, and extractives, along with minor inorganic components represented by ash content. Variations in these components significantly influence pulping efficiency, fiber quality, and overall industrial utility (Haygreen J. G. and Jim L. Bowyer, 1982; D. Fengel and G. Wegener, 1989). The present study evaluated the chemical composition of three industrially important species *Acrocarpus fraxinifolius*, *Eucalyptus camaldulensis* and *Casuarina equisetifolia* to assess their potential for pulp and paper production.

Ash Content

Ash content is an indicator of the inorganic mineral content present in wood. High ash content may cause scaling problems in industrial processing and affect combustion efficiency. In the present study, ash content ranged from 0.38% to 0.65% among the species studied. *Acrocarpus fraxinifolius* recorded the highest ash content (0.65%), followed by *Eucalyptus camaldulensis* (0.46%**)** and *Casuarina equisetifolia* (0.38%). The relatively higher ash content in *Acrocarpus fraxinifolius* indicates a greater proportion of mineral elements in its wood. However, the values obtained in this study fall within the normal range for hardwood species (0.2–1.0%), indicating that all three species are suitable for industrial processing without major mineral-related issues. Similar ash content ranges in hardwoods have been reported by D. Fengel and G. Wegener (1989).

Acid Insoluble Lignin

Lignin is a complex phenolic polymer that provides rigidity and structural integrity to plant cell walls. In pulping industries, lignin must be removed to obtain pure cellulose fibers, and therefore species with lower lignin content are generally preferred. The acid-insoluble lignin content among the studied species ranged from 23.0% to 25.9%**.** Among the species analyzed, *Acrocarpus fraxinifolius* exhibited the highest lignin content (25.9%), closely followed by *Casuarina equisetifolia* (25.7%), while *Eucalyptus camaldulensis* recorded the lowest lignin percentage (23.0%). The lower lignin content observed in *Eucalyptus camaldulensis* suggests that it may require comparatively less chemical treatment during pulping, thereby improving pulping efficiency and reducing processing costs. These findings are consistent with earlier reports indicating that *Eucalyptus* species typically possess lower lignin content and are widely preferred in the pulp and paper industry (D. Fengel and G. Wegener, 1989).

Pentosans

Pentosans represent the hemicellulosic fraction of wood and play an important role in fiber bonding during paper formation. The pentosan content of the studied species ranged from 13.0% to 20.1%**.** *Acrocarpus fraxinifolius* showed the highest pentosan content (20.1%)**,** followed by *Casuarina equisetifolia* (18.5%)**,** whereas *Eucalyptus camaldulensis* recorded the lowest value (13.0%)**.** Higher pentosan content contributes to improved paper strength properties, as hemicelluloses enhance fiber flexibility and bonding capacity. Therefore, the relatively high pentosan content observed in *Acrocarpus fraxinifolius* and *Casuarina equisetifolia* may contribute positively to paper strength characteristics.

Holo-cellulose

Holo-cellulose represents the total carbohydrate fraction of wood, consisting of cellulose and hemicellulose. High holo-cellulose content is desirable in pulpwood species since it indicates a greater proportion of fiber-forming components. In the present study, holo-cellulose content ranged from 70.7% to 74.8%**.** *Eucalyptus camaldulensis* exhibited the highest holo-cellulose content (74.8%)**,** followed by *Casuarina equisetifolia* **(**71.6%**),** while *Acrocarpus fraxinifolius* recorded the lowest value (70.7%)**.** The high holo-cellulose content observed in *Eucalyptus camaldulensis* indicates its superior suitability for pulp and paper production, as greater cellulose availability typically results in higher pulp yield and improved paper quality. Similar observations regarding the high cellulose content in *Eucalyptus* species have been documented in previous wood chemistry studies (Haygreen J. G. and Jim L. Bowyer, 1982).

Hot Water Solubility

Hot water solubility represents the proportion of low-molecular-weight carbohydrates, tannins, gums, and other soluble substances present in wood. In this study, hot water solubility ranged from 3.20% to 3.6%**.** *Casuarina equisetifolia* exhibited the highest hot water solubility (3.6%)**,** followed by *Eucalyptus camaldulensis* (3.4%) and *Acrocarpus fraxinifolius* **(**3.20%**).** Higher solubility values generally indicate the presence of a greater amount of water-soluble extractives and degraded carbohydrates, which may influence pulping behavior and chemical consumption during processing.

1% NaOH Solubility

The 1% sodium hydroxide solubility test is commonly used to estimate the amount of low-molecular-weight carbohydrates and degraded cellulose present in wood. In the present study, NaOH solubility ranged from 12.2% to 14.0%**.** *Casuarina equisetifolia* recorded the highest solubility (14.0%)**,** followed by *Acrocarpus fraxinifolius* (13.6%) and *Eucalyptus camaldulensis* (12.2%)**.** Higher NaOH solubility values may indicate the presence of degraded polysaccharides or higher extractive content, which could influence pulping performance and chemical consumption.

Alcohol–Benzene Extractives

Alcohol–benzene solubility represents the extractive components present in wood, including resins, waxes, fats, tannins, and phenolic compounds. These extractives can influence pulping efficiency, paper quality, and industrial processing. In the present study, extractive content ranged from 1.2% to 4.4%**.** Among the species studied, *Acrocarpus fraxinifolius* exhibited the highest extractive content (4.4%)**,** while *Eucalyptus camaldulensis* (1.4%) and *Casuarina equisetifolia* (1.2%) recorded comparatively lower values. Higher extractive content may interfere with pulping processes and affect bleaching efficiency, whereas lower extractive levels are generally considered favorable for pulp production.

The comparative evaluation of the chemical composition of the three species indicates distinct advantages for industrial utilization. *Eucalyptus camaldulensis* exhibited higher holo-cellulose content and lower lignin concentration**,** making it particularly suitable for pulp and paper production due to improved cellulose yield and reduced chemical requirements during pulping. *Acrocarpus fraxinifolius* demonstrated higher lignin, pentosan, and extractive contents, indicating a greater presence of non-cellulosic components. While this may require more intensive pulping conditions, the higher hemicellulose content could contribute positively to paper strength properties. *Casuarina equisetifolia* showed moderate chemical composition values**,** suggesting a balanced profile suitable for pulpwood applications. Its chemical characteristics, combined with its rapid growth and adaptability to marginal soils, make it an important industrial species for plantation forestry.

Overall, the results indicate that all three species possess favorable chemical properties for pulp and paper production, with *Eucalyptus camaldulensis* showing a slight advantage due to its higher cellulose content and lower lignin concentration. These findings support the potential use of these species as alternative pulpwood resources for sustainable industrial applications.

Pulp yield and kappa number

The kraft pulping characteristics of the selected wood species revealed noticeable differences in chemical requirement, pulp yield, and delignification efficiency. The chemical charge, expressed as Na_2O percentage, ranged from 15% to 17% among the species studied. *Eucalyptus camaldulensis* required the highest chemical charge (17%), followed by *Acrocarpus fraxinifolius* (16%), whereas *Casuarina equisetifolia* required the lowest charge (15%). The variation in alkali requirement may be associated with differences in lignin and extractive contents, which influence chemical consumption during the delignification process. Similar variations in chemical charge among hardwood pulpwood species have been reported in recent studies evaluating alternative raw materials for the pulp and paper industry (Bajpai, 2018; Hubbe *et al*., 2020).

The unbleached pulp yield ranged from 42.84% to 48.50%. Among the species, *Casuarina equisetifolia* recorded the highest pulp yield (48.50%), followed by *Eucalyptus camaldulensis* (47.80%), while *Acrocarpus fraxinifolius* showed the lowest yield (42.84%). The comparatively higher pulp yield observed in *Casuarina equisetifolia* may be attributed to its favourable cellulose and hemicellulose composition and efficient carbohydrate retention during pulping. In contrast, the relatively lower yield of *Acrocarpus fraxinifolius* may be due to the dissolution of carbohydrates or differences in wood chemical composition. However, the yield obtained for *Acrocarpus fraxinifolius* still falls within the typical range reported for hardwood kraft pulping processes (Bajpai, 2018; Sixta, 2019).

The percentage of screen rejects was very low across all species, ranging from 0.42% to 0.52%, indicating efficient pulping and effective fiber liberation. *Eucalyptus camaldulensis* exhibited the lowest screen rejects (0.42%), while *Casuarina equisetifolia* recorded slightly higher rejects (0.52%). Low reject levels generally indicate uniform chip impregnation and adequate chemical penetration during cooking. The screened pulp yield ranged from 42.40% to 47.98%. *Casuarina equisetifolia* again showed the highest screened yield (47.98%), followed by *Eucalyptus camaldulensis* (47.38%), whereas *Acrocarpus fraxinifolius* recorded the lowest screened yield (42.40%).

The kappa number, which represents the residual lignin content remaining in the pulp after cooking, ranged from 17.5 to 21.4. Among the species, *Casuarina equisetifolia* exhibited the lowest kappa number (17.5), indicating more effective delignification during pulping. Conversely, *Acrocarpus fraxinifolius* showed the highest kappa number (21.4), suggesting comparatively higher residual lignin content. However, these values fall within the acceptable range typically observed for hardwood kraft pulps, where kappa numbers between 15 and 25 are commonly reported (Hubbe *et al*., 2020; Sixta, 2019).

The characteristics of black liquor further provide insights into the pulping efficiency and chemical utilization. The pH values ranged from 11.96 to 12.90, reflecting the strongly alkaline conditions characteristic of the kraft pulping process. *Eucalyptus camaldulensis* exhibited the highest pH value (12.90). Total solids content ranged from 224 to 231 g L^{-1}, with *Acrocarpus fraxinifolius* showing the highest value (231 g L^{-1}). The total titratable alkali (TTA) values ranged from 30.10 to 31.87, again with *Acrocarpus fraxinifolius* recording the highest value (31.87). Residual active alkali (RAA) varied from 3.72 to 8.90, with *Casuarina equisetifolia* showing the highest residual alkali (8.90), suggesting comparatively lower alkali consumption during the cooking process. Such variations in black liquor properties are commonly observed among different hardwood species and provide useful indicators of chemical consumption and pulping efficiency (Bajpai, 2018).

Overall, *Casuarina equisetifolia* demonstrated superior pulping performance with the highest pulp yield and lowest kappa number, indicating efficient delignification. *Eucalyptus camaldulensis* also exhibited favourable pulping characteristics, including high screened yield and minimal screen rejects. Although *Acrocarpus fraxinifolius* produced a slightly lower pulp yield and a higher kappa number, its performance remained within acceptable limits for hardwood pulping. Considering its satisfactory pulping characteristics, rapid growth, and adaptability to tropical conditions, *Acrocarpus fraxinifolius* can be considered a promising alternative raw material for the pulp and paper industry. The inclusion of such fast-growing species in plantation programmes could contribute to diversifying pulpwood resources and ensuring a sustainable supply of raw materials for the paper sector.

Strength properties of *Acrocarpus fraxinifolius*

The strength properties of paper pulp derived from the studied species showed considerable variation, reflecting differences in fiber morphology and bonding characteristics. Among the mechanical properties evaluated, the tensile index, breaking length, tear index, and burst properties provide important insights into the suitability of pulp for papermaking applications. The tensile index, which is a key indicator of the tensile strength of paper and the bonding ability between fibers, ranged from 24.09 to 50.00 Nm g^{-1} among the species studied. *Eucalyptus camaldulensis* recorded the highest tensile index (50.00 Nm g^{-1}), indicating superior fiber bonding and strength characteristics. This may be attributed to its favorable fiber dimensions and high cellulose content, which contribute to stronger inter-fiber bonding during sheet formation. *Casuarina equisetifolia* also showed good performance with a tensile index of 43.5 Nm g^{-1}. In contrast, *Acrocarpus fraxinifolius* recorded a considerably lower tensile index of 24.09 Nm g^{-1}, suggesting comparatively weaker fiber bonding. However, such values are still within the range reported for several hardwood pulps used in paper manufacturing (Bajpai, 2018; Hubbe *et al*., 2020). Breaking length, another important parameter representing the maximum length of a strip of paper that can support its own weight before breaking, varied from 2421 to 5100 m among the species. *Eucalyptus camaldulensis* exhibited the highest breaking length (5100 m), reflecting its superior fiber strength and bonding characteristics. *Casuarina equisetifolia* showed a moderate breaking length of 2800 m, while *Acrocarpus fraxinifolius* recorded the lowest value (2421 m). The relatively lower breaking length observed in *Acrocarpus fraxinifolius* may be associated with differences in fiber length, cell wall thickness, and fiber flexibility, which influence the formation of strong fiber networks in paper sheets (Sixta, 2019).

The tear index, which represents the resistance of paper to tearing and is largely influenced by fiber length and fiber strength, ranged from 3.9 to 4.7 $mNm^2\ g^{-1}$. Among the species, *Casuarina equisetifolia* recorded the highest tear index (4.7 $mNm^2\ g^{-1}$), indicating better resistance to tearing. *Eucalyptus camaldulensis* followed with a value of 4.10 $mNm^2\ g^{-1}$, while *Acrocarpus fraxinifolius* recorded the lowest tear index (3.9 $mNm^2\ g^{-1}$). The comparatively higher tear resistance in *Casuarina equisetifolia* may be attributed to favorable fiber morphology and fiber strength, which enhance resistance to crack propagation in paper sheets (Hubbe *et al*., 2020).

Similarly, the burst index and burst factor, which reflect the ability of paper to withstand pressure applied perpendicular to its surface, ranged from 1.5 to 2.7 kPa $m^2\ g^{-1}$ and 15 to 27.5, respectively. Among the species, *Eucalyptus camaldulensis* again demonstrated superior performance, recording the highest burst index (2.70 kPa $m^2\ g^{-1}$) and burst factor (27.5). These values indicate strong fiber bonding and high sheet strength. *Casuarina equisetifolia* showed moderate burst strength, whereas *Acrocarpus fraxinifolius* recorded comparatively lower values. Burst strength is closely related to fiber bonding capacity and sheet formation quality, which tend to be higher in pulps with favorable fiber flexibility and cellulose content (Bajpai, 2018).

Overall, the results indicate that *Eucalyptus camaldulensis* possesses superior strength properties in terms of tensile, burst, and breaking length, making it highly suitable for high-strength paper products. *Casuarina equisetifolia* also exhibited satisfactory mechanical properties, particularly with respect to tear resistance. Although *Acrocarpus fraxinifolius* demonstrated comparatively lower strength properties, its values remain within acceptable ranges for certain grades of paper. Therefore, when blended with other pulpwood species or used for specific paper products, *Acrocarpus fraxinifolius* can still serve as a viable supplementary raw material for the pulp and paper industry.

CONCLUSION

The present study evaluated the potential of *Acrocarpus fraxinifolius* as an alternative raw material for the pulp and paper industry in comparison with *Eucalyptus camaldulensis* and *Casuarina equisetifolia*. The results demonstrated that although *Eucalyptus camaldulensis* and *Casuarina equisetifolia* exhibited comparatively superior pulping performance and paper strength properties, *Acrocarpus fraxinifolius* also showed acceptable characteristics for pulp production. In the kraft pulping process, *Acrocarpus fraxinifolius* required a moderate chemical charge and produced an unbleached pulp yield within the acceptable range for hardwood species, although slightly lower than the other two species. The screened yield and low percentage of screen rejects indicated efficient pulping and satisfactory fiber separation. The kappa number values suggested that the species underwent adequate delignification, even though the residual lignin content was slightly higher compared to the other species studied. The properties of black liquor, including pH, total solids, and alkali parameters, further confirmed that the pulping process proceeded under suitable alkaline conditions.

The evaluation of paper strength properties revealed that *Acrocarpus fraxinifolius* exhibited lower tensile index, breaking length, tear index, and burst strength compared with *Eucalyptus camaldulensis* and *Casuarina equisetifolia*. However, the observed values remained within acceptable limits for several grades of paper, particularly when the pulp is blended with stronger fibers. These results indicate that although the species may not match the mechanical strength of conventional pulpwood species, it can still contribute effectively as a supplementary raw material.

Considering its fast growth, adaptability to tropical conditions, and satisfactory pulping characteristics, *Acrocarpus fraxinifolius* shows considerable promise as an alternative pulpwood species. The incorporation of this species into plantation programs could help diversify the raw material base of the pulp and paper industry and reduce dependence on traditional species. Further studies on fiber morphology, pulping optimization, and large-scale plantation performance would strengthen its potential for commercial utilization in pulp and paper production.

Table 1. Physical characteristics of *Acrocarpus fraxinifolius*

Sl. No.	Physical properties	*Acrocarpus fraxinifolius*	*Eucalyptus camaldulensis*	*Casuarina equisetifolia*
1.	Moisture Content (%)	8.9	9.76	8.67
2.	Bulk density (OD basis) (kg /m^3)	230	270	191
3.	Basic density (OD basis) (kg /m^3)	510	510	435
4.	**Chips Classification**			
	+ 45 mm	Nil	Nil	Nil
	+ 8mm (over thick)	4.2	4.4	5.4
	+ 7 mm (accepts)	80.5	82.8	81.5
	+ 3 mm (pin chips)	14.9	12.4	12.6
	- 3mm (dust)	0.4	0.4	0.5

Table 2. Proximate Chemical Composition of *Acrocarpus fraxinifolius*

Sl. No.	Chemical properties	*Acrocarpus fraxinifolius*	*Eucalyptus camaldulensis*	*Casuarina equisetifolia*
1.	Ash content (%)	0.65	0.46	0.38
2.	Acid insoluble lignin (%)	25.9	23.0	25.7
3.	Pentosans (%)	20.1	13.0	18.5
4.	Hollo cellulose (%)	70.7	74.8	71.6
5.	Hot water Solubility (%)	3.20	3.4	3.6
6.	1% NaOH Solubility (%)	13.6	12.2	14.0
7.	Alcohol benzene Solubility (%)	4.4	1.4	1.2

Table 3. Pulping results of *Acrocarpus fraxinifolius*

Sl. No.	Pulping properties	*Acrocarpus fraxinifolius*	*Eucalyptus camaldulensis*	*Casuarina equisetifolia*
1.	Chemical charge as Na_2O (%)	16	17	15
2.	Unbleached pulp yield (%)	42.84	47.80	48.5
3.	Screen rejects (%)	0.44	0.42	0.52
4.	Screened yield (%)	42.4	47.38	47.98
5.	Kappa number	21.4	20.48	17.5
	Black liquor			
6.	pH	11.96	12.90	12.7
7.	Total solid (gpl)	231	224	227
8.	TTA* as Na_2O	31.87	31.70	30.10
9.	RAA* as Na_2O	3.72	4.60	8.9

Cooking conditions

Temperature : 170^{o}C

Time : 90 min.

* TTA and RAA as Na_2O are calculated at 200 gpl total solids basis

Table 4. Strength Properties of *Acrocarpus fraxinifolius*

Sl.No	Strength Properties	*Acrocarpus fraxinifolius*	*Eucalyptus camaldulensis*	*Casuarina equisetifolia*
1.	Tensile index (Nm/g)	24.09	50.00	43.5
2.	Breaking length (M)	2421	5100	2800
3.	Tear index (mNm^2/g)	3.9	4.10	4.7
4.	Tear Factor	39.82	41.8	47
5.	Burst index ($kPam^2/g$)	2.0	2.70	1.5
6.	Burst Factor	20.50	27.5	15

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