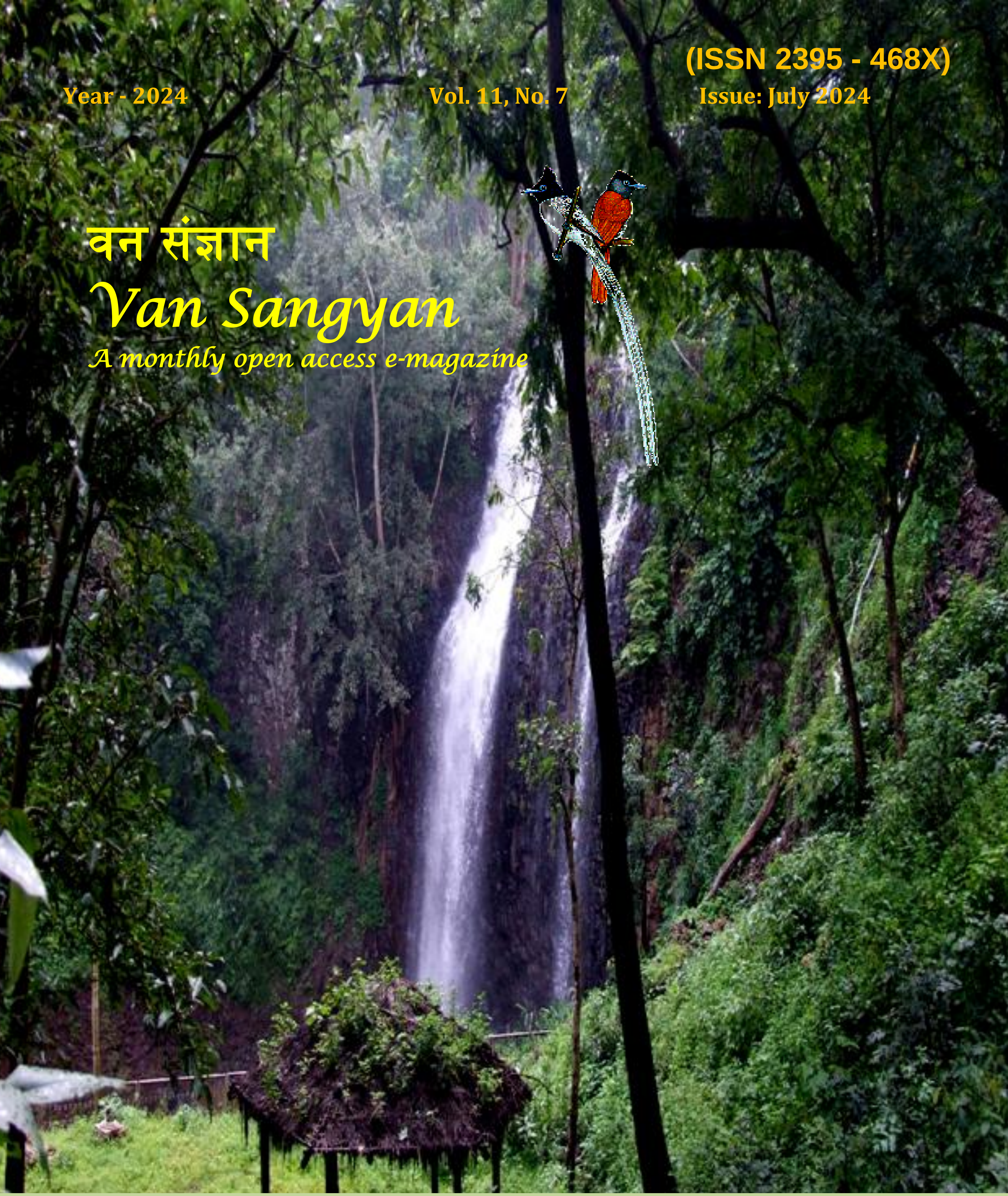
(ISSN 2395 - 468X)
Year - 2024 Vol. 11, No. 7 Issue: July 2024

वन संज्ञान
Van Sangyan
A monthly open access e-magazine



Indexed in:

COSMOS Foundation (Germany) | International Inst. of Org. Res. (Australia) | IIJIF

ICFRE-Tropical Forest Research Institute
(Indian Council of Forestry Research and Education)
Ministry of Environment, Forests and Climate Change (MoEFCC)
PO RFRC, Mandla Road, Jabalpur – 482021, India

Van Sangyan

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Cover Photo: Panoramic view of Achanakmar-Amarkantak Biosphere Reserve

From the Editor's desk

Aonla (Emblica officinalis Gaertn), also known as Indian gooseberry, is a highly esteemed minor fruit native to India, Sri Lanka, Malaysia, and China, and is celebrated for its remarkable health benefits. Belonging to the Euphorbiaceae family, this fruit is a crucial component of tropical and subtropical agriculture in the Indian subcontinent. Aonla is adaptable to various climates and soil conditions and is recognized by several names, including 'Amla,' 'Amalakki,' and 'Nelli.' It is exceptionally rich in vitamin C, as well as other nutrients like polyphenols, pectin, iron, calcium, and phosphorus. The fruit boasts powerful antioxidant, hypolipidemic, antibacterial, antiviral, and digestive properties. However, its highly acidic and astringent taste, combined with low soluble solids and poor flavor and color, limit its popularity as a fresh fruit. Aonla is highly perishable, available only briefly from October to January in India, with a shelf life of just 5–6 days under normal air conditions. Proper storage and processing techniques can reduce postharvest losses to 30% and extend its availability. Unfortunately, existing postharvest technologies are complex and costly for small-scale farmers. Additionally, due to its astringent taste, many consumers are hesitant to eat it raw. Efforts are underway to develop value-added products that not only retain its nutritional benefits but are also more palatable to consumers.

In line with the above this issue of Van Sangyan contains an article on Value addition and processingof Amla – Phyllanthus emblica (Indian gooseberry). There are also useful articles viz. Nyctanthes arbor-tristis: A botanical miracle with multifaceted applications, Dioscorea species: An important under exploited medicinal plant and a potential root crop for agroforestry, Enhancing climate resilience and mitigation in forestry and tree-based agroecosystems through biochar applications, Biochar use in Indian forests: Opportunities and challenges, Biopulping: An energy efficient and environment friendly technology for pulp and paper industry, Cycas circinalis-an endemic and endangered species, Production and management of tree fodder in smallholder agroforestry systems in India, Unraveling the proteomes of trees: A comprehensive omics approach to understanding tree biology and Silviculture of intensively managed plantations: Maximizing productivity and sustainability .

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Looking forward to meet you all through forthcoming issues

Dr. Naseer Mohammad

Chief Editor

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Value addition and processingof Amla – *Phyllanthus emblica* (Indian gooseberry)

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Abstract

Amla, sometimes referred to as Indian gooseberries, grown all across India and its neighboring nations, amla has become popular worldwide as a "super fruit." Including this age-old super fruit in our diet could help us feel better overall. The vitamins and antioxidants in amla berries provide a number of health advantages. Amla's high vitamin C content facilitates the body's ability to heal from sickness. Amla berries also include a number of flavonols, which are compounds associated with advantages including enhanced memory. Your body absorbs sugar more slowly when you consume amla berries because their soluble fiber degrades quickly. This can help reduce blood sugar spikes. Amla berries also have a positive effect on blood glucose and lipid counts in people with diabetes.Amla berries contain fiber, which aids in the regulation of bowel motions and may help alleviate symptoms associated with illnesses such as irritable bowel syndrome. If you take iron and other mineral supplements, Amla berries may be beneficial because of their high vitamin C content, which aids in the body's absorption of other nutrients.Vitamin A, which is abundant in amla berries, is essential for enhancing eye health. In addition to enhancing eyesight, vitamin A may reduce the risk of degeneration of the retina brought on by aging. Because amla contains vitamin C, which fights bacteria, it helps keep your eyes healthy by preventing infections and conditions like conjunctivitis, or pink eye. A serving of 100g (about half a cup) of amla berries contains 300 mg of vitamin C, which is more than double the daily recommended amount for adults. Amla's phytonutrients and antioxidants help protect brain cells from harm by scavenging free radicals, which can impair memory.Amla's high vitamin C content aids in the body's production of norepinephrine, a neurotransmitter thought to enhance dementia patients' brain function. Owing to its significance, it must be remembered for the future; hence, amla must undergo post-harvest processing and value-adding in order to extend its shelf life.

Dried amla pulp (Deseeded)

Tools/equipment required

Amla Shredding machine	
Amlade-stoning machine	
Weighing scale	
Tarpaulin sheets	

Amla Juice Machine

Raw Material (Collection)

When they turn from a bright green to a drab greenish yellow, amla fruits should be plucked in February. Robust shaking is necessary because the mature fruits are rigid and do not fall when touched gently. Moreover, large bamboo poles with hooks attached can be used to gather fruit. After roughly ten years of maturity, a mature tree will produce 50–70 kg of fruit. It is recommended to gather the fruits from the trees and transport them to the collection unit using plastic crates or bags.

The Amla tree and fruit gathering

Figure 1: Amla Manual Plucking

Figure 2: Collection of Amla

Value addition/processing

Washing of RawAmlaFruit–The raw Amla fruit that has been harvested from the branches must be manually cleaned in big buckets or metal drums. In order to cut labor expenses and improve consistency in the quality of the cleaned fruit, washing machines can also be used for the procedure of washing.

De-stoning of amla fruit

Amla fruit has an uneven form and a pulp that adheres tightly, making it challenging to manually remove the stone before processing. In addition to being laborious, manual removal leaves 15-20% of the pulp stuck to the stone and causes the fruit to split into pieces. To increase the effectiveness of this crucial segment separation process, mechanical equipment are available for destoning the fruit. A manually controlled device to de-stone Amla fruits has been designed and developed. The machine's core, die, and plunger are its three primary functional components. It operates on the principles of compression and coring. The Amla fruit is left whole following this procedure, with only roughly 6–8% of the pulp still stuck to the stones.

Figure 3: Amla de-stoning machine

Drying of amla fruit segments

There are various ways to dry Amla fruit, and the best technique depends on the desired level of quality, the properties of the raw materials, and other economic considerations. The fruit segments should mostly be dried in the sun to reduce the fruit's moisture content. Depending on the amount of sunlight and the surrounding weather, it could take five to six days to reduce the moisture content.

Powdering of dried amla segments

Fruit segments that have dried can be mashed in a mortar and pestle and then in an electric grinder to create dehydrated powders. The powdered dehydrated amla can be packed using a sealing machine in airtight jars or plastic and kept for around ninety days in a storage environment devoid of moisture, direct sunlight, and other contaminants.

Value added products

Jam

Jam is a fruit product that has been condensed and processed to have a rich, naturally occurring fruit flavor. Fruit has a good set because to pectin and its high sugar content helps to preserve it. To prepare it, boil the fruit pulp and juice with enough sugar until the mixture becomes a thick enough consistency to keep the fruit pieces in place. About fifty percent of the fruit portion and 68% of the total soluble solids should be present in a fruit jam.

Sauce

The components for sauce and ketchup are the same as for chutney, and they can be prepared similarly. The only difference is that after simmering, the fruit or vegetable pulp or juice must be sieved to separate the skin, seeds, and stalks from the fruit, vegetables, and spices, giving the finished product a smooth consistency. Chutneys cook more quickly than sauces or ketchups because fine pulp or juice is utilized in the former. You can produce five kg of sauce with 50 percent Amla pulp and 50 percent tomato pulp, along with 75 grams of sugar, 10 grams of salt, 60 grams of onion, 6 grams of garlic, 12 grams of ginger, 5 grams of red chilies, and 12 grams of hot spices. First, add 1 milliliter and 0.3 grams per kilogram of fina product to the acetic acid and sodium benzoate preservatives, respectively.

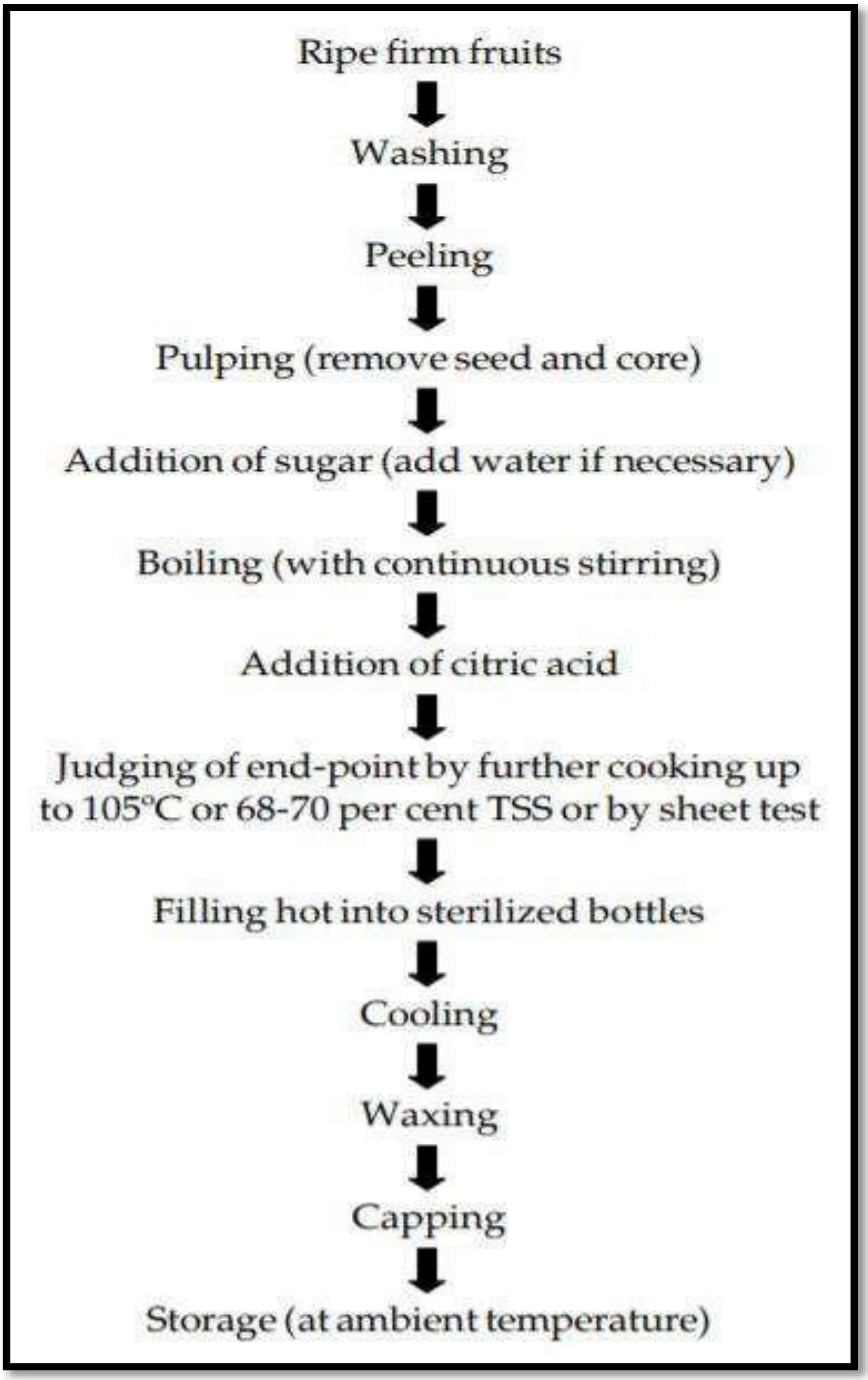

Figure 4: Technological flow-chart for processing of Jam

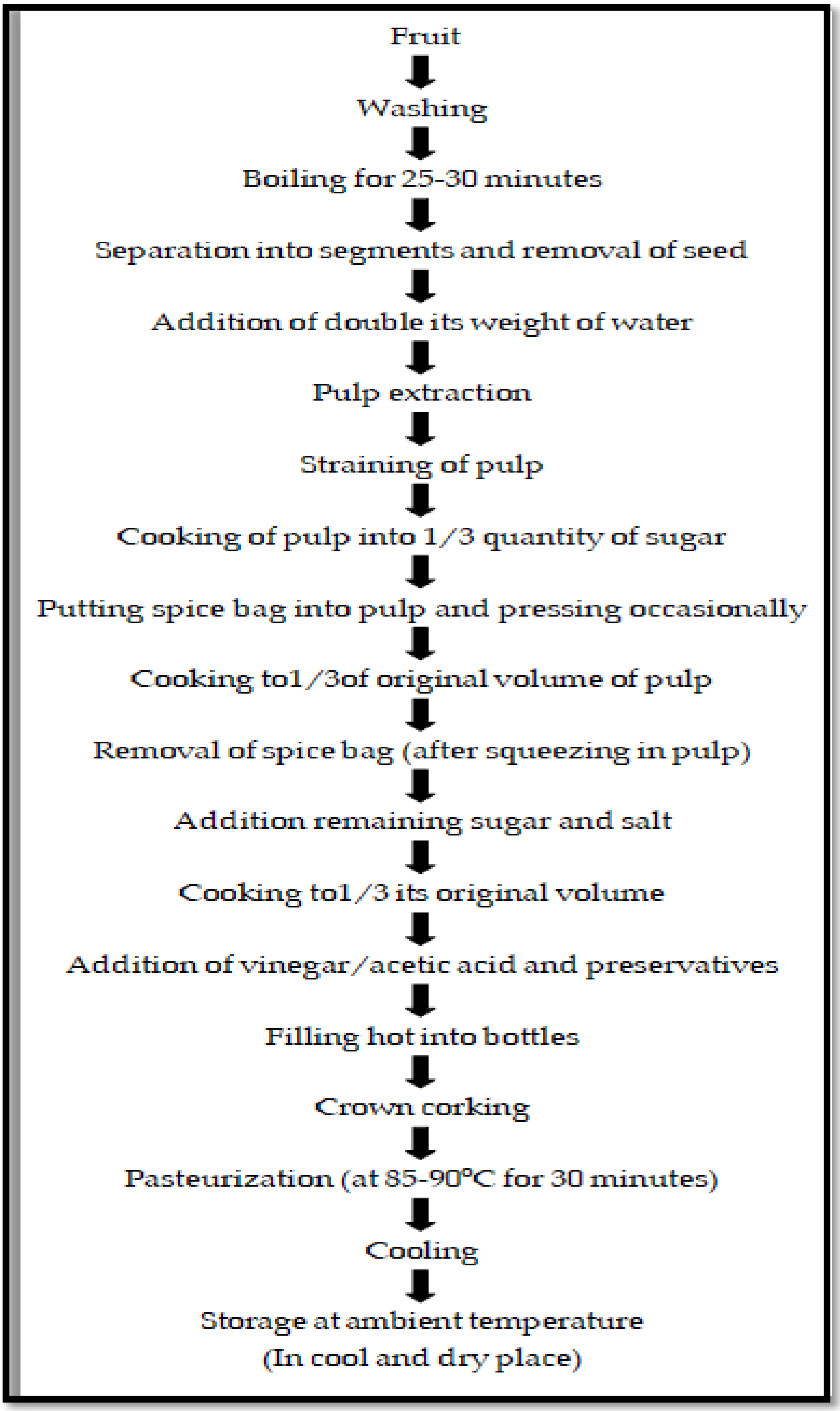

Figure 5: Technological flow-chart for processing of Sauce

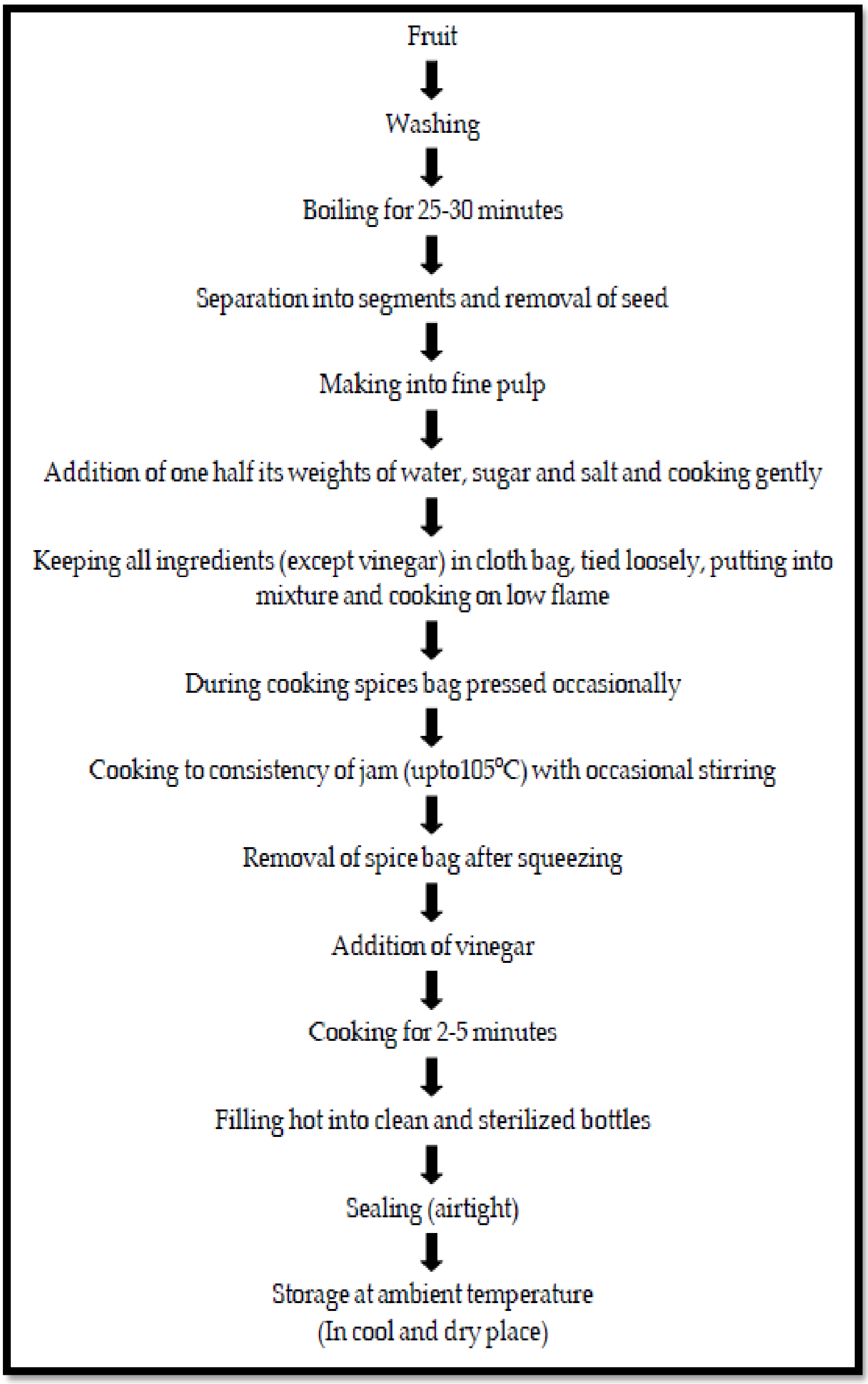

Figure 6: Technological flow-chart for processing of Chutney

Chutney

The typical flavors of Amla chutney include mellow, smooth, spicy, sweet, and spicy. It also looks good. Its flavor and nutritional content can occasionally be enhanced by adding dry fruits and rising.Preserve/murabba

Amla preserve, sometimes called murabba in India, is a very well-liked traditional product. In addition to its favorable effects on blood purification, it lowers cholesterol and improves vision. Matured fruit, either whole or in large chunks, can be used to make preserves. The fruit is impregnated with sugar until it turns translucent and soft. A minimum of 55% of the preserve should be made of fruit. To get the syrup inside the fruits and to remove the astringency, pricking, or piercing, should be done in amla.

Figure 7: Amla preserve/ murabba

Candy

Fruit candies are growing in popularity due to their increased nutritional value, longer shelf life, less volume, and high acceptance. These also have the benefit of being readily consumable and least thrust-provoking treats. Candied fruit, also known as fruit candy, is fruit that has been infused with sugar, extracted, drained, and then dried. A maximum of 75% of the total soluble solids should be present. Mature fruits must be cleaned, poked, and immersed in a two percent salt solution for a whole day in order to make Amla candy. After that, the fruits need to be cleaned and immersed in a 2% alum solution for a whole day. The fruit needs to be well cleaned, blanched in boiling water for five minutes, then steeped for twenty-four hours in a solution of 50 ºBrix syrup. Steeping should be done at 60º Brix for 24 hours the next day. Once more, steeping needs to be done for 72 hours at 70º Brix. It is necessary to drain any extra syrup. After that, the fruit was dried to 15% moisture content and covered with powdered sugar or pectin. Packing ought to be done using 400 gauge polythene pouches.

Juice

Juice can be extracted using the following methods: (A) pasteurization at 90 degrees Celsius for one minute, followed by hot filling in pre-sterilized glass bottles; (B) treatment with 300 parts per million SO_2 (KMS); and (C) pasteurization at 90 degrees Celsius for one minute, cooled to 60 degrees Celsius, and 350 parts per million SO_2 to be added before sealing in glass bottles.

Figure 8: Amla Juice

Pickle

Pickling is the process of preserving fruit or vegetables in conventional salt or vinegar. Pickles can also have oil and spices added to them. It stays fresh longer when salted with 15% common salt. Additionally, 2% vinegar serves as a preservative.

Storage of value added product

Because there is very little time for amla fruits to be stored in the atmosphere after harvest, they are extremely perishable in nature. For 7-8 days, the fruits can be refrigerated at 0–2 degrees Celsius and 85–90% relative humidity. Amla fruits are perishable, making long-distance storage and transportation challenging. Amla needs to be sold on the market as soon as possible in order to yield a healthy profit.

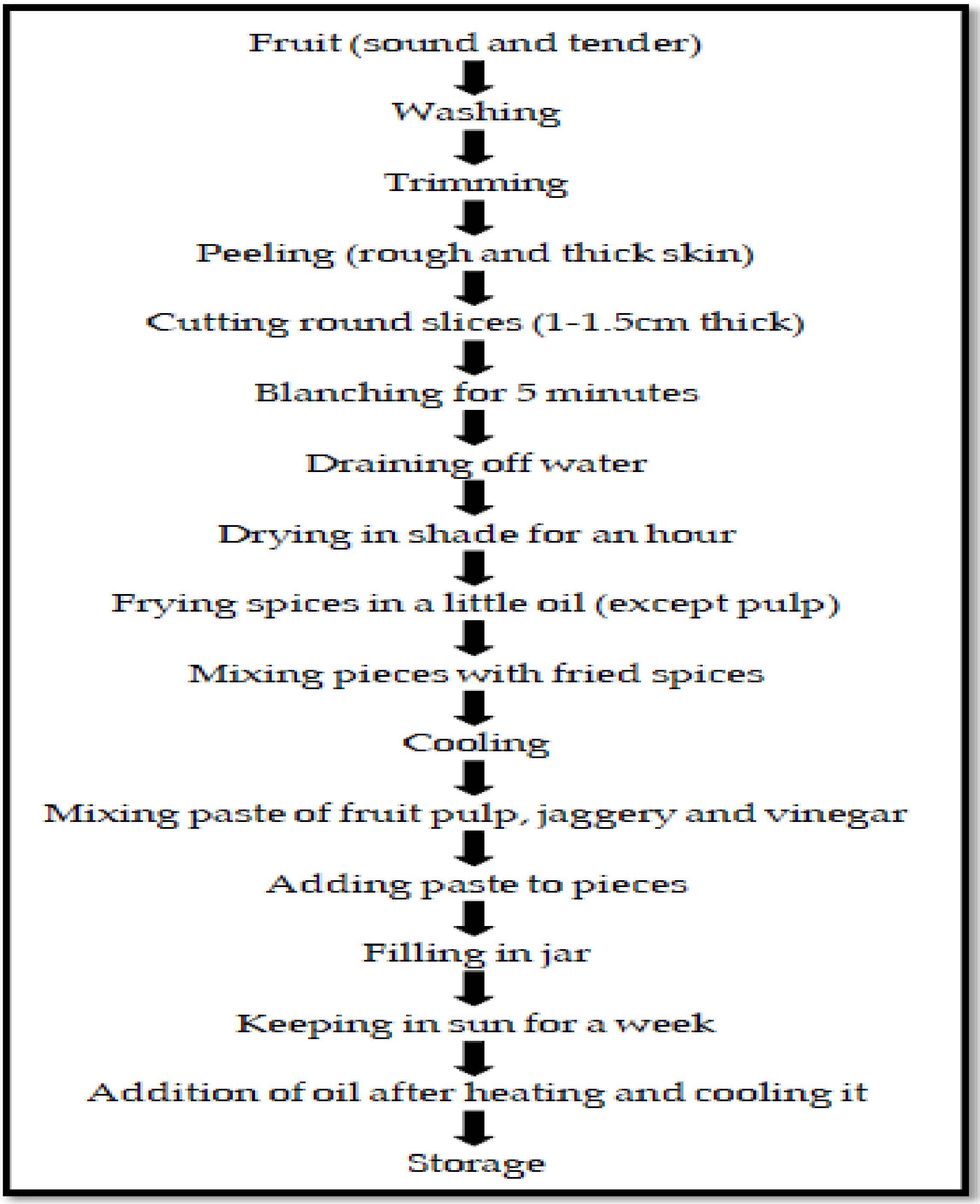

Figure 9: Technological flow-chart for preparing pickle

Nyctanthes arbor-tristis: A botanical miracle with multifaceted applications

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Introduction

The world of plants is full of wonders, but few can compare to Nyctanthes arbor-tristis, a botanical gem that goes by names such as "Parijat" or "Night-flowering Jasmine." Native to the lush landscapes of Southeast Asia, particularly India and Bangladesh, this unassuming tree or shrub has enthralled people for generations with its mesmerizing beauty and diverse array of uses. In this article, we will explore the multifaceted applications of *Nyctanthes arbor-tristis*, shedding light on its significance in culture, traditional medicine, and horticulture.

Multifaceted applications

Nyctanthes arbor-tristis occupies a unique and cherished place in the hearts of people throughout the Indian subcontinent, thanks to its rich cultural heritage. It plays a prominent role in Hindu mythology and religious rites, symbolizing the divine and serving as a common offering in temples. Yet, beyond its cultural significance, Nyctanthes arbor-tristis assumes an essential role in traditional medicine. Different parts of the plant, such as its leaves and flowers, are thought to house potent medicinal properties. However, its appeal isn't limited to its cultural and medicinal value alone; it extends to its aesthetic charm. This hardy and easily managed plant thrives in gardens, courtyards, and even in pots, making it a versatile and beloved addition to various settings.

Edible and medicinal uses

The *Nyctanthes arbor-tristis*, or Night-flowering Jasmine, offers a unique combination of edible and medicinal applications. Its flowers can be consumed as a vegetable, either fresh or dried, imparting a pleasantly bitter flavor. Additionally, its leaves are commonly employed in the preparation of curry dishes. Medicinally, this plant is a versatile treasure, known for its anthelminthic properties, aphrodisiac qualities, immune-stimulant effects, antibacterial features, and anti-inflammatory potential. It has been explored for regulating blood sugar levels, enhancing digestive health, and providing relief from various ailments. Key compounds like nyctanthic acid, friedlin, β-sitosterol, oleanolic acid, and iridoid arbor-tristoside-A contribute to its antidiabetic and anticancer properties. This plant finds utility in addressing issues related to weight gain, fetal growth, female disorders, hair loss, fever, and intestinal worms.

Craft and artisanal uses

Historically, the scabrous leaves of the *Nyctanthes arbor-tristis* served as a final polish on ivory objects, showcasing its significance in craft and artisanal practices. Furthermore, the pale red wood, although quite hard, is predominantly used for fuel due to its rapid drying properties. It occasionally finds application in crafting boards and baskets, underlining its role in artisanal endeavors.

Soap making and traditional dyes

This versatile plant extends its utility to the world of soap making. Its seeds are effective in combatting dandruff, offering a practical solution for personal care. Moreover, the bright orange corolla tubes of its flowers contain a coloring substance called nyctanthin, identical to ά-Crocetin from Saffron. In the past, these corolla tubes were utilized for dyeing silk, occasionally in combination with Safflower or turmeric. The Nyctanthes arbor-tristis flowers are also collected and processed to obtain a saffron-colored dye, which is employed in coloring silk or cotton. This dye is even used domestically for coloring fabric and as a cost-effective substitute for saffron in coloring the robes of Buddhist clergymen.

Perfumery, tanning material and fuel

The Nyctanthes arbor-tristis doesn't stop at practical applications; its essential oil, derived from its fragrant flowers, contributes to the production of perfumes, incense, and scented oils. Additionally, its bark is employed as a tanning material. The wood, primarily used as fuel due to its rapid drying characteristics, is recognized for its multifaceted role in various everyday applications.

Religious and cultural significance

Highly esteemed in Hindu culture, this plant plays an integral part in religious rituals and is often planted near temples and homes. Its fragrant flowers serve as offerings in temples, reflecting its sacred nature. Beyond religious contexts, this plant has been a source of inspiration for poets, writers, and artists across different cultures. It often appears in traditional poetry and literature, symbolizing themes of love, longing, and ethereal beauty. The Coral Jasmine also finds its place in traditional practices, such as making garlands for religious rituals and adorning statues and idols of deities during ceremonies.

Ornamental and traditional roles

Its ornamental value cannot be overstated; the Nyctanthes arbor-tristis is widely cultivated as an ornamental plant in gardens and landscapes. Its visual appeal, fragrant blooms, and striking appearance make it a cherished choice for both private gardens and public parks. Its significance transcends practicality, encompassing aesthetics, culture, and tradition.

Propagation

The renewed interest in plant-based remedies, along with the rapid growth of the pharmaceutical industry, has fueled the demand for this medicinal plant, resulting in over-exploitation. The destruction of its natural habitat, excessive harvesting, and persistent issues include ineffective seed germination, susceptibility to seed infections, inhibited coleoptile growth, imbalanced root-to-shoot ratios during germination and the death of young seedlings have led to a decline in the population of this important medicinal and ornamental tree. The natural propagation is also a slow process that could not fulfil market demand. Hence, for commercial, ornamental and conservation purposes studies are needed to be conducted on production of the plant in large scale.To address these pressing concerns, initiatives like the All India Coordinated Research Project on Seed Technology, funded by CAMPA (Ministry of Environment, Forest, and Climate Change), are actively underway. This research project, hosted at the ICFRE-Tropical Forest Research Institute in Jabalpur, Madhya Pradesh, is dedicated to various forestry species, including Nyctanthes arbor-tristis. Its primary objective is to harness and enhance technology related to seed processing, handling, viability, storage physiology, and nursery techniques. By leveraging the natural resources found in the forests of Central India, specifically in Madhya Pradesh, Maharashtra, and Chhattisgarh, this research endeavor aims to mitigate the challenges associated with the cultivation and conservation of this significant plant.

Conclusion

Nyctanthes arbor-tristis, the Night-flowering Jasmine, is a botanical marvel that transcends mere aesthetics. Its multifaceted applications encompass culture, spirituality, traditional medicine, and horticulture. The fragrance and beauty of its night-blooming blossoms have woven a delicate tapestry of tradition and reverence, while its leaves and flowers serve as valuable remedies in natural healing. As a low-maintenance garden favorite, it continues to bring joy to horticultural enthusiasts. In its many roles, Nyctanthes arbor-tristis remains an enduring and versatile presence in the lives of those in the Indian subcontinent and beyond, exemplifying the beauty and utility of nature's creations.

Dioscorea species: An important under exploited medicinal plant and a potential root crop for agroforestry

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Abstract

In India, over 7000 species of plants found in different ecosystems are said to be used for medicine and about 20,000 medicinal plants can be used for curative purposes. There is manifold increase in demand for medicinal plants and their products in coming years. A large majority of these plants are still collected from their wild habitats. The total quantity required for pharmacies could not met from these sources. So, introduction of such medicinal species in farmlands as an agroforestry system is in need for sustainable production, to improve the agro-ecosystem and to achieve 33% of the total geographical area under forest cover as envisaged in National Forest Policy, 1988. Agroforestry which is considered as an alternative land use system offers wide scope for integration of medicinal plants along with perennial crops. It plays a potential role in meeting food, fodder, fuelwood and other timber, raw materials for pharmacies and maintaining environmental stability. In agroforestry economic or medicinal tree species can be grown along with annual medicinal herbs. *Dioscorea* is one of such important medicinal plant species (yam or Maragenasu) which belongs to the family Discoreaceae and are underutilized tuber crops cultivated in the tropics and in West Africa, West Indies, Tropical America and South East Asia. Yam is grown in the southern and eastern parts of India. The crop is seasonal in nature and hence it is not available in large quantity throughout the year. Yam is essentially a crop of subsistence agriculture. Yam is the common name for some plant species in the genus *Dioscorea* (family Dioscoreaceae) that form edible tubers. These are perennial herbaceous vines cultivated for the consumption of their starchy tubers in Africa, Asia, Latin America the Caribbean and Oceania. Yam tuber is consumed after roasting, boiling or with other vegetables. Some poisonous types like *D. dumetorum* and *D. hispida* are eaten during food scarcity after clarification or as such used as an aid in hunting, fishing arrow poisoning and for insecticidal purpose. The genus Dioscorea contains about 600 species. Of the total species, about 12 are known for edible purposes. The species *Dioscorea alata L, D. rotundata (L) Poir, D. esculenta* (Lour), Burk. *D. bulbifera* and *D. trifida* L. are the principal yams of the tropics. However, the former three are

cultivated on large scale for edible purposes. In India, *D. alata*, *D. esculenta* are extensively cultivated in different regions as a subsidiary food crop. The wild species in most cases have chromosome number based on x = 10. The primitive section stenophora has 2n = 2x = 20, but any tropical species used as food have 2n = 4x= 40. The cultivated types are comparable to potatoes in taste and quality. The tubers of some species, *e,g, D.alata*, are employed for the extraction of starch on a commercial scale. Some species of Dioscorea are reported to be rich in vitamins B_1, B_2 and B_3 and possibly also in other members of the Vitamin B complex. They are poor in protein, calcium and iron. The alkaloid, dioscorine and the saponin, dioscin, occur in varying quantities in different species of yams. Dioscorine (C_{13} H_{19} O_2 N) is abundant in *D. hispida* and its tubers when consumed in large enough quantities cause paralysis of the respiratory organs and even death. The tubers of *D. deltoidea* are rich in saponins and are used for washing silk, wool and hair, and as fish poison.

Keywords: Fragile ecosystems, Subsistence agriculture, Agro-ecosystem, Bio-remediation mechanism, Environmental stability, Water-logged soils, Restoration agent.

Introduction

Dioscorea (*Dioscorea* species; Eng-Yam, Kan-Maraganasu) is an important medicinal plant. It is propagated by means of seeds, stem cuttings and tuber spieces. Yams are under utilized tuber crops cultivated in the tropics and in West Africa, West Indies, Tropical America and South East Asia. Yam is grown in the southern and eastern parts of India. The crop is seasonal in nature and hence it is not available in large quantity throughout the year. Yam is essentially a crop of subsistence agriculture. Yam is the common name for some plant species in the genus *Dioscorea* (family Dioscoreaceae) that form edible tubers. These are perennial herbaceous vines cultivated for the consumption of their starchy tubers in Africa, Asia, Latin America the Caribbean and Oceania. There are many cultivars of yam. Although some varieties of sweet potato (*Ipomoea batatas*) are also called *yam* in parts of the United States and Canada, sweet potato is not part of the family Dioscoreaceae but belongs in the unrelated morning glory family Convolvulaceae.

Origin

The Dioscoreaceae show some promising characters of both monocot and dicot and were considered as earlier angiosperms. It was suggested by Coursey (1975) that the ancestral Discoreaceae might have originated in South East Asia. Earlier, Burkill (1960) had also indicated the origin of early Discoreaceae in South East Asia.

Distribution

In Asia, the cultivars *Dioscorea alata* have been developed as a result of selection from wild form related to *D. hamiltonii* and *D. persimilis* in South East Asia. *Dioscorea esculenta* is indigenous of the same area and also developed by selection (Alexander and

Coursey, 1969: Coursey, 1975). The major center of diversity of cultivars of both species is in Pupua New Guinca (Coursey, 1976). The evolution of African yams as crop plant is mainly due to the identification of *D. cayenenis* (Ayensu and Coursey, 1972). Of the two major species, *D. cayenenis* is indigenous to forest zone of Africa, while *D. rotundate*, a cultivar is very close to *D. cayenesis* and is considered as a subspecies.

Species	Moisture %	Carbohydrate %	Fat %	Crude Protein %	Fiber %	Ash %
D. alata	65-73	22-29	0.30-0.27	1.12-2.78	0.65-1.40	0.67-2.06
D. rotundata	58-73	23	0.12	1.09-1.99	0.35-0.79	0.68-2.86
D. esculenta	67-81	17-25	0.04-0.29	1.29-1.87	0.18-1.51	0.50-1.24

Composition

The Tubers contain most of the essential nutrients including minerals, vitamins and possess mechanical properties. They are rich sources of protein and amino acids. The chemical composition of yam is given below (Coursey, 1967).

Uses

Yam tuber is consumed after roasting, boiling or with other vegetables. It is also used for making chips, flakes and flour. Some poisonous types like *D. dumetorum* and *D. hispida* are eaten during food scarcity after clarification or as such used as an aid in hunting, fishing arrow poisoning and for insecticidal purpose. Many species of yam contain small amounts of sapogenins and alkaloids for various use and also used as corticosteroid drugs.

Species

The yam belongs to the family Discoreaceae and genus Dioscorea which contains about 600 species. Of the total species, about 12 are known for edible purposes. The species *Dioscorea alata L, D. rotundata (L) Poir, D. esculenta* (Lour), Burk., *D. bulbifera* and *D. trifida* L. are the principal yams of the tropics. However, the former three are cultivated on large scale for edible purposes. In India, *D. alata, D. esculenta* are extensively cultivated in different regions as a subsidiary food crop. The wild species in most cases have chromosome number based on x = 10. The primitive section stenophora has 2n = 2x = 20, but any tropical species used as food have 2n = 4x= 40 (Coursey, 1967).

The morphological characters of the three important species of edible yam are given below:

D. alata

It is also called the greater yam which has winged spineless stems twining to the right, leaves are large and arranged in opposite manner. The tubers of cultivated type are normally round, oval or irregular in shape. The skin of the tuber is black or brown while flesh is white, yellowish or purplish and roduce usually 1-3 tubers ***D. esculenta***

This is of short duration (7-8 month) and is called lesser yam. It is characterized by thin, pubescent and spiny stems which twine to the left. Leaves are small, cordate and alternate in arrangements. Tubers are small as compared to other yams and they are produced in clusters of 10-15 tubers. They have thin yellowish brown skin and white flesh.

D. rotundata

This species is mainly cultivated in West Africa and is known as white yam. It is characterized by sturdy, spiny and roughly circular stem, which twines to the right. Leaves are small, simple, cordate and opposite or alternate in arrangement. Tubers are normally cylindrical with brown skin and white flesh.

Commercial exploitation of yams for diosgenin occurs most predominantly in Mexico where *D. mexicana*, *D. floribunda*, and *D. composita* are grown for this purpose (Onwieme, 1978).

Cultivars

The central Tuber Crops Research Institute, Trivendrum (ICAR) has a large collection of germplasm of *D. alata* and *D. esculenta* mostly from indigenous sources. After systematic screening and testing, three superior types of *D. alata* have been identified *viz.*, Da 60, Da 80 and Da 122. Da 60 has large conical shaped tubers, Da 80 has medium sized irregular tubers and Da 122 has medium sized, round to oval tubers. These cultivars give high yield of about 30-35 tonnes of tubers per hectare.

Soil

Tuber growth and development largely depend on tilth of the soil. Some tubers of Dioscoreas go deep into the soil and some spread on the upper strata. Well drained, loose friable soil containing good amount of organic matter is preferred for yam cultivation. In stiff clay soil, deformed tubers are formed with poor storage quality. Yam can be grown in wide range of soil pH between 5-7.

Climate

Plants are mainly grown in the tropic and sub-tropics of the world. However, major yam growing areas are in the tropical region. The optimum range of temperature is between 25 and 30 ^{0}C. Yams cannot tolerate frost and growth is affected at a temperature below 20 C. High rainfall is beneficial for obtaining higher yield of tubers. Yam requires a well distributed rainy days for 7-10 months. Low moisture supply at the early stage may kill the young shoots which have exhausted reserve food of the old set. The moisture stress in the early stage of growth resulted in delay in the onset of tubering. Day length of more than 12 hours at the early stage promotes vine growth, while short photoperiod favours tuber development.

Propagation

Yams are mainly propagated vegetatively and the material commonly used for planting is tuber piece or small tubers. The tuber is cut into seed pieces consisting of head, middle and tail. The size and weight of tuber pieces at planting influence the yield. The relationship between set weight and yield was confirmed by Nwoke *et al* (1973). Among the portions of tuber, heads are the best, which sprout readily followed by tails and middles. Although large sized seed tubers give higher yield, a seed tuber weighing 200-250 g is ideal for optimum production in *D. alata*. Multiplication of yams by vine cuttings is also possible but tuber production by this method is slow. Production of successful cottage has been established in *D. florbunds*, *D. dumetorium* and *D. rotundata*. Propagation is also possible through seed and bulbils. In *D. pentaphylla* and *D. alata*, small bulbils are produced in abundance, whereas in *D. hispida* bulbils are not produced but fertile seeds are formed. In *D. esculenta* and *D. trifida*, small tubers are produced in cluster, which are utilized for the purpose of propagation. Tissue culture has been used for clonal propagation of yams. A technique of micro propagation has been developed for *D.esculenta* at CTCRI, Trivendrum (Nair, 1984).

Seed dormancy

Yam tubers undergo a period of dormancy at the end of the season, usually for 2-3 months. Early sprouting causes considerable shrinkage and damage to seed tubers, hence sprouts are frequently removed. Treatment with 8% solution of ethylene chlorohydrin by quick dip breaks the dormancy of yam. Soaking of tubers in 1% solution of malic hydrazide (MII) on the other hand delayed the sprouting in storage. Pre-harvest application of MII also proved effective in this respect (Hayward and walker, 1961).

Land preparation and planting

The soil should be deeply ploughed, pulverized and leveled. Yams are planted in flat or raised beds or on mounds formed over pits. The seed tubers are planted on the onset of monsoon. The weight of seed tuber for optimum yield is 200-250 g in *D. alata* and 100-125 g in *D. esculenta.* Cut tubers are suberized or smeared with wood ash before planting.

Spacing

Plant population per unit area depends upon the growth habit of the species and in general, cultivars having broader leaves and vigorous growth require wider spacing. A spacing of 75x75 cm for *D. esculenta* and 90x90 cm for *D. alata* may be followed for the optimum yield of tubers (Anon, 1985). Onwueme (1978) reported that yams are planted at a spacing of 1 m between rows and tubers.

Mulching

Mulching after the planting of tuber, is very useful for increasing the yield as it providers protection from excessive temperature, conserves soil moisture, ensures quick and uniform sprouting of the tubers and suppression of weeds.

Trailing of vines

Trailing of vines is an important operation to expose the leaves to sunlight. This influences the tuber yield and it has been found that trailed plants give higher yield than the nonstaked ones. The emerging shoots should be immediately provided with supports to avoid any injury to the tender shoots. The species *D. alata* requires trailing to a greater height as compared to *D. csulenta.* Trailing is done within 15 days of sprouting by coir rope attached to artificial supports or trees in the growing areas. The most effective method is 'pendal' system, which produced a yield of 22.0 tonnes, while the control plants without trailing showed a yield of 14.7 tonnes/ha (Abraham and Easwariamma, 1984). Yams are also staked on to living or dead trees or other quick growing plants. Branched stakes are found to be superior over unbranched stakes (Haynes and Coursey, 1969). In Trinidad, Chapman (1965) reported a reduction in yield by more than 50 percent in the unstaked crop.

Manuring and fertilization

Yams require plenty of organic manure, well decomposed FYM at the rate of about 10 tonnes/ha is recommended. The result of the experiments on the effect of fertilizers on he yield of tubers clearly indicated that yams are very responsive to the application of inorganic fertilizers along with organic manures. Applications of NPK at the rate of 80:60:80: kg/ha has been recommended for *D. esculenta* and *D.alata*. Fertigation of NPK @ 120:80:80 kg/ha was optimum for obtaining high yield of good quality tuber. If the soil moisture is not adequate the plants should be irrigated after fertilization. Half dose of nitrogen and potassium along with full dose of phosphorous should be applied at the time of first inter-culturing. The remaining half dose of nitrogen and potassium should be applied a month later along with second interculturing. The nutrient uptake in several species of Dioscorea varied between 116.1 and 168.0 kg N, 25.5 and 30.0 kg. P and 108 and 146 kg K per hectare (Mohankumar *et al*, 1984).

Interculture and weed control

Adequate fertilizer and moist soil are conducive conditions for the rapid growth of numerous monocot and dicot weeds. Control of weeds is very important for the proper growth of the plants and normally 2-3 intercultural operations would be sufficient to check the growth of weeds. The first interculturing sufficiently deep should be done one week after sprouting of 50% tubers and the second and third ones at an interval of 15 days to 1 month depending on weed growth. Renaut and Merlier (1973) found that Diuron at the rate of 3-3.5 kg/ha was effective in per-emergence control of weeds in yam plots in Ivory Coast.

Diseases

Two major fungal diseases, the blight and die back, caused by *Cercospora Sp* and *Colletotrichum Sp* are found in *D. esculenta* and *D. alata* respectively. The symptoms start as brown to black leaf spots at the beginning of the rainy season. The spots gradually coalesce and blight the leaves. The diseases cause defoliation and plants die in severe infection. Spraying of Cercobin or MBC (0.2%) at monthly interval controlled the disease and increased the tuber yield by 29 to 34 per cent (Anon. 1985). Yam tubers are also infected with wet rot, soft rot or brown rot during storage (Adne. ji, 1970). These diseases are caused by *Batrudipladia sp, Penicillium sp, Aspergilius spp, Fusarium spp, etc*. Storage rot diseases are controlled to some extent by treatment with copper fungicide and lime washing.

Mosaic viral disease like symptoms are observed in *D. alata*, *D. esculenta* and *D. rotundata*. The symptoms of *D. alata* include leaf puckering, chlorosis and necrosis of veinus on the surface. Leaf mottling is also noticed. In *D. esculenta* the symptoms are dark and light green areas on leaves, green vein banding, crinkling of leaves and stunting of plants.

Pests

Yams are attacked by more than a dozen pests in the field and storage. The important pests include the scale insects, white grubs, termite, chrysomelids and hairy caterpillars. Among these scale insects are the most serious (*Pillai and Palaniswami*, 1984). While scale insect (*Aspidella hartii*) is a serious pest on *Dioscorea esculenta* and *D. alata*. The insects attack the base of vines and tubers and plants wither when infestation is severe. The attacked tubers shrivel and lose the quality and marketability. The pest spreads through infested seed tuber and they migrate in the tuber during storage (*Palaniswami et al*, 1979). Soon after the harvest, infested tubers are removed and destroyed. The seed tubers should be dipped in 0.1 percent monocrotophos before planting.

Harvesting

When the leaves turn yellow and the vines completely dry up, the crop is ready for lifting, which will be in about 8-9 months after planting. *D. esculenta* matures early as compared to other species. There is a practice of double harvesting, *i.e*, removing mother tubers after two months of growth and allowing subsequent production of side tubers. However, double harvesting is not economical as compared to single harvesting. While harvesting care should be taken so that tubers are not cut or damaged as this causes roting of tubers.

Yield

The tuber yield depends on species and cultural practices. *D. alata* has been found to give a yield of 20-40 tonnes of tubers per hectare, whereas *D. esculenta* yields 10-30 tonnes per hectare under field conditions.

Storage

Among the tuber crops, yam possesses on excellent quality of post-harvest storage. Yam tubers after harvest develop few layers of cork cells around it and protect the tuber from the loss of water. Curing of tubers at 29-30 ^{0}C at 90-95% relative humidity for 4 days is suggested. The loss of weight during storage may be as much as 20 percent due to various factors. Yams are stored in the tropical countries at a temperature of 30 ^{0} C. Tubers may suffer from chilling injury when stored below 12^{0} C.

Several storage methods are followed in different yam growing countries.

The most common practice is to leave yam as such in the field and harvest whenever required but in this method the quality of tubers deteriorates after the onset of rains. In some regions the tubers are kept in shallow pit and covered with soil. In some cases they are heaped in a pyramid shape and covered with moist soil. Yam barns are constructed consisting of vertical wooden frame on which yams are tied. In Oceania, specially constructed huts are used for stacking the yams. In some parts of India, yams are stored in the layers of sand. Dipping of tubers in fungicides like Benlate and Captan and in 250 ppm of Thiabendazole are effective in controlling storage rots.

Medicinal uses

The cultivated types are comparable to potatoes in taste and quality. The tubers of some species, *e,g, D.alata,* are employed for the extraction of starch on a commercial scale. Some are used for alcohol production. Some species of Dioscorea are reported to be rich in vitamins B_1, B_2 and B_3 and possibly also in other members of the Vitamin B complex. They are poor in protein, calcium and iron.

The alkaloid, dioscorine and the saponin, dioscin, occur in varying quantities in different species of yams. Dioscorine (C_{13} H_{19} O_2 N) is abundant in *D. hispida* and its tubers when consumed in large enough quantities cause paralysis of the respiratory organs and even death. The tubers of *D. deltoidea* are rich in saponins and are used for washing silk, wool and hair, and as fish poison. Some of the American species of the genus are reported to contain the steroidal sapogenins, diosgenin, yamogenin, krypotogenin and others. Botogenia obtained from *D. mexicana*. Guilbemin is a promising starting material for the partial synthesis of cortisone, used in the treatment of rheumatoid arthritis and rheumatic fever (Lewis and Lewise, 1976).

Diosgen in the steroid present in dioscorea tubers. The diosgenin content of dioscorea was first identified from *Dioscorea tokoro* one of the species indigenous to Japan.

Diosgenin content of *Dioscorea spp*

S. No	Species	Diosgenin (%)	Remarks
1.	*D.deltoidea*	2-5	Growing wild in sub Himalayan region. Cycle = 5 years
2.	*D. Prazeri*	1.0	North- Eastern region
3.	*D.floribunda*	2-5	Central American species. Cycle =1-3 years
4.	*D. Composite*	2-4	Central American species. Cycle = 3 years.

Diosgenin is commercially extracted from tubers of *D. deltoidea* and to a lesser extent from *D. prazeri* obtained from natural habitant in the Himalaya and North-Eastern region respectively. This extraction of diosgenin is only limited to their natural source due to prolonged maturation of tubers.

Diosgenin extraction

The rhizomes are thinly sliced, dried and ground further to pass through 20 mesh sieve. The powder is then hydrolyzed with 6 percent sulphuric acid for 6 hour. The hydrolyzed mass is cooled filtered and washed first with water followed by sodium bicarbonate solution and finally with water. The residue is oven dried and extracted with n-hexane for 8 hour. The diosgenin is filtered after removal of solvent washed with a little petroleum ether (40-60 0 grades) and air-dried. The diosgenin thus obtained has 95 per cent purity (Sarin *et al*., 1977).

Indian institute of Horticulture Research (IIHR), Bangalore had introduced *D. floribunda* a central Amirican species for commercial exploitation of Diosgenin for steroid industry. IIHR has released two cultivars (Chada and Ramrao, 1984). They are:

i. **FB (C) - 1:** It is a composite strain of *D. floribunda*. The plants are vigorous and free from diseases and pests and contains 2.5 to 3 per cent of diosgenin. Tuber yield of 20-25 and 60 tonnes can be obtained during first and second year respectively.

ii. **Arka Upkar :** It is a high yielding and has vigorous growth habit. The diosgenin content ranges from 3.5 to 4.0 per cent and tuber yield exceeds 60 tonnes per hectare.

Diosgenin content (%)

Cultivar	First year	Second year
FB (C) -1	2.5 – 3.0	3.0 – 3.5
Arka Upkar	3.0 – 3.5	3.5 – 4.0

Cultivation practices of *D. floribunda*

It is cultivated in an area of 1000 ha in Karnataka, Tamil Nadu, Assam, Meghalaya, Maharashtra, Andaman and Goa.

Crop is raised from tuber pieces of crown and medians. Tuber pieces are treated with 3000 ppm Benamyl to prevent tuber decay. Dioscorea vines need support for their optimum growth. Hence, each plant is supported by gunny twines tied to overhead wires. Fertilizer dose required is: 300: 150: 200 kg/ha N: P_20_5: K_20 respectively.

Nitrogen and potassium are applied in four splits at 2 months interval and phosphorus as basal dose.

Irrigation: At 10-15 day interval

Inter crops: Cowpea, horse gram, French beans

Net Income: Rs. 10.000 per hectare

Possibilities of integration of *dioscorea* species in agroforestry

Looking into the importance of this species, its cultivation in the arable land outside its natural habitat is important. The transitional tract of Karnataka is feasible to cultivate this medicinal tree under agroforestry systems by scattered planting / border planting. The possible ways of integration of *Dioscorea species* in agroforestry are as follows:

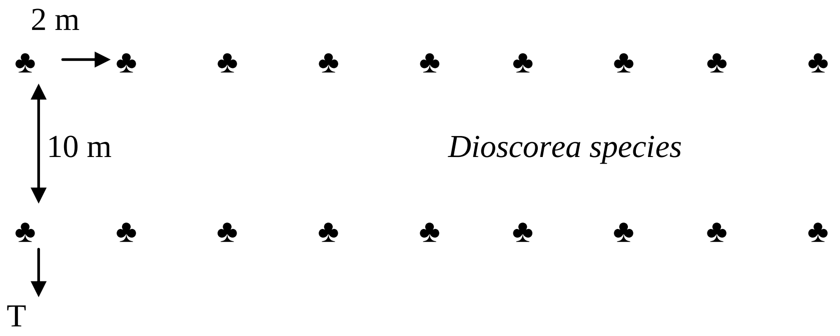
1. **Block plantation:** *Dioscorea species* can be integrated under block plantations with fruit yielding tree species *viz., Emblica officinalis, Syzygium cumini, Tamarindus indica.*
2. **Boundary planting**: *Dioscorea species* can be planted all along the borders of tree rows at 3 m apart which reduces the sun scorching effect and also gives additional income. It can also be grown on borders under the coconut plantation.
3. **Agri-horti system:** *Dioscorea species* can be grown under orchards of *Anacardium occidentale* (cashew), *Mangifera indica* (mango), *Citrus aurantifolia* (lemon), *Psidium guazava* (guava), *Achrus zapota* (sapota) with protective irrigated conditions. As an inter crop, it provides additional income to the farmers along with the main crop.
4. **Silvi-pastoral system**: Wide spaced tree species like *Azadirachta indica* (neem), *Pongamia pionnta* (honge), *Dalbergia Sissoo* (sissoo), *Dioscorea species* can be inter cropped in between four trees along with grass as one of the component to conserve the moisture.

***Dioscorea* species based agroforestry systems**

In agroforestry, trees may be planted either in a fixed spacing or randomly in the field. Trees are planted in fixed spacing and inter space is used for growing of medicinal plants. Sometimes horticultural species such as sapota, mango, drumstick, curry leaf etc., can be integrated with medicinal plants. Some of the important agroforestry systems are as follows:

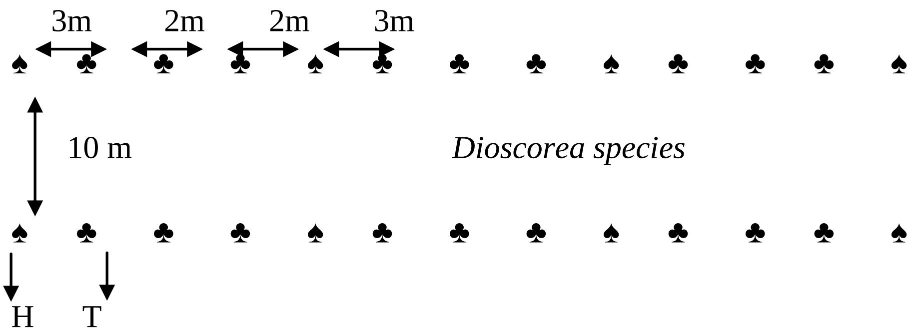
a. **Silvi-medico system**

In this system tree are planted at a spacing of 10 x 2 m and in-between *Dioscorea species* can be grown. After 6-8 years alternative trees are removed for further growth.



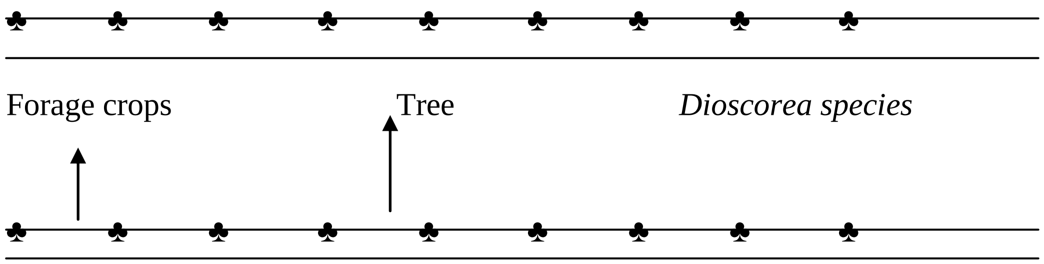
b. **Silvi-horti-medico system**

Here horticultural species are planted at 10 x 10 m and in-between two plants three tree species at one side are planted in 3-2-2-3 m spacing. In remaining space *Dioscorea species*can be grown.



c. Silvi-medico-pasture system

In this system trees are planted at wide spacings and inter-space is used for growing of *Dioscorea species*. In-between trees, forage crops are maintained in two rows as hedges.



d. Alley cropping

In alley cropping, perennial bushes/hedges/trees are planted at certain distance. In-between the alleys, *Dioscorea species* are grown.

Dioscorea species is propagated by means of seeds, stem cuttings and tuber species. The main emphasis is to collect superior genotypes of *Dioscorea species* and undertake mass multiplication to establish large scale plantations in farmers as well as in private farms.

It is now being realised that agroforestry can be used as an effective medium to fight the battle against environmental degradation by motivating the farmers to grow *Dioscorea species* as an alternative income generating crop under agroforestry systems.

Summary and conclusion

Medicinal plants have been used by the man since time immemorial. In the early ages, the demand for medicinal plant was very low, as these plants were used for limited purpose of meeting their medicinal needs.

Moreover, the knowledge of medicinal plants and healing was known to very few persons, and they have very carefully conserved and utilized these precious plants of the wild. The scientific inventions and discoveries during 18th and 19th centuries have made remarkable progress in the medicinal field. This period saw the demand for synthetic medicines and chemical mixture. The 20th century has produced a plethora of discoveries in the field of medicine. The medicines derived from natural products and from mineral were mostly used during this period. Recent thinking that natural remedies are healthier than that of the synthetic products has created more demand for plant products and medicines derived from these plants.

Therefore, agroforestry is considered as an alternative land use system which offers wide scope for integration of medicinal plants along with perennial crops. It plays a potential role in meeting food, fodder, fuelwood and other timber, raw materials for pharmacies and maintaining environmental stability. Also agroforestry on small land holding can provide livelihood security and on large land holdings it may be a commercially profitable proposition. Although agroforestry is desirable in every region, it can be applied mainly in arid and semi-arid regions, fragile ecosystems, saline-alkali soils, waterlogged soils etc. In agroforestry economic or medicinal tree species can be grown along with annual medicinal herbs for an annual additional income to the farming community.

Acknowledgement

The authors are grateful to the Dean (Forestry) and staff of College of Forestry, Sirsi, Uttara Kannada district and AICRP on Agroforestry, Dharwad (UASD), Karnataka for guidance, facilities and support in preparing this manuscript.

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Enhancing climate resilience and mitigation in forestry and tree-based agroecosystems through biochar applications

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Forests, spanning nearly 4 billion hectares or 30% of Earth's land, play a pivotal role inregulating the global carbon cycle. Distributed across various biomes, including equatorial, tropical, Mediterranean, warm temperate, temperate, and boreal regions, natural forests exhibit diverse characteristics such as evergreen broadleaf, evergreen needleleaf, deciduous broadleaf, deciduous needleleaf, or mixed types (Easterling et al. 2007; Nabuurs et al. 2007; De Fries et al. 1998). The FAO reported a total biomass-C pool of approximately 282 Pg, with global forests' carbon pool estimated at around 633 Pg in 2005 (Marklund & Schoene 2006).

Undisturbed forests tend to accumulate carbon due to photosynthesis exceeding respiration, but disturbances like wildfires, droughts, diseases, and anthropogenic activities offset this balance. Land-use changes, particularly deforestation, led to a significant reduction in forest area, with a global deforestation rate of 12.9 million ha year^{-1} from 2000 to 2005 (Nabuurs et al. 2007). Forest degradation, partly reversible through forestry projects, showed potential improvement as intensively managed forest plantations, constituting about 4% of the global forest area, experienced annual growth (Easterling et al. 2007).

Efforts in forestry, landscape restoration, and natural forest expansion have mitigated the net loss of forest lands to 7.3 million ha year^{-1}(Nabuurs et al. 2007). A recent synthesis study comparing primary and secondary natural forests with afforestation and reforestation plantations revealed a 11% lower above-ground biomass in plantations.

In plantation ecosystems, fine root biomass, soil organic carbon (SOC) concentration, and soil microbial carbon concentration were 66%, 32%, and 29% lower compared to natural forests, as reported by Liao et al. (2010). Additionally, Liao and colleagues found a 22%, 20%, and 26% reduction in available nitrogen (N), phosphorus (P), and potassium (K), respectively, in plantation soils compared to natural forests.

The relationship between forest productivity and climatic changes is significant. With global temperatures averaging 0.46°C above the 1961–1990 average from 2001 to 2010, there is a projected increase in the magnitude, frequency, and duration of extreme climatic events due to atmospheric warming. Particularly, warming trends in Africa, parts of Asia, and the Arctic have been notable. The Saharo-Arabian region, east Africa, central Asia, Greenland, and Arctic Canada experienced temperatures 1.2–1.4˚C above the long-term average during 2001–2010, marking a 0.7–0.9˚C increase compared to any previous decade (WMO 2011).

While rising atmospheric carbon dioxide (CO_2) concentrations may initially have a 'fertilization effect' on forests, enhancing their production capacity, continued warming is anticipated to diminish or potentially override this effect. Coupled with air pollution and decreasing nutrient availability, the overall impact on forest productivity remains uncertain. Global warming is expected to heighten risks from ozone (O_3), as increased fossil fuel use promotes O_3-forming pollutants, leading to decreased carbon sequestration in biomass and soil (Beedlow et al. 2004). The interplay between a system's productivity and resilience underscores the close association between mitigation and adaptation capacities in forest ecosystems (Kandji et al. 2006).

Biochar, a by-product of C-negative pyrolysis technology in bio-energy production, is generated through oxygen-excluded thermal decomposition of organic materials. When applied to soil, biochar's high porosity and negative charge enhance water-holding capacity and nutrient retention, leading to increased water and nutrient availability for plant uptake. This application improves soil physical and chemical qualities, resulting in higher net primary productivity of the agro-ecosystem. Additionally, biochar's recalcitrant nature hinders microbial decomposition, enabling long-term carbon sequestration in soil. The characteristics of biochar, such as salt and ash content, carbon-nitrogen ratio, and cation exchange capacity, are influenced by feedstock type and pyrolysis temperature. The production process is cost-effective, making it accessible to low-income populations. In 2011, the International Biochar Initiative reported 154 biochar projects across 43 developing countries, involving various organic materials and production scales. These projects ranged from household to regional levels, utilizing technologies like batch retort kilns and continuous process kilns.

Despite the agronomic and environmental benefits of biochar, its production and use pose potential environmental and health risks due to the presence of toxic compounds such as heavy metals, dioxins, and polycyclic aromatic hydrocarbons (PAHs), likely originating from contaminated feedstocks or specific processing conditions (Verheijen et al., 2010). Temperature modification during pyrolysis can partially control PAH composition (Kloss et al., 2012), and careful control of feedstock and pyrolysis conditions may reduce PAH levels, as well as emissions of dioxins and particulate matter associated with biochar production (Verheijen et al., 2010).

Despite widespread use in agriculture, limited research has explored biochar's application in forestry and tree-based agro-ecosystems. This study aims to assess the potential of enhancing carbon sequestration in these systems through the application of stable carbon-based soil amendment. Additionally, the study investigates the anticipated improvement in soil quality and fertility, exploring the potential of biochar to enhance forest resilience or adaptation to climate change. Considering four major pathways for mitigating carbon emissions in forestry activities (increasing forested land area, raising carbon density in existing forests, sustainable use of forest products, and reducing emissions from deforestation and land degradation), this review addresses each pathway directly or indirectly. The objectives of this review include raising awareness of biochar applications, highlighting implementation challenges, and emphasizing the need for international regulations to facilitate widespread adoption of this practice.

Carbon cycle in relation to deforestation

Deforestation is identified as the second-largest anthropogenic contributor to atmospheric CO_2 levels, following fossil fuel combustion. Recent estimates attribute between 12% (van der Werf et al., 2009) and 20% (Gullison et al., 2007) of total emissions to cumulative deforestation and forest degradation. Conservative estimates suggest emissions of approximately 1.2 Pg C year^{-1} from 1997 to 2006 (van der Werf et al., 2009). Wildfires, a significant factor in altering forest characteristics, emit substantial CO2 while also generating ash and charcoal that modify forest lands. In particular, wildfires provide valuable insights into the impact of charcoal on forest ecosystems, as demonstrated in a greenhouse study in the northern boreal zone of Sweden. The study revealed increased shoot-to-root ratio in Silver birch (Betula pendula Roth) and Scots pine (Pinus sylvestris L.) when exposed to wildfire-produced charcoal, attributed to enhanced nutrient uptake. This research contributes crucial information given the limited studies on biochar in forestry systems, enhancing our understanding of related processes. For instance, findings align with Wardle et al. (1998), DeLuca et al. (2006), and MacKenzie and DeLuca (2006), emphasizing the positive effects of charcoal on nutrient dynamics and nitrification rates in different forest ecosystems.

The persistence of ash, charcoal, or black carbon in ecosystems has been widely acknowledged (Lehmann et al. 2008; Abiven and Andreoli 2011; de Lafontaine and Asselin 2011). Nocentini et al. (2010) found that the decomposability of charcoal is influenced by particle size, with <0.5 mm charcoal from a moderate-intensity wildfire being 24% of the total mass and rich in N, potentially susceptible to microbial decomposition. Wood-derived charcoal was prevalent in >2 mm fractions, while smaller fractions contained pine needles and herbs. Extreme fires in mixed-species, eucalypt forests and temperate rainforests in Victoria, Australia, converted tree biomass into ash, depositing 4.8 to 8.1 Mg C ha^{-1} on the forest floor with subsequent redistribution. Wardle et al. (2008) reported increased forest humus loss when mixed with charcoal in a Swedish boreal forest study, suggesting that despite long-term sequestration of charcoal-C, it may be partially offset by stimulating plant litter-C loss. However, a 240-day study by Abiven and Andreoli (2011) found no impact of charcoal on decomposition rates in a mixed forest in Switzerland. The influence of charcoal on surrounding organic substances appears to depend on their nature, soil conditions, and temporal duration.

Deforestation heightens the impact of climate change on remaining forests, especially in tropical regions facing increased drought risks (Gullison et al. 2007). The Amazon Basin, at risk due to more frequent and severe droughts, could emit 15 to 26 Pg C into the atmosphere if droughts persist (Nepstad et al. 2008). Model projections suggest a more than 20% decrease in rainfall across some parts of the Amazon Basin by the end of the twenty-first century due to the accumulation of greenhouse gases (GHGs) and associated radiative forcing (IPCC 2008).

Afforestation of degraded lands and carbon cycle

Afforestation is crucial for addressing widespread land degradation, affecting approximately 24% of the world's terrestrial area and impacting 1.5 billion people (Bai et al., 2008). Degradation processes, such as reduced vegetation cover and soil organic carbon (SOC) depletion, lead to compromised soil structure and increased vulnerability to erosional processes (Lal, 2002). This results in heightened raindrop impact, reduced soil hydraulic conductivity, and loss of the fertile top layer (Stavi & Lal, 2011a). SOC lost through erosion can either be emitted as CO_2 or accumulate in depositional sites, contributing to soil fertility degradation (Stavi & Lal, 2011b; Gregorich et al., 1998). Afforestation efforts play a crucial role in mitigating these negative impacts, promoting sustainable land management and restoring soil productivity.

Afforestation projects are feasible on degraded lands across various terrestrial and climatic conditions globally. These projects, aimed at improving ecosystem services and biodiversity conservation, are already underway in many countries and involve millions of smallholder farmers engaged in tree planting and forest management. Chazdon (2008) emphasizes the need for adaptive management in creating resilient forests that can withstand climate change, habitat fragmentation, and other disturbances.

Biochar application has been identified as a promising method to restore degraded lands. Studies by Sohi et al.

(2009) and Stavi (2012) demonstrate its capability. Utilizing biochar on degraded lands for afforestation is proposed, as it enhances water and nutrient retention in the soil, promoting favorable conditions for tree growth. The alkaline nature of biochar can also positively impact soil pH, particularly in highly weathered soils, potentially neutralizing acidity and increasing tree productivity, thus enhancing land restoration capacity.

The application of biochar can be achieved by spreading it on the land surface and either incorporating it into the soil or retaining it on the ground. While surface retention minimizes soil erosion risk, it may limit soil nutrient improvement and is susceptible to redistribution. Incorporating biochar into the soil is preferred, though limited machinery is currently developed for this purpose. Modified conventional spreaders and hand-operated rotavator machines can be utilized for small-scale application, while tractor-drawn ploughs, disk ploughs, or rotavators are suitable for extensive land areas, with application depth tailored to terrestrial conditions and tree species.

For optimal results, biochar application should precede tree planting, covering the entire project area for new afforestation projects. In established projects, biochar should be applied in inter-rows. When determining application rates, terrain conditions, such as steep slopes or exposed bedrocks, must be considered, as they impact accessible land area.

Pyrolysis feedstocks for biochar production, whether for co-production with bio-energy or standalone biochar production, can include diverse materials like forestry residues, domestic wastes, sewage sludge, and low-input, non-food competing crops. However, residues crucial for maintaining soil organic carbon (SOC) stock, supporting the soil food web, and preventing erosion, like wheat straw or corn stalk, should not be considered as relevant feedstocks.

Maintenance actions for established afforestation systems, such as trimming and thinning, should ideally leave some prunings on the surface to prevent erosion and replenish SOC stock. Waste materials, when cleared could be repurposed as feedstock for bio-energy or biochar production.

Biochar management presents environmental, social, and economic benefits. It can lead to new businesses, job opportunities, and increased income in rural regions. However, economic calculations and site-specific life-cycle assessments are crucial to ensure net economic profit and carbon sequestration, considering costs and emissions related to waste collection, transportation, and processing. Inclusion of biochar management under international carbon finance mechanisms may help offset costs.

Niles et al. (2002) conducted a comprehensive 10-year study (2003-2012) on reforestation projects in 48 sub-tropical and tropical developing countries. They determined reforestation rates of ~1.7, 1.1, and 0.7 million ha year−1 in Latin America, Asia, and Africa, potentially totaling ~3.5 million ha year−1. The resulting vegetative-C accumulation capacity, excluding soil organic carbon (SOC), was ~178, 96, and 42 Tg, totaling ~316 Tg over the study period. Biochar application to soil could enhance carbon stocks in these systems. In developed countries, integrating biochar into the established bio-energy industry is feasible, while in developing countries, low-tech biochar production may be more practical.

Despite the potential benefits, rural populations in developing countries relying on traditional energy sources may lack motivation to use biochar. To encourage change, international policies should consider biochar application in reforestation projects for funding under carbon finance mechanisms. Extension activities should educate locals on the long-term advantages, promoting widespread implementation.

Life cycle assessments of residue conversion into bio-energy or biochar should be site-specific to verify environmental sustainability, considering emissions from feedstock collection, transportation, processing, and spreading. The overall environmental footprint should be lower than alternative practices.

Reforestation and carbon

In managed reforestation lands, retaining some residues on the forest floor is preferable to maintain SOC stocks and control erosion. Gregg and Smith (2010) suggested a minimum retention of 20 Mg ha−1, allowing excess residues beyond this threshold to be used for bio-energy or biochar production. The 'whole tree method' in some regions may pose environmental risks, and converting some residues to biochar could improve soil quality.

Despite the potential benefits of biochar application in forest lands, it has received limited attention. Studies in Indonesia and Japan have shown positive effects on tree growth, mycorrhizal fungus yields, and seedling survival. Wood ash derived from biomass burning in power plants has also been studied for soil amendment in forestry systems. Further research and promotion of biochar application in forest lands are warranted.

Despite limited documentation on biochar application in forest lands, extensive research has been conducted on the use of wood ash derived from biomass combustion in power plants. Wood ash serves as a valuable soil amendment in forestry systems, mitigating soil acidification and compensating for nutrient depletion resulting from intense logging practices like whole-tree harvesting (Saarsalmi et al. 2004). In northwestern Spain, Santalla et al. (2011) investigated the impact of mixed wood ash, applied at a rate of 7.5 Mg ha^{-1}, on soil nutrient status in an intensive forest system planted with Monterey pine (Pinus radiata D. Don). In this subhumid Mediterranean region, characterized by an organic-rich, highly acidic A horizon with low nutrient availability, the application of ash restored soil reserves of Ca, Mg, and K in the organic layer. However, wood ash also decreased P availability due to its charcoal content, temporarily reducing mineral P solubility. Despite this, the combined application of wood ash and mineral P fertilizer improved P concentration in needles, litterfall, and soil. Additionally, wood ash decreased soil N mineralization rate and mineral N concentrations, attributed to increased microbial activity and the high C : N ratio in the ash. This impact may negatively affect tree growth by inducing N deficiency in plants. Studies have shown that wood ash alone may have negligible economic benefits on poor mineral soils, while its combination with mineral N can enhance tree growth in N-rich mineral soils (Solla-Gullón et al. 2008).

The impact of wood ash combined with mineral N on plant nutrient availability and tree growth has been intensively studied. For example, in southern Finland, the application of 3 Mg ha−1 of wood burnt-bark ash combined with 150 kg N ha^{-1} in a 45-year-old Norway spruce stand increased pH, base saturation, and concentrations of nutrients in the soil's organic layer (Helmisaari et al. 2009). However, over a 10-year period, this treatment reduced fine root biomass by ~30%, while K concentrations in needles increased. Overall tree growth remained similar to non-amended soil. In another study in 31- and 75-year-old coniferous stands in southern Finland, wood ash alone had no impact on needle nutrient concentrations, but combined with N fertilizer increased nutrient concentrations. No impact on tree growth was observed under ash alone, with a slight increase when combined with N, diminishing after the first 5 years (Saarsalmi et al. 2004, 2006).

Wood ash chemistry is influenced by factors such as tree species, burning process, and application site conditions. Hardwood species produce ash with higher macronutrient levels than conifers, and furnace temperature during burning (500°C to 900°C) is crucial for nutrient retention, particularly K. The mode of ash application and particle size also affect nutrient availability, with soil incorporation enhancing solubility and promoting tree growth.

Concerns about wood ash increasing heavy metal concentrations in soil, such as cadmium (Cd), have been raised. Fly ash, a lighter component accumulating in the flue system, can contain high levels of Cd, Cu, Cr, Pb, and As. However, mixed wood ash, comprising fine fly ash and bottom wood ash, is less reactive and contains lower trace element amounts, reducing the risk of heavy metal contamination (Pitman 2006; Solla-Gullón et al. 2008).

The impact of higher wood ash application rates on forestry system productivity and potential toxic effects is debatable (Saarsalmi et al. 2006; Pitman 2006). Biochars, derived from different feedstocks and pyrolysis conditions, may contain heavy metals and other contaminants, necessitating pre-pyrolysis testing of feedstocks and post-production examination of biochars to avoid ecotoxic effects

(Ernsting 2011). Further research is required to understand the mechanisms leading to the formation and retention of contaminants in biochar (Verheijen et al. 2010).

The economic viability of converting forest residues into bio-energy or biochar depends on various factors, including terrain, climate, fuel prices, technology, transportation, and proximity to power plants. To minimize costs associated with transportation, on-site conversion is recommended (Leinonen 2004; Matovic 2011). Economic calculations for bio-energy or biochar production should be site-specific, encompassing all feedstock processing costs.

For reforestation lands, biochar application before tree planting can enhance capacity and potential production. Similar to afforestation, consideration of physical terrain restrictions is crucial in calculating biochar application capacity.

The impact of wood ash on soil and stand productivity varies with site, time, and ash features. Most studies focus on humid and temperate regions with acidic soils and coniferous stands, leaving a significant gap in research for Mediterranean or drier regions, alkaline soils, and broadleaf stands.

Multipurpose agroforestry

Agroforestry systems, covering 46% of global agricultural land area, are prevalent in Southeast Asia, Central America, and South America, impacting over 1 billion ha of land and 558 million people (Zomer et al. 2009). These multipurpose systems provide various products over time intervals, optimizing space and nutrient extraction from different soil layers efficiently. Agroforestry systems can sequester carbon (C), enhance resilience to climate change, and provide additional ecosystem services, such as improved water use efficiency, shading, nutrient turnover, and micro-habitat conditions for crops. However, the efficiency of C sequestration depends on factors like perennial crops and management practices. Agroforestry systems may also influence nitrous oxide emissions and exhibit resilience to pest infestation through increased plant biodiversity. More research is needed to understand the full potential and limitations of agroforestry systems in different regions and under various management practices.

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In agroforestry systems, the use of biochar from tree prunings serves as an effective means of erosion control, maintaining soil quality on-site and safeguarding water sources off-site. However, the collection, transportation, and processing of prunings may lead to greenhouse gas emissions, potentially offsetting carbon sequestration gains. Despite this, the transition from burning prunings to biochar production is considered environmentally sustainable. The integration of biochar into agroforestry systems is anticipated to decrease nutrient leaching, minimizing groundwater contamination, and enhance soil stability, reducing water overland flow and erosional processes. These positive effects extend to mitigating eutrophication and siltation in above-ground water sources. Additionally, biochar application is linked to reduced emissions of N_2O and CH_4, contributing to improved fertilizer efficiency and decreased greenhouse gas emissions.

Monoculture plantations and tree orchards

In agroforestry systems, the assumed 50% coverage of ground surface by trees' inter-row spaces suggests potential cultivability, mitigating the limitation observed elsewhere. Existing agroforestry systems alone could sequester a minimum of 2 Pg of biochar-C. Additional sequestration is feasible in global fruit tree orchards and bio-energy plantations. Implementing biochar management practices has the potential to enhance soil quality, bolstering the resilience and adaptive capacity of forestry and tree-based agro-ecosystems to changing climatic conditions. However, site-dependent impacts are anticipated, necessitating region-specific biochar types and application rates. Combining biochar with mineral N or P, or livestock manure, may enhance nutrient availability and productivity. Notably, existing studies predominantly focus on wildfire charcoal or wood ash from biomass burning, underscoring the need for extensive research to comprehend biochar's effects on forestry and tree-based agro-ecosystems. Addressing potential ecotoxic effects is crucial to mitigate adverse impacts on human health and the environment. International regulations should recognize biochar as an eligible strategy for funding under the C finance mechanism, facilitating its global expansion.

Expanding on these benefits, incorporating biochar into mono-culture fruit tree orchards and bio-energy tree plantations is a relevant management practice. Similar to other tree-based agro-ecosystems, applying biochar across the entire area before planting maximizes carbon sequestration capacity. In established orchards or plantations, biochar application in inter-row spaces is suggested. Various tree prunings, such as those from vines, olive, apple, pear, peach, citrus, almond, hazelnut, coconut, cocoa, and date palm trees, can serve as ample feedstocks for biochar production. Despite the associated greenhouse gas emissions during collection and processing, the overall environmental benefits of converting prunings to biochar are highlighted, especially in regions where burning is a common disposal practice. Highly productive bio-energy crops, such as eucalyptus, can efficiently provide sufficient biochar for on-site application during a single harvest, offering a sustainable approach to soil improvement. Historical evidence from Japan supports the positive impact of biochar on fruit tree growth, demonstrating enhanced root length, shoot productivity, net primary productivity (NPP), and mycorrhizal development. The combination of agroforestry systems and biochar application emerges as a powerful strategy for climate change mitigation and adaptation, presenting significant agricultural and environmental advantages.

In forestry and tree-based agro-ecosystems, the use of biochar is expected to enhance productivity and reduce environmental impact, similar to agroforestry systems. This includes a decrease in fertilizer rates, leading to a reduction in greenhouse gas emissions and pollution in water sources. The global focus on mitigating carbon emissions has led to international projects, such as tropical deforestation prevention and reforestation efforts, with the potential for significant funding through carbon credit trading mechanisms. However, challenges include the need for technical and institutional capacities, measurement systems, and commitment from developed countries. The Clean Development Mechanism (CDM) and Reducing Emissions from Deforestation and Degradation (REDD) programs have been applied to developing countries but may have strict rules and limitations for small-scale farmers. Successful implementation requires addressing social, cultural, and political contexts, local stakeholder participation, and fair CDM payments. Additionally, the biochar management practice is proposed as a strategy for carbon sequestration, but its application is not currently eligible for CDM funding.

Biochar production costs and C offset values vary, with considerations for feedstock types. Despite its potential in forestry and tree-based systems, biochar projects require regulated financing to be viable. A life cycle assessment indicates the profitability of biochar systems depends on offset prices and feedstock costs.

Considering the unresolved regulatory framework for biochar projects, authorities could provide payments to landowners for ecosystem service improvements, including carbon sequestration, soil erosion control, water quality preservation, and biodiversity increase. Extensive research is needed to assess the potential of biochar application in forestry and tree-based agro-ecosystems for climate change mitigation and adaptation.

In conclusion, natural carbon sequestration in forestry and tree-based systems can be enhanced through biochar application, offering potential benefits in offsetting atmospheric CO_2 concentrations. However, the regulatory framework, financing mechanisms, and comprehensive research must be addressed to ensure the success of such practices.

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Biochar use in Indian forests: Opportunities and challenges

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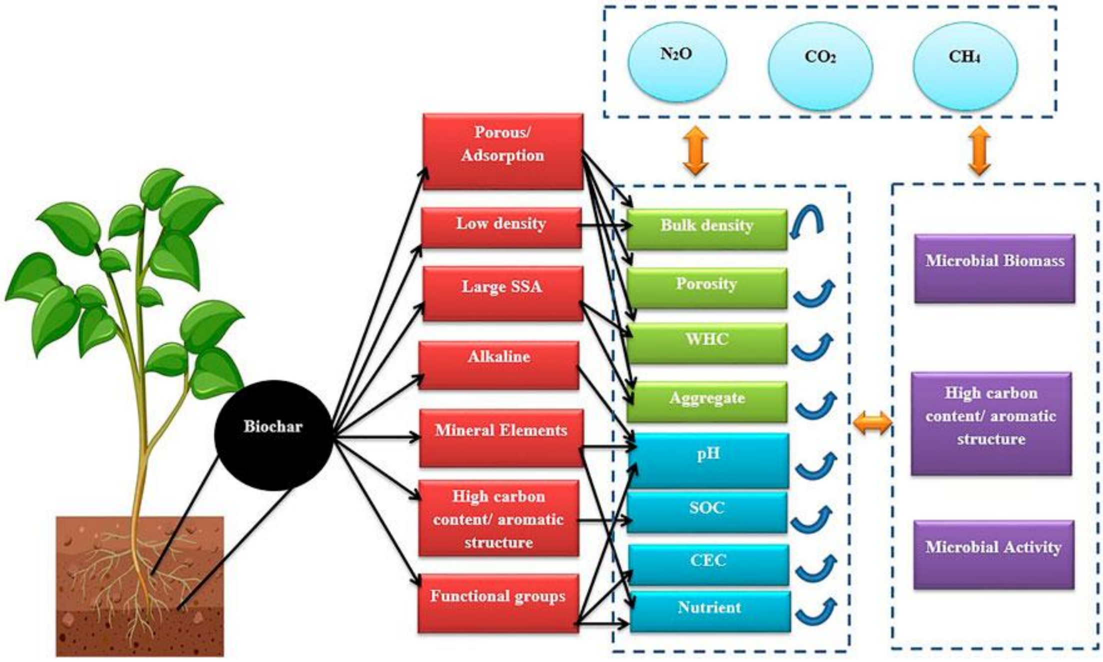
Introduction

In the field of sustainable land management, Biochar, a carbon-rich substance derived from biomass through pyrolysis, has attracted considerable attention due to its various advantages. In India, where safeguarding forests is crucial for biodiversity preservation and climate resilience, biochar holds great promise. Primarily, biochar improves soil health by enhancing its structure, water retention, and nutrient availability. In a country like India, where soil degradation is a significant issue, biochar usage can revitalize depleted lands, thus boosting agricultural output and ensuring food security. Additionally, biochar aids in carbon sequestration by trapping carbon in the soil for extended periods, thereby reducing greenhouse gas emissions and addressing climate change. Given India's commitment to curbing carbon emissions and meeting climate objectives, biochar presents a sustainable method for carbon sequestration, particularly in forest environments.

Furthermore, applying biochar in Indian forests can enhance biodiversity by creating conducive environments for various plants and animals. It can also alleviate the impacts of deforestation and land degradation by restoring soil fertility and supporting forest regeneration endeavors. Nevertheless, the widespread adoption of biochar in Indian forests encounters several obstacles, such as technological constraints, limited stakeholder awareness, and the necessity for policy backing and financial investment. Overcoming these challenges necessitates collaborative endeavors involving government bodies, research establishments, local communities, and private enterprises. Exploring this captivating subject can offer insights into how biochar could revolutionize forest ecosystems.

Understanding Biochar

Biochar, a form of charcoal, is produced from organic substances via pyrolysis, a method involving the heating of biomass in a low-oxygen environment to prevent full combustion. This process decomposes the organic matter into biochar, a carbon-rich solid residue, alongside by-products like syngas and bio-oils, which can serve as bioenergy sources. Despite its ancient origins, this technique has garnered contemporary attention for its capacity to enhance soil fertility, moisture retention, biological properties, and carbon dioxide sequestration from the atmosphere. Consequently, integrating biochar into forest ecosystems could potentially revitalize plantation productivity amidst the challenges of global climate change and intensive management practices.



Effects of Biochar application on soil physical and chemical properties

Soil physical properties, such as bulk density, soil structure, water retention capacity, and aggregate stability, play a crucial role in determining the retention, movement, and accessibility of soil nutrients, as well as influencing soil microbial activity, all of which ultimately impact plant growth. Activities like forest clear-cutting, the conversion of natural forests into plantations, and the intensive management of these plantations have been observed to degrade soil physical health. This degradation manifests as increased bulk density, reduced porosity, and compromised soil structure. Addressing these detrimental effects of forest plantation management on soils is imperative and finding a cost-effective solution is essential. Biochar, with its characteristic features such as high porosity, low density, and large surface area, offers a potential remedy to counteract these negative impacts. When applied, biochar typically decreases soil bulk density while enhancing soil porosity, water retention capacity, and aggregate stability.

The growth and productivity of forests are intimately linked to soil chemical characteristics such as pH, cation exchange capacity (CEC), organic carbon content, and nutrient levels. In recent times, prolonged and intensive management of plantations, which often involves practices like chemical fertilization and understory removal, has been shown to reduce soil pH and diminish the organic carbon reserves in plantation soils, consequently impeding the growth of forest vegetation. The introduction of biochar can directly impact soil chemical properties due to its alkaline nature, diverse mineral composition, and significant carbon content characterized by highly aromatic structures and numerous functional groups such as COO^{-} on its surface. Furthermore, biochar application can indirectly influence soil nutrient availability and transformation by modifying soil physical properties.

Opportunities in Indian Forests

Soil Enrichment: Indian forests often face challenges of soil degradation due to deforestation, agricultural practices, and erosion. Introducing biochar into forest soils can enhance fertility, improve water retention, and promote microbial activity, fostering healthier ecosystems. This can help to support the growth of native vegetation, restore degraded lands, and promote biodiversity conservation.

Carbon Sequestration: With its remarkable capacity to store carbon for hundreds to thousands of years, biochar offers a promising solution for mitigating climate change. By integrating biochar into forest management strategies, India can significantly contribute to global efforts to reduce greenhouse gas emissions.

Forest Regeneration: Biochar acts as a substrate for microbial communities, facilitating nutrient cycling and plant growth. In degraded forest areas, the application of biochar can accelerate the regeneration process, aiding in the establishment of diverse and resilient vegetation.

Agroforestry Systems: Many forest regions in India are also used for agroforestry, where trees are integrated with agricultural crops or livestock production. Incorporating biochar into agroforestry systems can enhance soil fertility, increase crop yields, and promote carbon sequestration. By integrating biochar into sustainable land management practices, forest-dependent communities can improve their livelihoods while conserving forest resources.

Waste Management: Forests generate various types of organic waste, including woody debris, leaf litter, and invasive plant species. Biochar production can provide a sustainable solution for managing this biomass by converting it into a valuable soil amendment. By recycling forest waste into biochar, forest managers can reduce the risk of wildfires, improve soil health, and minimize the need for landfilling or open burning.

Challenges to Overcome

Infrastructure and Technology: Establishing the necessary infrastructure and technology for biochar production can be a significant challenge, especially in remote or rural forested areas. The adoption of appropriate pyrolysis technologies and equipment requires investment, technical expertise, and supportive policies.

Knowledge and Awareness: There is a need to raise awareness and build capacity among forest managers, policymakers, researchers, and local communities about the potential benefits and best practices of biochar application in forest ecosystems. Outreach programs, training workshops, and knowledge exchange platforms can help disseminate information, build skills, and foster collaboration among stakeholders.

Policy and Regulatory Frameworks: Developing supportive policy and regulatory frameworks is essential for promoting the sustainable production and use of biochar in Indian forests. This includes addressing issues related to land tenure, property rights, land-use planning, waste management, and carbon accounting. Clear guidelines, incentives, and standards can help create an enabling environment for biochar adoption while ensuring environmental integrity and social equity.

Long-Term Effects: While biochar offers numerous benefits, its long-term effects on soil health and ecosystem dynamics require further research. Monitoring and research initiatives are essential to assess the efficacy and sustainability of biochar use in Indian forests.

Success Stories

In Karnataka, a pioneering initiative introduced biochar into degraded forest lands, leading to a remarkable increase in soil fertility and biodiversity. Similarly, the Forest Department of Himachal Pradesh has implemented biochar-based soil amendments to restore degraded watersheds, resulting in improved water quality and enhanced vegetation cover.

The implementation of this technology among hill farmers in Sikkim has facilitated effective soil health management and sustainable production within organic systems. With the understanding that the incorporation of biochar into soil yields unequivocally positive results, soil scientists advocate for incentivizing agriculture in Sikkim for carbon sequestration through biochar utilization.

Conclusion

The adoption of biochar holds immense potential for transforming Indian forests into thriving hubs of biodiversity and sustainability. By addressing challenges and leveraging opportunities, India can harness the power of biochar to safeguard its forests for future generations and combat climate change on a global scale. Let us embark on this journey towards a greener and more resilient future for our forests and the planet.

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Biopulping: An energy efficient and environment friendly technology for pulp and paper industry

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Introduction

The pulp and paper industry has historically been associated with the release of greenhouse gases into the environment, particularly due to the traditional pulping methods such as chemical and mechanical pulping. These processes involve using chemicals, such as sodium hydroxide and sodium sulfide, to break down the lignin in wood fibres; a complex organic polymer that binds fibres in wood and it is undesirable in the papermaking process because it hinders the separation of fibres and reduces the quality of the final product. This process requires high temperatures and consumes large amounts of energy. The combustion of fossil fuels, such as coal and oil, to generate this heat leads to the release of CO_2 emissions. This process releases greenhouse gases and other harmful pollutants into the environment. Biopulping, on the other hand, utilizes specific fungi to degrade the lignin, eliminating the need for harsh chemicals and reducing energy consumption. Biopulping is indeed a sustainable method for paper production that can help reduce greenhouse gas emissions compared to traditional pulping processes.This method has gained attention due to its potential to reduce the environmental impact of traditional chemical and mechanical pulping methods.

Overview of traditional pulping methods

The manufacture of pulp for paper and paperboard employs chemical and mechanical pulping methods.

Chemical pulping

Chemical pulping is a process of separating wood fibers from the other components of wood using chemical treatments. It involves the use of chemicals to break down lignin and hemicellulose, allowing for the extraction of cellulose fibers that can be used in the production of paper and other wood-based products (Cheremisinoff & Rosenfeld, 2010). There are several methods of chemical pulping, but the two most used are Kraft pulping and sulfite pulping.

Mechanical pulping

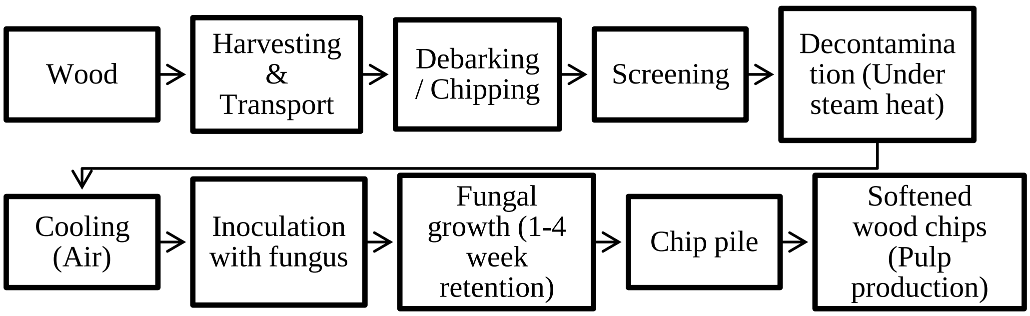
In mechanical pulping, the process of converting wood chips or other fibrous materials into pulp relies primarily on mechanical actions rather than chemical treatments. Mechanical pulping methods are typically used to produce pulp for specific types of paper products, such as newsprint and packaging materials. Mechanical pulping requires substantial amounts of energy, particularly in the refining process. This energy demand contributes to greenhouse gas emissions and increases the overall carbon footprint of the pulp production. The mechanical forces applied during refining in mechanical pulping can result in the degradation of fibers. This leads to shorter and weaker fibers, reducing the overall quality and strength of the paper produced.

The biopulping process

Despite having many advantages with the traditional pulping methods, these methods have several disadvantages that the use of harsh chemicals, such as sulfur-based compounds, which are used to dissolve lignin and separate the fibers are not environmentally friendly and can have negative impacts on the ecosystem. Biopulping, on the other hand, offers a more sustainable and eco-friendlier alternative.

Biopulping is a process that utilizes biological agents, such as fungi or bacteria, to break down lignin, a complex polymer found in wood, to facilitate the pulping process. In simple terms, Biopulping is defined as the treatment of wood chips with lignin-degrading micro-organisms (Fungi) before pulping. This works on the concept that the ability of the fungi to fully colonize and selectively degrade the lignin in wood leaving the cellulose relatively intact. The biopulping process typically involves inoculating wood chips with specific lignin-degrading microorganisms, such as white-rot fungi (Schaechter, 2009). These microorganisms produce enzymes, called lignin degrading enzymes such as Laccase, Lignin peroxidase (LiP), and Manganese peroxidase (MnP) which can easily break down lignin and modify its structure. This enzymatic action selectively degrades lignin while preserving the cellulose of the wood. Examples of the fungi include *Trametes versicolor*, *Ganoderma lucidum*, and *Schizophyllum commune.*

Step by step process of Biopulping



Wood is being harvested and transported from field to the pulp mill. The wood is then debarked, and mechanical processes are used to turn it into chips. The undesired chips that cannot be inoculated with fungus are subsequently removed by screening those chips. The chips are then steam decontaminated to eradicate naturally existing competing bacteria and fungus. They are then sprayed with a dilute inoculum of a specific fungus. Inoculated chips are incubated in an aerated chip pile for 1-4 weeks. Under warm, moist conditions the lignin degrading fungi colonize chip surfaces and penetrate chip interiors with a network of hyphae. These treated chips are more readily broken apart and softened for pulp production (Das and Houtman 2004).

The fungi used in biopulping

There are several types of wood rotting fungi generally employed in biopulping applications. Some of them have been discussed hereunder: -

White-rot fungi (WRF) comprise a category of wood-degrading fungi recognized for their capacity to decompose lignin within wood. Approximately 90% of wood-rot fungi belong to this group, with a primary focus on lignin degradation. This distinguishes them from brown rot fungi, which mainly target cellulose. Notably, white rot fungi possess a notable ability to break down lignin selectively and efficiently, a crucial aspect in biopulping processes. They are taxonomically diverse, including members from Basidiomycetes and Ascomycetes, with prominent genera like Phanerochaete, Trametes, and Ganoderma. These fungi are prevalent in forest environments, where they play a pivotal role in decomposing deceased wood. Utilizing a sophisticated enzymatic system, they produce various lignin-degrading enzymes such as lignin peroxidases, manganese peroxidases, and laccases. Working in tandem, these enzymes dismantle lignin's complex structure into simpler compounds, serving as carbon and energy sources for the fungi. Overall, white rot fungi exhibit remarkable abilities in lignin breakdown, positioning them as significant contributors to wood decay processes and offering potential applications in sustainable industrial practices (Eriksson et al., 1990).

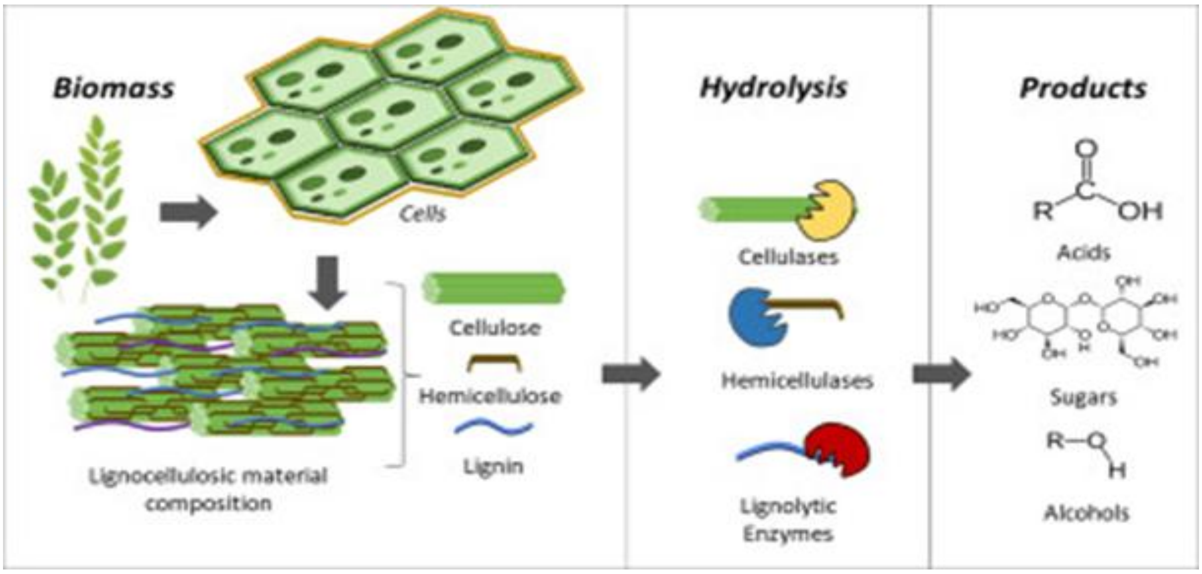
Brown-rot fungi (BRF) constitute a group of wood-decaying fungi primarily focused on cellulose degradation within wood, while preserving lignin. These fungi belong to Basidiomycota but lack lignin-degrading enzymes. Approximately 7% of known wood-decaying fungal species fall under BRF, with a preference for coniferous substrates. Unlike white rot fungi, which efficiently break down lignin, brown-rot fungi have evolved specialized mechanisms to target cellulose selectively, leaving lignin relatively intact. Their decay process involves carbohydrate degradation (cellulose and hemicellulose) and substantial demethylation of lignin, resulting in a brownish wood residue. Initiated by enzymatic cellulose breakdown, brown-rot fungi produce a set of enzymes called "cellulases." These include endoglucanases, exoglucanases, and β-glucosidases, working in concert to cleave cellulose chains into smaller glucose units. They play a crucial role in forest ecosystems by decomposing wood and facilitating nutrient recycling. Additionally, their unique cellulose-degrading abilities hold promise for diverse biotechnological applications. Examples of BRF include *Serpula lacrymans* and *Sulfur shelf* (Renvall, 1995).

Soft-rot fungi (SRF) represent a group of wood-decaying fungi responsible for a form of wood decay termed soft rot. Differing from white rot fungi and brown-rot fungi, which target lignin and cellulose respectively, soft-rot fungi possess the capability to degrade both cellulose and hemicellulose within wood. Soft rot manifests as wood softening and discoloration. Taxonomically diverse, these fungi belong to groups such as Ascomycetes and Deuteromycetes and are prevalent in various environments including soil, freshwater, and marine habitats. Soft rot can affect living trees, causing conditions like wetwood or slime flux, as well as processed wood products like lumber and paper.The decay process initiated by soft-rot fungi involves the secretion of enzymes targeting cellulose, hemicellulose, and pectin. Cellulases and hemicellulases degrade cellulose and hemicellulose polymers into simpler sugars, while pectinases target pectin, a component of the middle lamella binding plant cells together. Soft rot holds significant economic and ecological ramifications. In forestry, it leads to timber and wood product deterioration, diminishing strength and durability, and causing widespread wood damage in structures like buildings and utility poles. In natural ecosystems, soft-rot fungi contribute to woody debris decomposition, aiding nutrient cycling and carbon turnover (Schwarze et al., 2000).

Enzymes in biopulping

The main enzymes involved in biopulping applications are ligninolytic enzymes, primarily lignin peroxidase (LiP), manganese peroxidase (MnP), and laccase. These enzymes play crucial roles in breaking down lignin, which is the complex polymer that binds wood fibers together.

Lignin Peroxidase (LiP) is an enzyme capable of oxidizing a wide range of lignin-related compounds. It catalyzes the breakdown of lignin into smaller, more manageable fragments, making it easier to separate fibers during pulping. LiP is produced by various white-rot fungi, such as *Phanerochaetechrysosporium*, which is one of the most extensively studied



Wood components by hydrolysis producing varied products

organisms for biopulping applications.

Manganese Peroxidase (MnP) is another lignin-degrading enzyme produced by white-rot fungi. It catalyzes the oxidation of Mn^{2+} ions, which in turn oxidize lignin and other phenolic compounds. MnP is particularly effective in breaking down lignin structures that are resistant to degradation by other enzymes.

Laccase is another enzyme that catalyzes the oxidation of phenolic and other aromatic compounds by using molecular oxygen. It plays a role in lignin degradation by oxidizing phenolic lignin subunits. Laccase is produced by a variety of fungi, including white-rot fungi, as well as some bacteria. These enzymes work synergistically to degrade lignin, which softens the wood chips and facilitates the separation of fibers from the lignin matrix.

Benefits of biopulping

- Biopulping saves substantial amount of electrical energy or increases mill throughput significantly.
- It also improves paper strength compared to traditional pulping methods.
- Studies suggest that fungal pretreatment is also effective for depitching wood chips.
- The cost of incorporating the fungal treatment process into existing mills is minimal. It is a relatively simple process that can be carried out in any woodyard.
- Biopulping reduces the amount of cooking chemicals, increases the cooking capacity, or enables extended cooking, resulting in lower consumption of bleaching chemicals.
- Increased delignification efficiency also results in an indirect energy saving for pulping and reduces pollution.
- The waste load produced by biopulping should be considerably lower and more benign than effluents currently produced by commercial CTMP mills.
- Biopulping also contributes to lowering the carbon footprint of the pulp and paper industries.
- Produces higher quality pulp with enhanced delignification and offers high quality paper products.
- Provides safer working environment for the employees as there is limited usage of harsh chemicals.
- Certain lignin-degrading fungi can degrade lignin in various types of wood and agricultural residues, including low-quality or underutilized biomass sources.
- It results in reducing dependence on traditional wood sources and promoting the utilization of agricultural residues and waste materials.
- Biopulping can be integrated into biorefinery concepts, where different components of the wood biomass are utilized for various value-added products.
- The lignin-rich byproduct generated during biopulping can be further processed and used to produce biofuels, chemicals, and other bioproducts which creates a more sustainable and economically viable approach to the utilization of

lignocellulosic biomass (Singh *et al.*, 2010).

Biopulping for sustainable paper production

For the paper to be produced in a sustainable manner, biopulping is the better strategy to be considered that will replace the usage of harsh chemicals with biological agents for the delignification process in the paper production. This technology will result in increasing the pulp quality, enhance the strength, brightness, and printability of the resulting paper.According to Nagpal *et al.,* (2021), Biopulping helped in improving various properties of the paper. They are:

- Higher pulp yield was obtained
- Brightness of the resulted pulp after pretreatment with micro-organisms has been improved.
- Improved paper quality

Despite having many advantages with the biopulping technology, there is a need to optimize the process in several steps which helps to increase the quality of the desired final product.

Selection of fungal strains

Different fungal strains have varying abilities to degrade lignin. It is important to select fungal strains that are highly effective in lignin degradation. Research and identify fungal strains with a proven track record of efficient lignin degradation and test their performance in biopulping experiments.

- Breaking strength which determines how much force or stress the paper can withstand, it also improved.
- It also resulted in increased double fold which is a property of the paper that evaluates its ability to withstand folding without breaking or showing signs of weakness. This property is particularly important for materials that undergo frequent folding, such as packaging or book page.
- This technology also improved burst index, tear index, and Viscosity of the paper.

They concluded this environmentally sustainable bio-pulping approach can decrease the chemical load and ultimately pollution.

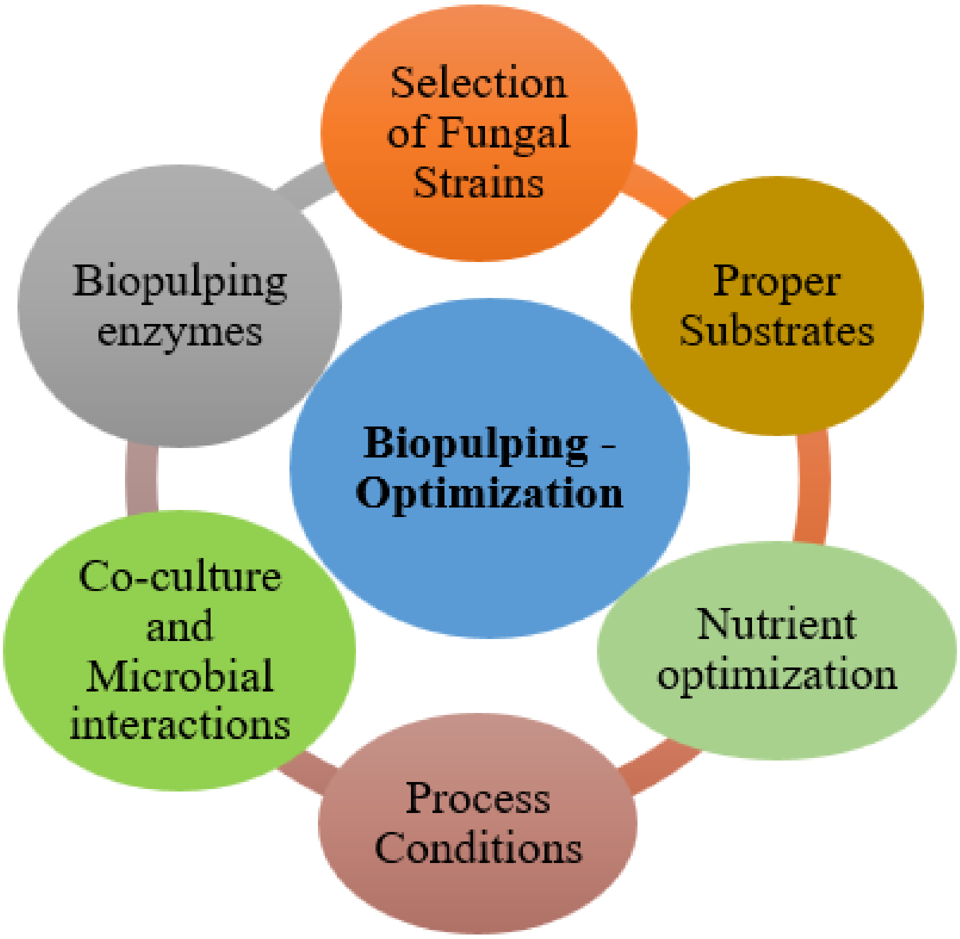
Biopulping process optimization

Proper substrates

Proper substrate preparation is essential for efficient biopulping. Ensure that the wood chips are appropriately sized, free from contaminants, and have sufficient moisture content for fungal growth and lignin degradation. Adjusting the wood chip size and moisture content can enhance the contact between fungi and lignin, leading to better results.

Nutrient optimization

Fungal growth and lignin degradation require essential nutrients. Optimize the nutrient composition of the growth



medium to promote fungal activity and lignin degradation. This may involve adjusting the carbon-to-nitrogen ratio, adding nitrogen sources, and incorporating other essential nutrients like phosphorus and potassium.

Process Conditions

The conditions under which biopulping is conducted can significantly influence its efficiency. Factors such as temperature, pH, oxygen availability, and incubation time should be carefully controlled. Experiment with different conditions to identify the optimal range for each parameter, as different fungal strains may have specific requirements.

Co-cultivation and microbial interactions

Consider exploring co-cultivation strategies by combining multiple fungal strains to enhance lignin degradation. Certain enzymes produced by other fungi can work synergistically with the selected fungal strains, leading to improved lignin degradation and biopulping efficiency.

Biopulping enzymes

Fungi secrete various lignin-degrading enzymes such as lignin peroxidase, manganese peroxidase, and laccase. Supplementing the biopulping process with commercially available or genetically engineered enzymes can further enhance lignin degradation. This approach can be particularly useful when working with fungal strains that have limited lignin-degrading enzyme activity.

Conclusion

Biopulping represents a promising environmentally friendly and sustainable alternative to conventional pulping techniques. With ongoing technological advancements and growing industry endorsement, it holds the potential to transform the paper and pulp sector by mitigating its environmental impact and fostering a more sustainable paper production approach. While laboratory and pilot-scale studies have demonstrated encouraging outcomes, further research and development efforts are necessary to refine the process for widespread commercial implementation. Key challenges, including maximizing enzyme efficiency, ensuring process scalability, and enhancing economic viability, must be tackled to facilitate the broader adoption of biopulping within the industry.

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Cycas circinalis-an endemic and end angered species

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Cycas circinalis

Common name

Queen Sago.

Other names

Eenthu Pana (Kerala), Mundisalu (Kannada), madanakama raja (Tamil) and Malabari supari (Marathi).

Distribution

Cycas circinalis also known as the queen sago, is an endangered and the only wild species of cycad that is endemic to southern India restricted to the Western Ghats, in the states of Kerala, Karnataka, Tamil Nadu, and the south of Maharashtra (Fig.1) (Varghese and Ticktin, 2008, Myers et al. 2000, Hill 1995; Hill et al. 2003). It is a gymnosperm species typically occurs in fairly dense, seasonally dry scrubby woodlands (Singh 1993; Lindstrom & Hill 2007).

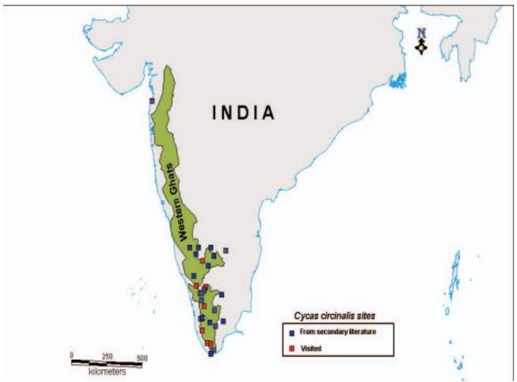

Fig.1 – Locations of *C.circinalis* populations along the Western Ghats, India.

(Images: Google search engine)

Morphology

Cycas circinalis is a medium-sized sucking cycad which can grow up to the heights of 3 to 5 meters, andin rare cases, up to 10 meters. It has feather-like leaves grouped in a rosette that crowns a single stem, giving it a palm tree-like appearance and develops one or more, usually unbranched stems around 27cm and 43 cm in diameter. The leaves are darkgreen pinnate, lustrous, have a maximum length of 150–250 cm and with a foot-long, thinleaflets that gently bend downward. The new foliage is pale green in colorwhich makes it stands out sharplyagainst the elder foliage. The male and female flowers are produced on different plants. Large orange seeds are produced by the female plants that resemble the cone and are situated in the middle of the leaf rosette. Male cones consist of numerous structures called microsporophylls that produce thousands of powdery pollen grains. Female cones consist of numerous megaporophylls, which are specialized leaf-like structures bearing seeds (Saneesh, 2009). *C. circinalis* is a facultatively deciduous plant as it is normally evergreen, extremely dry seasons might cause it to lose its leaves.

Uses

In general, species from this genus are poisonous if improperly harvested. The plant is collected in the wild and used locally for food, medicine, and building materials. It is also occasionally sold in neighbourhood markets (Varghese &Ticktin 2008). The pith can be used to make sago because it is high in carbohydrates. The plant must not have flowered in order for the starch to be extracted, since fruiting uses up the stem's starch reserves. The raw seed is deadly, but it can be made edible by slicing it thinly, drying it, steeping it in water for a short while, and then drying it again. It must be submerged in multiple changes of water. The seed can be used as a sago substitute because it has around 20 to 30 percent starch. The tender, succulent leaves, which are still somewhat unfurled, are cooked and consumed as a vegetable when they are between 30 and 40 cm long. 'Eenthakkapodi' which is the flour made from the seeds of *Cycas circinalis* is popularly used in parts of Kerala (Saneesh, 2009).

The pollen contains drugs. In Indian bazaars, male cone scales are frequently offered for sale as an anodyne. Using oil, the bark and seeds are crushed into a paste and applied topically to sores, cuts, wounds, ulcers, and swellings. Boils and swollen glands are treated with the mucilaginous terminal buds crushed in rice water or water containing finely ground clay particles in suspension. The juice of tender leaves can be used to cure vomiting and flatulence. A leaf decoction is ingested to relieve coughing. The plant's gum has been used medicinally, especially as an agent administered topically to malignant ulcers that are supposed to cause fast suppuration. The gum also has the property to use as a good antidote for snake and insect bites. (Chopra et al., 1986)

Other Uses

A gum exudes through wounds in the plant, especially from the megasporophylls, stems and leaves. It is used medicinally and as an adhesive. The gum commences flowing soon after the damage is made, it is somewhat like toothpaste at first, but soon fuses into a mass, becoming mucilaginous and transparent, though later hardening and becoming light brown. When placed in water, Cycas gum begins to swell almost immediately. By the end of several days, it expands to many times its original size and becomes so colourless and transparent that it cannot be seen in water but must be felt for with a rod (Thieret, 1958).

Cycas gum has been likened in its properties to that of *Sterculiasetigera*. The gum is also said to resemble tragacanth gum (obtained from *Astragalus gummifer*). Tragacanth has a wide range of uses including as a thickening agent in preparing dyes for calico printing, textile dyes and for dressing fabrics, it is also a thickener in making glues, water colours, ink (where it supplies a gloss), it is a binding agent in paper making, a culture medium in laboratories etc. Surface fibres from the leaves have been made into cloth. The fruits are strung together to make children's toys or rattles. The dry, stony seedcoats are sometimes used as playthings or whistles. Empty seedcases are used as snuff boxes

Cultivation and propagation

Cycas circinalis, in cultivation requires a strong loam with sharp sand and good drainage but in the wild it succeeds in dry soils and in poor soils. Cycads will generally not grow well in clay soils unless those soils are heavily amended with sand and organic matter. A neutral soil (pH 7), is generally best for most species of cycads and allows the proper absorption of nutrients. Plants are slow-growing. It is a dioecious species, with individual plants producing either all male or all female cones. Therefore, both male and female forms of the plant need to be grown if seed is required. On very rare occasions, usually when a plant has been under severe stress, it can change sex and produce either all female or all male cones. Seeds can be best sown as soon as they are ripe, though the seeds of many species will take a few months to finish maturing the embryo before they are ready to germinate. (Whitelock, 2002)

Conclusion

Cycas circinalis is seeing a sharp decline in population. More than half of its natural habitat is believed to have been destroyed by land clearing, and harvesting leaves for the urban floriculture market. The pith and leaves of the stem are used medicinally; large and old specimens are ruthlessly hacked down for the extraction of the pith. The seeds are regularly collected and consumed as food, and a large harvest seems to be having a detrimental effect on the people. Furthermore, variables like climate change, which has already caused changes in the global distribution of species (Thuiller et al. 2005), also found to have an impact on the species population.

In addition, categorized as an 'Endangered' in the IUCN Red List of Threatened Species (Varghese et al. 2010) and critically endangered (in the states of Karnataka and Tamil Nadu) or vulnerable (in Kerala) by the Foundation for Revitalisation of Local Health Traditions (Ravikumar & Ved 2000). Kerala farmers recently observed that the plantsare dying as a result of an unknown disease spreading over it. This poses a threat to the remaining populations of the species. According to Hill et al. (2003), the loss of pollinators is causing *C. circinalis* to reproduce poorly. There is a dearth of scientific information on pollination and other facets of species growth. Therefore, long term studies for *C. circinalis* for research and conservation measures involving local communities are needed for the species focusing the sustainable use of this endemic species.

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Production and management of tree fodder in smallholder agroforestry systems in India

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Introduction

India is one of the populous countries for livestock with a population of 535.78 million. The rapid increase in the number of cattle has resulted in a complete mismatch between the availability and demand for both green and dry feed. The nation's 29 million hectares of open forests, which can be cultivated with fodder trees, have a canopy density of less than 0.4. In terms of green fodder, dry fodder, and concentrates, India has a 26 million tonnes (MT), 21 MT, and 34 MT shortfall in 2015. By 2025, that deficit is predicted to raise to 40 MT, 21 MT, and 38 MT, respectively. This necessitates a concerted effort to increase fodder availability through scientific fodder production. In these situations, shrub and tree species are essential for providing fodder and can serve as a source of nitrogen for further feeds. These tree forages offer numerous other benefits, such as easy availability, flexibility, and influence on the laxative system, in addition to being an inexpensive source of nutrients, energy, and nitrogen.

In contrast to anti-nutritive components, which are a major issue in livestock feed, tree fodders have high amounts of crude protein and minerals, as well as high levels of digestibility and acceptance by the cattle. Certain varieties of fodder trees increase soil fertility by fixing atmospheric nitrogen, producing green mulch, and even producing wood for building materials, firewood, shelter, shade, or edible pods. Gathering fodder from certain tree species guarantees a consistent supply all year long, possibly as often as five or six times. Compared to other conventional fodder crops, fodder yields remain exceptionally high when irrigation is done with confidence. In rainfed areas, these tree fodder species represent a profitable option for farmers because to their cheap cultivation costs after initial establishment. Furthermore, by effectively cycling plant nutrients and acting as a nutrient pump, trees managed as species mixtures have a high potential to provide "micro-site enrichment." Furthermore, nitrogen-fixing trees have the capacity to provide the environment with significant amounts of atmospheric nitrogen.

The entire area under cultivation for fodder in Tamil Nadu is 1.72 lakh hectares, or 3.28 percent of all the cultivated land, which means that the districts of Erode, Namakkal, and Salem make up 73.6% of the fodder area. Four hundred and sixty thousand tons of green fodder is produced. Only 1.10 lakh hectares of land are used for permanent pastures and other grazing, showing how much more space there is in Tamil Nadu to increase the production of fodder. A 71.1 million ton shortfall of green fodder exists since the required amount of green fodder is 83.8 million tons, but only 12.7 million tons are available.

Arable land is primarily used for food and cash crops due to the pressure of an ever-increasing human population. As a result, there is limited likelihood of having good-quality arable land accessible for the production of fodder, unless milk production becomes profitable for the farmer relative to other crops. The immediate answer is to cultivate perennial fodder varieties that can generate higher biomass per unit area in order to meet the current level of livestock output and its annual expansion in population

Importance of fodder trees

Trees that bear edible leaves, flowers, stems, and pods are known as fodder trees. Historically, multipurpose trees, shrubs, and woody elements have been used in the farm management system as a source of the six Fs: fuel, feed, fiber, forest, food, and fertilizer (green manure). The meal made from tree leaves may provide nutrients, energy, fat, protein, and energy to sheep and cattle. Fodder trees provide animals with healthy feed all year round, but especially during the lean season, in the form of leaves and pods that are rich in proteins and minerals.

A good fodder tree should be easy to establish, competitive, tolerant of frequent pruning or grazing, low input (no fertilizer needed), hardy to pests and diseases in the area, reliable for vegetative propagation or able to produce seed, high in nutritional value, and somewhat palatable to animals.

- Provide shade to the grazing animals which increases the efficiency of digestion of feed
- Provide a variety of products such as fuel, small timber, fiber, human food, medicines *etc*.
- Source of organic matter and fertilizer, increasing the total level of soil nitrogen besides improving the soil texture.
- Serve as lining fences and hedges besides yielding green fodder.
- Serve as wind breaks besides intercepting the windblown soil particles by the tree canopy and washing to the ground beneath.
- Provide shade for cocoa, coffee and tea plants and supports for yams, vanilla and black pepper.
- Prevent soil erosion and conserve moisture
- Increase the yield and improve the quality of grasses grown under their shade due to change in the microclimate condition.
- Cause minimal soil disturbance and prevent nutrient loss from the soils
- Provide yields of edible components comparable to pastures

Classification of Fodder species

On the basis of crude protein, fodder trees and shrubs could be divided into three categories

1. High protein content (CP > 17% of DM) species eg. *Acacia nilotica, Grewia oppositifolia, Zizyphus jujuba*
2. Medium protein content (14% < CP < 16.9% of DM) eg. *Morus nigra, Ailanthus chinensis, Indigofera*

gerardiana, and Impatiens bicolor

3. Low protein content (CP < 14% of DM) eg. *Celtis australis, Celtis caucasica, Olea cuspidata, Ficus tetrasperma, Melia azedarach and Artemisia maritima*

On the basis of digestibility, fodder trees and shrubs could be divided into three categories

1. Highly digestible fodder trees (more than 60% IVDMD) eg. *Ailanthus chinensis, Grewia oppositifolia, Zizyphus jujuba, Melia azedarach*
2. Intermediate digestible fodder trees (50-60% IVDMD) eg. *Acacia modesta, Betula utilis, Morus nigra, Acacia nilotica*
3. Least digestible fodder trees and shrubs (less than 50% IVDMD) eg. *Quercus dilatata, Celtis australis, Celtis caucasica, Olea cuspidata, Dodonaea viscosa*

On the basis of palatability (Potential Intake Rate), fodder trees and shrubs could be divided into three categories

1. Higher Potential Intake Rate species eg. *Grewia oppositifolia, Zizyphus jujuba, Betula utilis*
2. Intermediate Potential Intake Rate species eg. *Melia azedarach, Acacia modesta, Acacia nilotica, Ficus sarmentosa, Salix tetrasperma*
3. Lower Potential Intake Rate species eg. *Artemisia maritima, Dodonaea viscosa,* and *Quercus dilatata*

Tree Fodder Production Systems

The perennial fodder species can be managed under a variety of systems, depending on the features of the land and the resources available. These species can be kept either solely for the production of fodder, or they can be kept for fuelwood and lumber with side branches chopped off for fodder. A number of tree species yield fruits and pods that are fed to cattle in addition to grain. The soil's fertility and moisture availability should be taken into account while choosing a fodder production strategy. A sufficient supply of water is necessary to establish a single crop of fodder. Since growth is inhibited during the dry season and fodder can only be obtained during the rainy season, it is advised against establishing fodder crops in these locations. The best places to establish fodder species are wastelands near rivers, sandy soils with a high water table, and saline soils in irrigated areas. It is preferable to do alley cropping in agricultural fields with high soil productivity by growing food crops in alleys and planting fodder trees in hedgerows.

In this system, various multipurpose tree species are intercropped on or around agriculture lands. Tree species commonly used as fodder, fire, pulp and plywood industries are *Morus indica, Leucaena leucocephala, Leucaena diversifolia, Gliricidia sepium, Sesbania grandiflora, Holoptelia integrifolia, Thespesia populnea, Albizia lebbeck, Melia dubia, Dalbergia sissoo, Neolamarckia cadamba, Ficus bengalensis, Ficus glomerata, Bauhinia variegate, Inga dulce, Moringa oleifera, Ceiba pentandra, Terminalia arjuna, Hibiscus tiliaceus, Ficus religiosa* etc.

A number of fodder production systems have been designed to produce sufficient foliage for livestock feeding particularly during the dry season. These production systems include various types of agroforestry-silvipastoral systems, where trees, animals and pastures are deliberately combined to obtain benefits and services.

- Alley cropping
- Silvi-pastoral systems
- Food-feed intercropping
- Three strata forage system
- Integrated tree cropping systems
- Planting a living fence around the household
- Range land farming

Multipurpose trees (MPTS)

All woody perennials that are intentionally intended to contribute significantly to the production and/or "service" activities of the land-use system they implement more than once are referred to as "multipurpose trees."

Nitrogen fixing trees (NFTS)

Few crops can be grown profitably without the addition of nitrogen, a plant nutrient, and no blooming plant can survive without it. Yield declines because many farmers and tree growers cannot afford to purchase nitrogen fertilizers. A NFT coexists in a symbiotic, or mutually beneficial, relationship with root microorganisms, which convert atmospheric nitrogen into a form that the trees can use. The trees then provide the microorganisms carbohydrates in return. In nitrogen-poor soils, an NFT's built-in living nitrogen fertilizer factory frequently enables it to grow faster than the majority of non-nitrogen-fixing trees while requiring fewer inputs. As a result, the nitrogen can be applied to other crops and trees as green manure in addition to the NFTS growth. Several NFTS produce excellent feed that animals readily consume, including protein-rich leaves and pods.

Conclusion

The Government of India envisions two national objectives: increasing the year-round supply of nutrient-dense tree fodder and obtaining higher continuous milk production. Currently available kinds of trees and shrubs that make good fodder can act as valuable feed sources. Tropical farming methods rely heavily on trees and shrubs for fodder, which contributes to soil fertility and upkeep, animal productivity, and the provision of feed during the dry season. Several native species in this area have not had their full potential fully and systematically realized due to the lack of attention they have received thus far from study efforts that have been focused on a small number of invasive species. Research on species like *Leucaena*, *Gliricidia*, and *Sesbania* should go on, but attention must gradually move to the indigenous species that farmers are now using for their own purposes.

Unraveling the proteomes of trees: A comprehensive omics approach to understanding tree biology

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Introduction

Proteins are important for life and have many roles in structural, metabolic, transport, immune, signaling, and regulatory functions. Proteome is a blanket term used for all proteins present in a cell that an organism can express. This term was put forward by an Australian researcher, Marc Wilkins. Each organism has its unique proteome. Proteomics is a field of molecular biology study focusing on the large-scale analysis of proteins. In the context of the proteomes of trees, proteomics offers a powerful approach to understanding the complex biological processes occurring within these organisms. As long-lived and structurally complex organisms, trees undergo various physiological and developmental processes throughout their lifecycle. Proteomics provides insights into the molecular mechanisms underlying these processes, including growth, development, response to environmental stresses, and interactions with other organisms.

Genomic technologies have provided clear insights into stress-dependent responses at cellular, tissue, and whole plant levels (Ashwath *et al.*, 2023). The proteins found in a tree's leaves, stems, roots, and flowers can be identified and measured using proteomics techniques like mass spectrometry (MS). Post-translational modifications (PTMs) like phosphorylation, glycosylation, acetylation, and ubiquitination can be found and identified using proteomics (Kosova *et al.*, 2011). PTMs are essential for controlling cellular functions and protein function. Proteomics methods such as affinity purification and co-immunoprecipitation in conjunction with mass spectrometry (AP-MS) allow the identification of interactions between proteins in intricate biological systems. By mapping protein interaction networks in tree proteomes, scientists can identify protein complexes and regulatory pathways involved in particular physiological processes. Proteomics data can be combined with other omics datasets, such as transcriptomics, metabolomics, and genomics, to provide a multi-omics approach that helps researchers understand the functional roles of proteins in the context of the entire biological system, as well as gene expression, protein abundance, and metabolic pathways in trees. Proteomics is useful for studying how trees react to environmental stressors like heat, cold, drought, etc. Proteomics is also used in studies related to biotic stress-like diseases which provide an insight into the molecular mechanism of plant disease resistance and also help in the early detection of disease. Researchers can find stress-responsive proteins and pathways involved in adaptive responses by examining changes in the tree proteome under various stress conditions (Barkla *et al.*, 2013). They can then use this information to develop strategies for enhancing the resilience and productivity of trees. It can also be used for the investigation of seed recalcitrance and traceability.

Steps of proteomics analysis

Sample preparation, Purification, Separation, Identification, Analysis, and Comparison are the main steps of proteomics analysis.

Sample preparation

Trichloroacetic acid/acetone (TCA) precipitation with the phenol is the extraction method used for protein extraction from the samples. In the extraction method for protein solubilization and denaturation strong detergents like sodium dodecyl sulfate (SDS), sodium deoxycholate (SDC), or chaotropic such as urea and thiourea or reducing agents such as dithiothreitol (DTT) were used and these detergents or reducing agents should be removed for the purification step.

Purification

Filter-aided sample preparation (FASP) (Wang *et al.*, 2018), suspension trapping (S-Trap), and single-pot-solid-phase-enhanced sample preparation (SP3) (Brajkovic *et al.*, 2023) are the different methods developed for the purification step. In the filter-aided sample preparation method, ultrafiltration columns have membranes with a molecular weight of 30 kDa that are used for the purification step. Completely denatures even small proteins with hydrodynamic volume during purification are retained in membranes and small organic molecules or detergents like SDS are washed out through the centrifugation. The proteins are directly digested on the membrane and they can be easily recovered for the MS analysis method (Wang *et al.*, 2018). The SDS method is used for the protein solubilization and then it will acidify, to produce a suspension of protein precipitate. This suspension is transferred into commercial S-Trap tips that have a filter to retain proteins and remove small molecules by centrifugation. In single-pot-solid-phase-enhanced sample preparation (SP3) method paramagnetic beads having high percentages of organic solvents (acetonitrile) were used for the precipitation of proteins. SDS and other small molecules are easily removed by washing beads with organic solvent and proteins are directly digested on the beads (Brajkovic *et al.*, 2023).

Separation

Separation methods can be broadly classified as gel-based or electrophoretic methods and non-gel-based methods. Gel based method include 2- Dimensional gel electrophoresis with 2 levels of separation. In the first level, proteins are separated according to their charge and in the second level; separation is done by using their molecular size (Abdallah *et al.*, 2012). One-dimensional gel electrophoresis coupled with the liquid chromatography method is a combination of both gel-based and non-gel-based techniques. First, the proteins are separated on SDS gel, after that the whole gel is divided into pieces before the proteolytic digestion. After that peptide fractions are subjected to liquid Chromatography (second separation) to advance to MS/MS analysis (Abdallah *et* *al.*, 2012). The non-gel-based methods include Ion-exchange chromatography (cation-exchange chromatography and anion-exchange chromatography). Here the peptides separated according to the charge (Abdallah *et al.*, 2012), Reverse phase chromatography is based on the analyte partition coefficient between the polar mobile phase and the non-polar (hydrophobic) stationary phase (Abdallah *et al.*, 2012) and 2D liquid chromatography is the combination of ion exchange chromatography and reverse phase chromatography which occur in two different dimensions.

Identification and quantitation

Quantitative methods are broadly divided into label-free techniques and labeling techniques. Label-free methods are mainly based on the comparison of the chromatographic peak area of extracted ions. Spectral counting (total number of MS/MS spectra associated with all peptides detected for a single protein) (Friso *et al.*, 2010), LC/MSE (based on the fact that the average intensities of the three most intense peptides for any protein are constant at or less than 10% variation at a given concentration) (Cheng *et al.*, 2009) and Exponentially modified protein abundance index (the ratio of the number of sequenced peptides to the theoretical number of peptides) (Ishihama *et al.*, 2005) are coming under the label-free methods. Labeling techniques include Isobaric tags for relative and absolute quantitation (iTRAQ) where the peptides are covalently labeled with stable isotope molecules with different mass tags (Wang *et al.*, 2017), Tandem mass tag (TMT) here the samples are labeled by using isobaric chemical tags (Zang *et al.*, 2022), Isotope-coded affinity tag (ICAT) which targets only cysteine-containing peptides and Stable isotope labeling by amino acids in cell culture (SILAC) is metabolic labeling method in which cells are grown in the presence of a specific isotope-labeled amino acid (Gruhler *et al.*, 2005).

Analysis

Mass Spectrometry (MS) is mainly used for the analysis step. The principle behind this was the biomolecules can be ionized, and the ionized molecules can be separated based on their mass-to-charge ratio. Different types of MS methods were used for the analysis steps. MALDI-TOF-MS (Matrix Assisted Laser Desorption/Ionisation – Time of Flight – Mass spectrometry) has two phases that are the ionization phase and time of flight phase where the samples are ionized using a laser beam (MALDI) and are separated by their mass to charge ratio which is determined by the time taken by the ions to reach the detector (TOF) (Lei *et al.*, 2022). SELDI-TOF-MS (Surface-enhanced laser desorption/ionization – Time of Flight – Mass spectrometry) on the SELDI surface samples are placed and are usually analyzed using time-of-flight mass spectrometry. In ESI-QIT-MS (Electrospray ionization -Quadrupole ion trap Mass spectrometer) proteins are ionized in solution and carry multiple charges. In this method, the ionization phase is different (Wang *et al.*, 2017).

Comparison

Comparison is mainly comprised of the bioinformatic analysis carried out by using different software. For different functions in proteomics, different software is assigned for particular purposes (Chen *et al.*, 2020). For peptide and protein identification SEQUEST, MASCOT, X! Tandem. IsobariQ, MaxQuant, MaxLFQ, and OpenMS were used for the protein abundance quantification. Enrichment analysis was carried out by using STRING, Signor, PANTHER (Protein analysis through evolutionary relationships), and KEGG (Kyoto Encyclopedia of gene and genomic).

Role of proteomics in forestry

The majority of studies on forest tree proteomics focused on biological processes, including development and growth, stress responses, modeling, and characterizing natural variability to identify proteins that might be employed as markers in breeding initiatives. Proteomics research in forest trees from 2012 to 2022 has significantly advanced our understanding of biological processes in tree species like Eucalyptus, Pinus, and Quercus. In recent times, proteomics has been utilized to investigate seed recalcitrance and traceability (Romero-Rodríguez *et al.,* 2019; Escandón *et al.,* 2022). This has demonstrated the nutraceutical worth of seeds and their derivatives, and it has evident potential for use in identifying allergens and bioactive peptides (Pedrosa *et al.*, 2020).

Proteomics has been particularly useful in the investigation of the stress response. In *Cupressus gigantea* proteomic analysis revealed the molecular mechanism in the drought tolerance. In this study sample is prepared by using the TCA/Acetone method. The separation is carried out by using the 2D gel electrophoresis method and the analysis step was carried out by using the MALDI-TOF MS analysis. KEGG is used for the analysis and formation of the functional pathways involved in different treatments. Through this study, it is clear that the post-transcriptional regulation of photosynthetic electron transport, and reactive oxygen species scavenging plays a major role in the drought response of *C. gigantea* seedlings. This study paves the path for the more careful molecular study and analysis of candidate genes (Lei *et al.*, 2022). Studies on abiotic stress have attempted to simulate near-future situations that pines may encounter due to ongoing climate change to get insight into their capacity for adaptation. In *Pinus massoniana* proteomics by 2DE coupled to MALDI-TOF/TOF was used to study the effect of acid rain and the role of calcium in the stress response (Hu *et al.*, 2014). A comprehensive physiological, proteomic, and metabolomic examination of *Pinus radiata* seedling reaction to ultraviolet light and subsequent recovery using shotgun proteomics demonstrated a reorganization of the proteome linked to metabolic reassignment in response to oxidative stress (Pascual *et al.*, 2017). Proteomic studies were conducted in *Acacia auriculiformis* to explain physiological and proteomic network analyses that reveal the effects of exogenous nitrogen in diminishing Cd detoxification. Through this study, the addition of N decreased the Cd detoxification by inhibiting plant growth, weakening photosynthesis, energy metabolism, stress and defense response, translocation and signaling pathways, and an insight into the influence of N in Cd tolerance in N-fixing trees at the proteomic level (Zhang *et al.*, 2021). Recent studies were carried out in the *Quercus ilex* to understand the recalcitrant character of these non-orthodox seeds the maturation and germination stages have been studied using different proteomics platforms. These studies' results showed that mature seeds have all the machinery necessary for rapidly resuming metabolic activities and starting the germination process, while post-germination events were similar to those of the orthodox seeds (Romero-Rodríguez *et al.*, 2014; Rey *et al.*, 2019).

Conclusion

Overall, proteomics provides an effective set of tools for deciphering the intricate proteomes of trees and comprehending the molecular underpinnings of their biology. Proteomics provides novel and important information for understanding the response of tree and plant species to abiotic stress. Proteomics advances tree biology and fosters the development of sustainable forestry practices by clarifying the roles of proteins in growth, development, stress responses, and interactions with the environment. Proteomics can be applied not only in the study of abiotic stress but also in the study of biotic stress such as diseases. Functional pathways related to the identified proteins can be developed by using different bioinformatics tools in proteomics analysis.

Future prospects

Proteomics has enormous promise and should be prioritized research for any organism. Proteomics has been restricted in the case of forest species due to the nature of the biological system itself. Thus, from a systems Biology standpoint, it is essential to link proteomics with other fields and omic approaches. Future methods ought to take into account various viewpoints for connecting data from single organisms to population studies as well as focused investigations that enable the selection of elite genotypes and individuals through the use of molecular markers.

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Silviculture of intensively managed plantations: Maximizing productivity and sustainability

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Abstract

The management of intensively managed forest plantations has evolved with advancements in environmental understanding and technology. This article explores key aspects including precision silviculture, long-term research integration, balancing production with sustainability, adaptive management, research and innovation investment, stakeholder engagement, and considering G × E × S interactions. These factors contribute to maximizing productivity while addressing environmental and social concerns. Silviculture in intensively managed plantations holds potential for shaping resilient landscapes, with strategic planning and collaborative efforts driving sustainable practices for future generations.

Keywords: Sustainability, Precision, Adaptation, Stakeholder engagement, Productivity, Silvicultural operations

Introduction

The management of intensively managed forest plantations has undergone significant evolution, driven by advancements in environmental understanding and technology. This article explores key aspects such as precision silviculture, long-term research integration, balancing production with sustainability, adaptive management, research and innovation investment, and stakeholder engagement. These factors contribute to maximizing productivity while addressing environmental and social concerns. Intensively managed forest plantations refer to areas of forest land that are actively managed with high levels of human intervention and manipulation to maximize productivity and meet specific objectives (Rubilar *et al.*, 2018). These plantations are typically characterized by densely planted and closely spaced trees, often consisting of a single species or a few select species that are chosen for their economic value or suitability to the site conditions. Intensive management practices commonly employed in these plantations include regular pruning, thinning, fertilization, and irrigation to promote rapid tree growth and enhance timber quality.

Additionally, precision silviculture techniques, such as remote sensing technology and spatial modelling, are often used to optimize resource allocation and monitor forest health. The primary goals of intensively managed forest plantations are to maximize timber production, achieve economic profitability, and ensure the long-term sustainability of forest resources. However, these objectives must be balanced with considerations for environmental conservation, biodiversity, and social impacts to achieve truly sustainable forest management outcomes. Hence, intensively managed plantations hold potential for shaping resilient landscapes, with strategic planning and collaborative efforts driving sustainable practices for future generations. Silviculture in these settings is crucial for optimizing resource use efficiency and enhancing ecosystem services, ensuring the long-term viability of forest ecosystems.

Understanding Silvicultural Effects on Forest Productivity

Intensive management of forest plantations increasingly relies on precision silviculture to estimate site-specific effects on productivity. Remote sensing technology, combined with ground data, provides spatial modelling tools essential for this endeavour (Rubilar *et al*., 2018). Long-term field experiments offer mechanistic insights into the environmental and silvicultural factors influencing forest production. However, the emphasis on maximizing production raises concerns about intensive land use and water use conflicts, necessitating a holistic approach to sustainability (Fox, 2000). Below are several key points outlining the advancement of sustainable practices in intensively managed forest plantations:

Utilizing Precision Silviculture

Intensively managed forest plantations rely heavily on precision silviculture, employing advanced techniques to assess site-specific productivity factors accurately. Precision forestry, a term commonly employed in this field, encompasses a spectrum of practices. These range from utilizing cutting-edge technologies for tree inventory and assessing wood quality characteristics to devising site-specific management strategies (Manasa*et al.*, 2023). For instance, targeted and localized applications of fertilizers to specific planting spots and root zones can improve plant nutrient uptake, particularly for less mobile nutrients like phosphorus (Jokela *et al*., 2010). These strategies aim to match tree genotypes with suitable sites and provide precise interventions to improve nutrition and manage competing vegetation effectively.Remote sensing technology, coupled with ground data, provides essential spatial modelling tools crucial for informed decision-making in silvicultural practices.

Integration of Long-Term Research Insights

Long-term field experiments offer valuable mechanistic insights into the complex interplay of environmental and silvicultural factors influencing forest production. This empirical knowledge serves as a cornerstone for refining management strategies and optimizing productivity while upholding ecosystem integrity.

Balancing Production Goals with Sustainability

While maximizing production remains a primary objective, the intensive land use associated with forest plantations raises concerns about sustainability. Addressing issues such as habitat fragmentation, biodiversity loss, and water use conflicts requires a holistic approach that prioritizes ecological conservation alongside productivity goals.

Implementing Adaptive Management Strategies

Adaptive management frameworks enable forest managers to respond effectively to changing environmental conditions and stakeholder needs (Yousefpour *et al.*, 2017). By monitoring ecosystem dynamics and integrating feedback loops into management practices, adaptive strategies promote resilience and long-term sustainability.

Investing in research and innovation

Continued investment in research and innovation is essential for advancing sustainable practices in intensively managed forest plantations. Collaborative efforts between academia, industry, and government institutions drive technological advancements, knowledge dissemination, and capacity building across the forestry sector.

Enhancing stakeholder engagement

Effective stakeholder engagement fosters transparency, inclusivity, and accountability in forest management decision-making processes. Involving local communities, indigenous groups, and other stakeholders ensures that management practices align with socio-cultural values and contribute to community well-being.

The intensification of silvicultural practices in forest plantations presents both opportunities and challenges for sustainable forest management. By embracing precision silviculture, integrating long-term research insights, balancing production goals with sustainability, implementing adaptive management strategies, investing in research and innovation, and enhancing stakeholder engagement, we can optimize productivity while safeguarding the ecological integrity of forest ecosystems.

Incorporating G × E × S Interactions for Improved Productivity

The successful implementation of new silvicultural technologies hinges on understanding the complex interactions between genetics, environment, and silviculture (G × E × S) (Rubilar e*t al*., 2018). This knowledge is essential for developing practical tools that enhance productivity while maintaining economic sustainability. Advances in remote sensing and biological understanding enable the integration of geospatial and temporal information into silvicultural decision-making, facilitating strategic, tactical, and operational planning.

Additionally, leveraging genomic technologies allows for the selection of tree species and cultivars with desirable traits suited to specific environmental conditions. By identifying genetic markers associated with growth rate, wood quality, and stress tolerance, forest managers can make informed decisions regarding species selection and breeding programs. Moreover, incorporating environmental data into genetic analyses enables a better understanding of genotype-environment interactions, further optimizing productivity and resilience.

Furthermore, implementing ecosystem-based management approaches considers the broader ecological context in which silvicultural practices operate. By assessing ecosystem services and functions, such as carbon sequestration, water regulation, and biodiversity conservation, managers can develop strategies that enhance overall ecosystem health while maximizing productivity (Hayes *et al.*, 2005). This integrated approach fosters sustainable forest management practices that balance economic, social, and environmental objectives.

Thus, incorporating G × E × S interactions into silvicultural decision-making enhances productivity, sustainability, and resilience in intensively managed forest plantations. By integrating genetic, environmental, and silvicultural considerations, managers can optimize resource use efficiency and mitigate risks associated with environmental variability. This holistic approach ensures the long-term viability of forest ecosystems while meeting societal needs for timber, ecosystem services, and biodiversity conservation.

Strategic silvicultural planning

A strategic silvicultural plan is developed by assessing potential productivity estimates against current levels and implementing treatments to maximize productivity cost-effectively. Common treatments include managing planting density and thinning, pruning, reducing site-specific limitations, and adding limiting resources like fertilization. By leveraging advancements in these areas and understanding site-specific constraints, managers can bridge the gap between current and maximum attainable productivity.

Furthermore, strategic planning involves considering long-term objectives and trade-offs associated with different management strategies. This entails evaluating the ecological, economic, and social implications of various silvicultural treatments to ensure alignment with broader management goals. For example, decisions regarding planting density and thinning must balance the need for maximizing timber yield with considerations for biodiversity conservation, soil health, and carbon sequestration. Moreover, strategic silvicultural planning integrates adaptive management principles, allowing for flexible adjustment of management strategies in response to changing environmental conditions and stakeholder preferences. Continuous monitoring and evaluation enable managers to assess the effectiveness of implemented treatments and make informed decisions about future management actions. Intensive management practices enhance forest plantation productivity by minimizing limitations to dry matter production and maximizing harvestable tree components. This increases fibre production from a smaller land area, incentivizing forest use (Vance *et al*., 2010).

Additionally, stakeholder engagement plays a crucial role in strategic planning, as it ensures that management decisions reflect the diverse interests and values of relevant stakeholders. Collaborative decision-making processes foster transparency, trust, and support for management interventions, enhancing the likelihood of successful implementation and long-term sustainability. Incorporating interdisciplinary perspectives is also essential in strategic silvicultural planning. By bringing together expertise from forestry, ecology, economics, sociology, and other relevant fields, managers can develop holistic strategies that address complex socio-ecological challenges while optimizing productivity and sustainability. By considering a range of factors, including site-specific conditions, long-term objectives, adaptive management principles, stakeholder engagement, and interdisciplinary collaboration, managers can develop effective strategies that promote the resilience and vitality of forest ecosystems while meeting societal needs for timber, ecosystem services, and biodiversity conservation.

Density management for high-value stems

Traditionally, stand management aimed at producing large-diameter forest products through recurrent thinning treatments. However, recent studies indicate that traditional strategies fall short of expectations, necessitating a shift towards incorporating process-based models to manage carrying capacity effectively. Additionally, while pruning was once a common practice to increase clear wood yield, market dynamics and technological advancements have led to a re-evaluation of its efficacy. Future improvements in clear wood yield require a focus on genotype selection, low planting densities, and individual tree pruning to optimize wood quality and mitigate water use conflicts.

Furthermore, research suggests that managing density for high-value stems requires a nuanced approach that considers interactions between tree genetics, environmental conditions, and silvicultural treatments. Selecting genotypes with desirable traits, such as rapid growth and straight stems, can enhance the potential for producing high-value timber products. Moreover, implementing low-density planting regimes allows individual trees to allocate resources more efficiently, resulting in improved stem quality and reduced competition for water and nutrients (David *et al*., 2018). Closer spacing promotes competition among trees, leading to vertical growth rather than lateral branching, which can enhance timber quality. Additionally, it allows for more efficient land use, maximizing the productivity of limited forest resources. Therefore, to maximize the yield of fast-growing species, they can be cultivated with narrower spacing (Manasa *et al*., 2022).

In addition, optimizing stand density through strategic thinning treatments can promote diameter growth and wood quality by reducing competition among trees and allowing for optimal light penetration and nutrient availability (Sterck *et al*., 2021). However, the timing and intensity of thinning operations must be carefully planned to minimize negative impacts on ecosystem functions and biodiversity. Furthermore, integrating individual tree pruning into management practices can enhance clear wood yield by removing lower branches and promoting vertical stem growth. This targeted approach not only improves timber quality but also reduces the risk of disease and pest infestations, thereby increasing the economic value of harvested wood products. The effective density management for high-value stems requires a holistic understanding of genetic, environmental, and silvicultural factors. By adopting innovative approaches that prioritize tree selection, low-density planting, strategic thinning, and individual tree pruning, forest managers can optimize wood quality, maximize economic returns, and promote sustainable forest management practices.

Conclusion

The intensification of forest management through precision silviculture offers immense potential for maximizing productivity and sustainability. By integrating advancements in technology with biological understanding, silviculture in intensively managed plantations can optimize resource use efficiency, enhance ecosystem services, and address challenges associated with climate change and water scarcity. However, realizing these benefits requires a concerted effort to incorporate G × E × S interactions into management practices and overcome existing barriers to adoption. With strategic planning and collaborative research efforts, silviculture can play a pivotal role in shaping resilient and productive forest landscapes for future generations.

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Published by:

ICFRE-Tropical Forest Research Institute
(Indian Council of Forestry Research & Education)
(An autonomous council under Ministry of Environmnet, Forests and Climate Change)
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Impact Factor
SJIF: 2022-6.071