

DEPARTMENT OF AGRICULTURE DEVELOPMENT
& FARMERS' WELFARE, GOVERNMENT OF KERALA



FARM INFORMATION BUREAU

KERALA KARSHAKAN

THE FIRST ENGLISH FARM JOURNAL FROM THE HOUSE OF KERALA KARSHAKAN

OCTOBER 2026
VOLUME 14 ISSUE 05

E-JOURNAL



Climate-Smart Fodder Cultivation in

Kerala

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KERALAKARSHAKAN

OCTOBER 2026 • VOLUME 14 • ISSUE 03

Mail editorejournalkkfib@gmail.com Log on to www.fibkerala.gov.in Phone: 0471 2314358

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Climate-Smart Fodder Cultivation in Kerala



Agriculture today is being shaped by a changing climate, shrinking natural resources, evolving food systems, and the growing need to improve farm incomes. Ensuring sustainability therefore requires approaches that make better use of land, water, biomass and biological resources while strengthening the resilience of farming communities. The October issue of Kerala Karshakan e-Journal brings together a range of articles that explore these possibilities, beginning with climate-smart fodder cultivation and extending to coconut-based fodder systems, fodder trees, hydroponic fodder production, and the conservation of surplus fodder through silage and hay. Together, these articles highlight practical approaches to addressing fodder shortages and strengthening livestock-based farming systems in Kerala.

The issue also looks beyond conventional crops to emerging opportunities in agricultural diversification and nutrition. Minni Payaru (*Vigna stipulacea*) is presented as a promising pulse crop with potential for food, fodder and green-manure production, while the nutritional characteristics of weedy rice open up an interesting area for crop improvement and genetic-resource research. The nutritional and health importance of fruit crops further demonstrates the close relationship between agricultural diversity, dietary diversity and nutritional security. Alongside these agricultural themes, the story of Muga silk highlights rural livelihoods and women's work, adding another dimension to the role of agriculture and allied activities in rural economies.

Sustainability also depends on the quality of the environment in which agriculture operates. The article on pollution policies examines the challenges of protecting air, water and soil, while highlighting the importance of effective standards, monitoring, enforcement and community participation. From fodder security and livestock production to crop diversification, genetic resources, nutrition, rural livelihoods and environmental protection, the October issue brings together diverse perspectives that are closely connected to the future of agriculture. We hope this collection of articles will provide useful knowledge, stimulate new ideas, and encourage farmers, researchers, students and agricultural professionals to explore practical pathways towards a more resilient, resource-efficient and sustainable agricultural future.

CLIMATE-SMART FODDER CULTIVATION IN KERALA: CURRENT STATUS AND OPPORTUNITIES

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INTRODUCTION

India, with only 2.42 per cent of the world's land area, supports a vast human population and the world's largest livestock population. Animal husbandry and dairy development play a vital role in the country's economy by generating rural employment, strengthening livelihoods, and supporting small and marginal farmers, agricultural labourers, women, and other vulnerable groups.

India has been the world's largest milk producer since 1998, contributing nearly 25 per cent of global milk production. Milk production has grown steadily at an annual rate of 5.8 per cent over the past three years, reaching 239.30 million tonnes in 2023-24, while per capita milk availability increased to 471 g per day (IASRI, 2025). Meat production also reached 10.25 million tonnes in 2023-24. According to

the 20th Livestock Census (2019), India has 535.78 million livestock, representing about 10.7 per cent of the global livestock population and reflecting a 4.6 per cent increase over the 2012 census. The livestock sector's contribution to agriculture Gross Value Added (GVA) increased from 24.4 per cent in 2014-15 to 30.2 per cent in 2022-23, accounting for 5.5 per cent of India's total GVA and recording an annual growth rate of 13 per cent (GOI, 2025).

The expanding livestock population has substantially increased the demand for quality feed and fodder, which account for 65-70 per cent of the total cost of livestock production (Kumar et al., 2023). According to IGFR Vision 2050, India will require 851.3 million tonnes of dry fodder and 530.5 million tonnes of green fodder. At present, the country faces deficits of 35.6 per cent in

green fodder, 10.95 per cent in dry crop residues, and 44 per cent in concentrate feed ingredients. Although around 8.5 million hectares are currently under cultivated fodder, an additional 11.5 million hectares of grasslands and nearly 100 million hectares of wastelands offer considerable scope for expanding forage production.

LIVESTOCK SECTOR IN KERALA

The livestock sector is a major contributor to Kerala's rural economy, accounting for 26.44 per cent of the state's agricultural Gross State Value Added (GSVA). According to the 20th Livestock Census (2019), Kerala has 29.1 lakh livestock, comprising 13.4 lakh cattle, 13.6 lakh goats, 1.0 lakh pigs, 0.9 lakh rabbits, and 289.4 lakh poultry.

Kerala's cattle population is distinctive, with nearly 95 per cent consisting of crossbred animals. The state has 1.251 million crossbred/exotic cattle compared with only 0.077 million indigenous cattle. This genetic improvement has enabled Kerala to achieve the second-highest average milk yield among Indian states, at 11.2 litres per cow per day in 2024–25, second only to Punjab (13.25 litres), and well above the national average of 8.95 litres for crossbred cows.

Despite this high productivity, Kerala's average lactation yield remains below the first-lactation yield recorded under the state's progeny testing programme, indicating that the genetic potential of dairy animals is not being fully realized. Inadequate scientific calf rearing, coupled with chronic shortages of feed and fodder, contributes to lower peak yields, reduced lactation persistency, and lower lifetime productivity.

PERSISTENT FODDER DEFICIT IN KERALA

The most significant constraint to sustainable dairy development in Kerala is the chronic shortage of feed and fodder. The state currently produces only about 60 per cent of the roughage required for its cattle population. This shortfall is primarily due to fragmented and stagnant fodder cultivation. In 2024–25, Kerala had 7,462 fodder plots, of which 74.8 per cent measured between one and 2.5 acres, while only 2.7 per cent exceeded five acres. The total number of fodder plots also declined during 2023–24 and 2024–25 compared with previous years (Kerala Development Report, 2026). As a result, Kerala's dairy sector depends heavily on imported commercial feed from neighbouring states, increasing production costs and reducing the profitability of dairy farming.

Climate change and the role of fodder production systems
Climate change is affecting every sector, including agriculture and livestock. Atmospheric carbon dioxide has increased from 278 ppm in the pre-industrial era to 428.53 ppm in 2026, far above the safe limit of 350 ppm. Agriculture contributes about 24% of global greenhouse gas (GHG) emissions, while livestock accounts for around 14.5%, mainly through enteric methane from cattle, manure management, and feed production.

Kerala is already experiencing higher temperatures and more erratic rainfall. Over the past century, the state's daily maximum temperature has increased by 1.7°C and the annual mean by 1.1°C. Even a 1°C rise can reduce milk production by 5–10%, posing a serious challenge to the dairy sector, where women make up more than 70% of the workforce. Rainfall is becoming increasingly uneven, with more frequent extreme rainfall events and shifting monsoon patterns, making fodder production and livestock management more difficult.

FODDER PRODUCTION AS A CLIMATE CHANGE SOLUTION

Fodder production systems can help mitigate climate change by sequestering carbon and reducing methane and nitrous oxide emissions. Grasslands and forage crops store nearly 30% of the world's soil carbon, and improved pasture management can significantly enhance this storage. Globally, about 29% of agriculture's carbon mitigation potential comes from pasturelands.

Studies at Kerala Agricultural University identified Hybrid Napier as one of the most efficient fodder crops for carbon sequestration, followed by hedge lucerne and fodder cowpea. Grass-legume

mixtures, especially Hybrid Napier with fodder cowpea, recorded the highest carbon sequestration under Kerala conditions. Integrating fodder grasses with trees in silvipastoral systems further increases soil carbon while improving farm sustainability.

Improved fodder quality also reduces methane emissions from livestock. Feeding high-quality, protein-rich fodder and silage can lower methane production by 15–30%. In addition, tropical forage grasses such as *Brachiaria* species naturally suppress soil nitrification, helping to reduce nitrous oxide emissions.

Thus, well-managed fodder production systems not only support sustainable livestock production but also serve as an effective nature-based solution for climate change mitigation by improving carbon storage, lowering greenhouse gas emissions, and enhancing the resilience of farming systems..

SCOPE FOR CLIMATE-RESILIENT FODDER PRODUCTION IN KERALA

Kerala possesses considerable potential for climate-resilient fodder production by utilizing diverse agroecosystems and adopting location-specific forage species. Although several exotic fodder grasses, including hybrid napier, guinea grass, signal grass, palisade grass, para grass, Congo signal grass, golden timothy, *Stylosanthes*, subabul, and gliricidia, have been introduced successfully, their cultivation remains largely confined to homesteads. Expanding these species into farming systems can substantially improve fodder availability.

RAINFED FODDER PRODUCTION

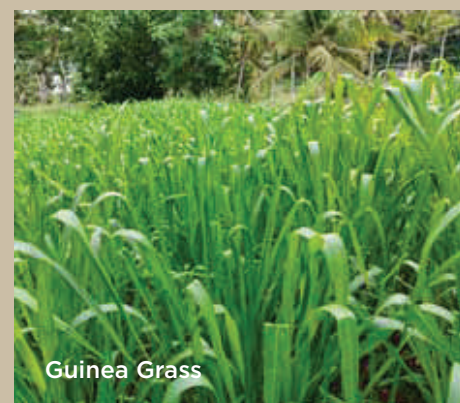
Despite receiving high annual rainfall, Kerala experiences prolonged dry

periods during summer, making drought tolerance an important criterion for fodder selection. Drought-tolerant grasses such as gamba grass (*Andropogon gayanus*), buffel grass (*Cenchrus ciliaris*), bermuda grass (*Cynodon dactylon*), golden timothy (*Setaria sphacelata*), deenanath grass (*Pennisetum*

pedicellatum), and guinea grass, together with legumes such as subabul (*Leucaena leucocephala*), gliricidia (*Gliricidia sepium*), centro (*Centrosema pubescens*), and siratro (*Macroptilium atropurpureum*), are well suited to rainfed conditions.

Among hybrid napier cultivars, CO-3

has consistently recorded superior fodder yield, leaf-to-stem ratio, and drought tolerance under rainfed conditions, while CO-4 and PTH also perform satisfactorily without irrigation. The guinea grass cultivar 'Makueni' has also been identified as suitable for drought-prone areas of Kerala (Antony and Thomas, 2015).



FODDER PRODUCTION IN COCONUT-BASED SYSTEMS

Coconut plantations offer significant opportunities for fodder cultivation because of their canopy structure and rooting pattern, which leave much of the soil profile available for intercrops. Mature and widely spaced plantations are particularly suitable for integrating perennial fodder grasses, legumes, and tree fodders.

Hybrid napier (CO-3, Suguna, IGFRI-3, NB-21, DHN-3), guinea grass, *Stylosanthes*, fodder cowpea, *centrosema*, *gliricidia*, subabul, and mulberry have demonstrated good performance under coconut gardens. Soil moisture conservation measures, such as coconut husk burial, further improve fodder productivity. Although fodder yield under moderate shade is lower than in open fields, forage quality is

generally superior. Shade-tolerant species such as *Stylosanthes* can be successfully grown under up to 50 per cent shade. Tree fodders, particularly mulberry and subabul, also perform well under appropriate planting density and pruning schedules, providing a cost-effective alternative to expensive concentrate feeds (Subramanian et al., 2007; Antony and Thomas, 2015).

Beyond fodder production, coconut-based agroforestry systems enhance ecosystem services. Coconut-gliricidia intercropping has been reported to nearly double ecosystem carbon stocks compared with coconut monoculture, highlighting its potential as a climate-resilient production system (Raveendra et al., 2017).

FODDER PRODUCTION IN STRESS-PRONE ENVIRONMENTS

Kerala's diverse agroecological conditions provide opportunities for cultivating specialized forage species adapted to different environmental stresses.

► **Waterlogged areas:** Para grass (*Brachiaria mutica*), jungle rice (*Echinochloa* spp.), swamp rice grass (*Leersia hexandra*), Koronivia grass (*Brachiaria humidicola*), and phasey bean (*Macroptilium lathyroides*) are suitable for low-lying and flood-prone areas, including fallow paddy fields.



► **Saline soils:** Karnal grass (*Diplachne fusca*), para grass, bermuda grass, and Koronivia grass perform well in saline coastal ecosystems, including Pokkali fields.

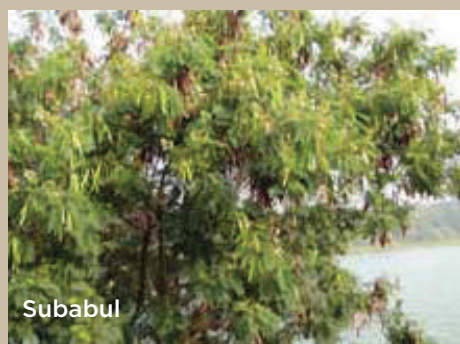
► **Acid soils:** Hybrid napier, guinea grass, signal grass, para grass, gamba grass, pangola grass, and Koronivia grass tolerate the acidic soils common in Kerala. Among tree fodders, gliricidia shows greater tolerance to soil acidity than subabul.

SOIL AND WATER CONSERVATION THROUGH FODDER CROPS

Several forage species contribute simultaneously to fodder production and natural resource conservation. Drought-tolerant Potha grass (*Themeda cymbaria*) is suitable for stabilizing terrace risers while providing livestock feed. Grasses such as signal grass, guinea grass, hybrid napier, para grass, buffel grass, and golden timothy are effective hedge species for reducing soil erosion. Likewise, fodder legumes including calopo, puero, centro, and *Stylosanthes* function as valuable cover crops that improve soil fertility while supplying quality forage.

TREE FODDERS AND AGROFORESTRY

Tree fodders offer substantial scope for expanding year-round fodder resources. Species such as subabul, agathi (*Sesbania grandiflora*), gliricidia, calliandra (*Calliandra calothyrsus*), Flemingia (*Flemingia macrophylla*), and hedge lucerne (*Desmanthus* spp.) can be integrated as live fences, boundary plantations, shade trees, and alley cropping systems. Their inclusion in farm forestry and social forestry programmes would strengthen climate resilience while reducing dependence on purchased feeds.



Subabul



Agathi



Moringa

UTILIZING PLANTATION AREAS, RICE FALLOWS, AND CROP RESIDUES

Plantation crops provide additional opportunities for forage production, as naturally occurring grasses, legumes, and fodder trees such as *Erythrina* can be harvested instead of being treated solely as weeds.

Similarly, residual soil moisture in rice fallows after the second paddy crop can support short-duration fodder crops such as fodder maize, sorghum, bajra, and cowpea.

Crop residues and agro-industrial by-products also represent valuable feed resources in Kerala. Besides paddy straw, farmers traditionally

utilize jackfruit waste, cassava stem shavings, pineapple waste, cocoa pod rinds, plantain leaves, sweet potato vines, and amaranth residues. The establishment of straw baling and processing units further enhances the efficient utilization of these locally available feed resources.



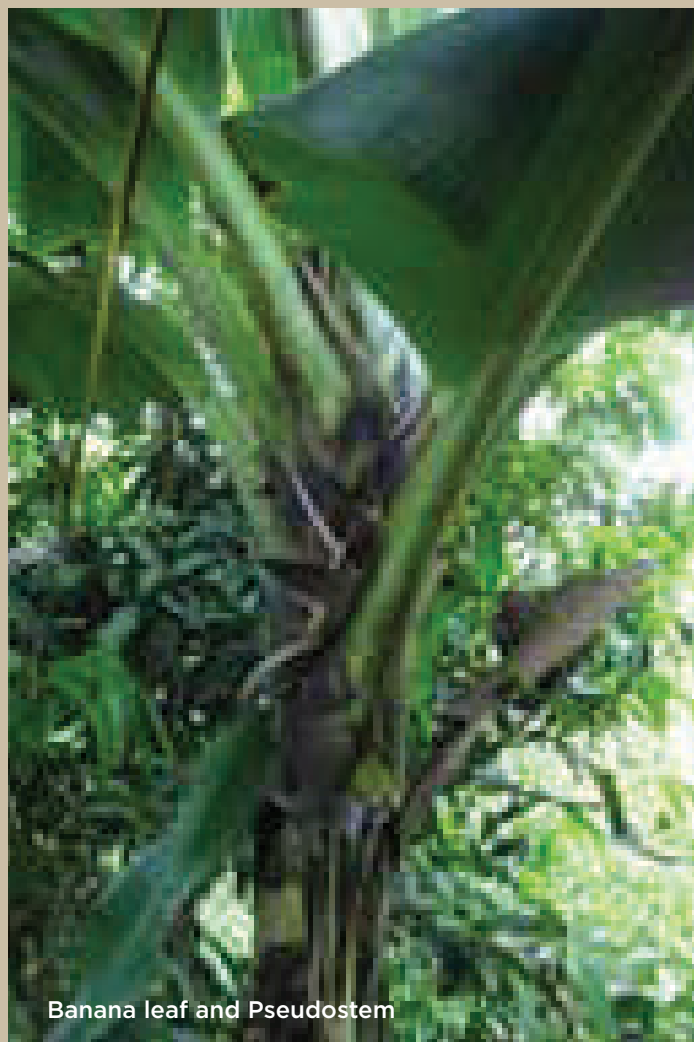
Jack Fruit



Cassava



Pineapple fruit waste



Banana leaf and Pseudostem



Jack Fruit

The nutritional quality of different fodder crops varies significantly, as reflected in their protein and fibre content. The following table presents the protein and fibre content of various fodder crops suitable for Kerala's conditions, helping farmers make informed choices based on their nutritional requirements of their livestock

FODDER	PROTEIN CONTENT (%)	FIBRE CONTENT (%)
Hybrid Napier	8.18	31.29
Guinea grass	6.9	37.33
Gamba grass	7.97	35.66
Setaria grass	6.29	36.50
Congosignal grass	7.29	32.53
Para grass	7.38	36.94
Creeping signal grass	6.86	36.72
Signal grass	7.38	35.21
Palisade grass	10.17	34.54
Multicut maize	9.0	27.87
Paspalum grass	8.54	31.97
Red Napier	10.20	31.04
Super Napier	10.60	33.41

AICRP on Forage Crops and Utilization, Vellayani, Kerala
The All India Coordinated Research Project on Forage Crops (ICAR) was started in 1971 at the College of Agriculture, Vellayani. Initially, the Centre carried out research on the agronomic aspects of forage crops suited to Kerala. Later, forage breeding programmes were also initiated. Research on breeding and agronomy of fodder crops suited to partially shaded coconut gardens is the focus of this centre. Germplasm collection, maintenance and evaluation are being done for guinea grass, napier grass, bajra, cowpea and rice bean. Research programmes have also been taken up to develop bajra-napier hybrids and hybrid derivatives in cowpea and rice bean. The Package of Practices Recommendations of Kerala Agricultural University for fodder crops like guinea grass, hybrid napier grass, congo signal grass, signal grass, fodder cowpea and rice bean were formulated based on experiments conducted at the Vellayani Centre.

Varieties released from AICRP on Forage Crops, Vellayani Centre

CROP	VARIETY
Bajra Napier Hybrid	Suguna, Supriya, Susthira
Guinea Grass	Haritha, Marathakom, Harithasree, KAU Suparna
Fodder Cowpea	Aiswarya
Fodder Rice Bean	Surabhi

Fodder Demonstration Programme under AICRP on Forage Scheme in Farmers Field



BN hybrid Variety Suguna



Guinea Grass variety KAU Suparna



CONCLUSION

Kerala’s crossbred cattle offer high productivity, but the sector is fundamentally constrained by a severe fodder deficit, with the state producing only 60 per cent of the roughage required. Climate change is exacerbating this challenge through rising temperatures and erratic rainfall, which reduce milk production and disrupt fodder availability. However, fodder production systems themselves are powerful climate tools that sequester carbon, reduce methane emissions by 15-30 per cent, and cut nitrous oxide emissions through biological nitrification inhibition.

The state has immense scope for climate-resilient fodder production through the utilization of coconut garden understories (7.98 lakh ha), rice fallows, homesteads, and saline coastal areas, with improved varieties like Suguna, Supriya, Harithasree, KAU Suparna, Aiswarya, and Surabhi specifically suited to Kerala’s conditions. The strong cooperative sector provides an excellent institutional framework for fodder development. With focused

investment, technological innovation, capacity building, and policy support, Kerala can transform its fodder deficit into a climate-resilient, productive system that supports its livestock population and enhances the livelihoods of millions of farming families.

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COCONUT BASED FODDER PRODUCTION SYSTEMS IN KERALA

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INTRODUCTION

Coconut (*Cocos nucifera* L.) is one of the most important plantation crops in India and serves as a major source of livelihood for millions of farmers, particularly in the coastal regions of Kerala, Tamil Nadu, Karnataka, and Andhra Pradesh. A significant share of coconut cultivation is managed by small and marginal farmers who depend on coconut-based farming for their income and household security. However, conventional monocropping of coconut often leaves a large portion of available land resources underutilised. The interspaces between coconut palms, along with available sunlight, soil moisture, and nutrients, provide considerable opportunities for introducing suitable companion crops.

In recent years, integrated farming approaches have gained importance as a means of improving farm productivity, profitability, and sustainability. Coconut-based intercropping is one such approach where compatible crops and livestock components are integrated within the plantation ecosystem. The unique architecture of coconut palms, with wide spacing and a favourable microclimate beneath the canopy, creates suitable conditions for growing a variety of intercrops without affecting coconut productivity.

Among the different intercropping possibilities, fodder production has emerged as a highly promising option, especially in regions where dairy and livestock farming are

important components of rural livelihoods. Cultivating fodder crops within coconut gardens transforms otherwise unproductive spaces into valuable feed resources, ensuring a regular supply of nutritious green fodder throughout the year. On-farm fodder availability reduces dependence on purchased feeds, lowers livestock production costs, and improves the economic efficiency of dairy enterprises. The integration of coconut, fodder crops, and livestock creates a mutually beneficial farming system. While fodder crops provide quality feed for animals, livestock contribute organic manure that improves soil fertility and promotes nutrient recycling within the plantation. Such systems enhance resource-use efficiency, improve farm resilience,

and provide additional income opportunities for farmers.

Coconut-based fodder production is therefore emerging as a practical and sustainable strategy for addressing fodder shortages, strengthening livestock-based livelihoods, and improving the overall productivity of coconut farming systems.

WHY COCONUT GARDENS ARE IDEAL FOR FODDER PRODUCTION?

Coconut plantations provide an excellent environment for growing fodder crops because of their unique spacing pattern and canopy characteristics. Coconut palms are generally planted at a spacing of 7.5 m × 7.5 m, leaving considerable open space between palms that can be effectively utilised for growing compatible crops. When coconut is cultivated alone, a substantial portion of available land, sunlight, and soil resources remains unused. Introducing fodder crops into these spaces improves overall land productivity without creating significant competition with the main crop.

The root distribution pattern of coconut palms further supports the suitability of intercropping. Although coconut develops an extensive adventitious root system, most active roots are concentrated close to the palm base. This leaves considerable soil volume between palms available for the growth of intercrops. Proper

selection and management of fodder species allow farmers to utilise these areas efficiently while maintaining healthy coconut palms.

The canopy architecture of coconut also creates a favourable microclimate for fodder production. Mature coconut plantations allow filtered sunlight to reach the ground, providing suitable growing conditions for many shade-tolerant fodder grasses and legumes. This partial shade helps reduce moisture loss, moderates soil temperature, and supports crop growth, particularly during dry periods.

The suitability of coconut gardens for fodder cultivation varies with the age of the plantation. During the early years after planting, when the coconut canopy is still developing, greater sunlight availability allows cultivation of a wider range of crops. During the mature phase, although shade levels increase, several shade-tolerant fodder species continue to perform well. In older plantations, increased light penetration due to changes in canopy structure again creates favourable conditions for fodder production.

Thus, coconut gardens offer a unique opportunity to establish productive fodder systems throughout the life cycle of the plantation. By selecting suitable fodder species and adopting proper management practices, farmers can convert the interspaces beneath coconut palms into a continuous source of quality

BN hybrid as intercrop in coconut garden



COCONUT BASED FODDER INTERCROPPING SYSTEMS IN KERALA

Fodder grasses play a vital role in improving livestock productivity and farm sustainability in Kerala, where land scarcity and fodder shortages are major challenges. Integrating high-yielding fodder crops with coconut-based agroforestry systems offers an efficient approach to utilize available land, improve farm income, and support dairy production.

Guinea Grass (*Panicum maximum*) is one of the most widely cultivated tropical fodder grasses due to its high productivity, palatability, persistence, and excellent shade tolerance. It is highly suitable for intercropping under coconut plantations. The grass is a perennial bunch type, growing 0.5–4.5 m tall, with a deep fibrous root system that ensures adaptability under varying conditions. Improved varieties include Harithasree, KAU Suparna and COGG-3. It grows well under warm humid climates from

sea level to 1800 m altitude and performs best in well-drained loamy soils. Planting is generally done during May–June with the onset of monsoon. Vegetative propagation through slips is preferred due to poor seed germination. Recommended fertilization includes FYM (10 t ha⁻¹), 50 kg each of P₂O₅ and K₂O, and 200 kg N ha⁻¹ in splits. Harvesting begins 9–10 weeks after planting, followed by cuts at 45–60 day intervals.



Guinea grass

Bajra-Napier Hybrid (*Pennisetum glaucum* × *Pennisetum purpureum*) is a high-yielding perennial fodder crop developed by crossing pearl millet and Napier grass. It combines high biomass production, rapid regrowth, softness, palatability, and drought tolerance. Popular varieties include Suguna, Supriya, Susthira, CO-3, CO-5, DHN-6 etc. The crop performs well in Kerala's tropical climate and is suitable for coconut gardens due to its shade tolerance. It is propagated through rooted slips or stem cuttings, requiring approximately 28,000–30,000 slips ha⁻¹ at 60 × 60 cm spacing. Application of FYM (25 t ha⁻¹), 50 kg each of P₂O₅ and K₂O, and 200 kg N ha⁻¹ is recommended.

The first harvest is obtained after 9–10 weeks, with subsequent cuts every 4–6 weeks. Under good management, it yields 200–250 t ha⁻¹ year⁻¹ of green fodder, making it one of the most productive fodder crops for tropical farming.



BN hybrid

Gamba Grass (*Andropogon gayanus*) is a drought-tolerant perennial grass suitable for regions with prolonged dry periods. It grows 1–2 m tall and has strong regeneration ability after drought or fire. It can be propagated through seeds or slips and performs well under coconut-based systems. Recommended nutrient management includes 10 t FYM ha⁻¹, 50 kg each of P₂O₅ and K₂O, and 200 kg N ha⁻¹. It produces approximately 50–80 t ha⁻¹ of green fodder annually with good nutritive value.

Congo Signal Grass (*Brachiaria ruziziensis*) is a creeping perennial fodder grass valued for its dense ground cover, soil conservation

ability, and shade tolerance. It grows 50–100 cm tall and is suitable for coconut plantations. It can be established using seeds (2–5 kg ha⁻¹) or slips at 40 × 20 cm spacing. Application of FYM (5 t ha⁻¹), phosphorus and potassium (50 kg ha⁻¹ each), and nitrogen (100–150 kg ha⁻¹) improves productivity. The crop yields 35–45 t ha⁻¹ under rainfed conditions and up to 100 t ha⁻¹ with irrigation.



Congo Signal

In addition to perennial fodder grasses, crops such as fodder sorghum (*Sorghum bicolor*) and fodder maize (*Zea mays*) can be cultivated for short-duration, high-quality green fodder production. Leguminous fodders like stylo (*Stylosanthes* spp.) and cowpea (*Vigna unguiculata*) improve forage quality through their higher protein content and nitrogen-fixing ability. Fodder trees such as agathi (*Sesbania grandiflora*), moringa (*Moringa oleifera*), and subabul (*Leucaena leucocephala*) are well suited for planting along bunds and field borders. These trees provide protein-rich fodder, improve soil fertility through leaf litter addition, and support sustainable coconut-based integrated farming systems.

Fodder-based coconut intercropping provides an economically viable and environmentally sustainable farming system. These grasses improve land-use efficiency, provide year-round green fodder, reduce dependence on purchased feed, enhance nutrient cycling, and support integrated crop-livestock farming. Among these options, Guinea grass and Bajra-Napier hybrid are particularly promising for Kerala's coconut gardens due to their high productivity, shade tolerance, and adaptability. Adoption of such systems can help address fodder shortages while improving the profitability and resilience of smallholder farming systems.

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Stylo



Fodder cowpea



Corn



Fodder Rice Bean

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FODDER TREES: A SUSTAINABLE FEED RESOURCE FOR LIVESTOCK PRODUCTION

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INTRODUCTION

Proper nutrition forms the foundation of profitable livestock production and is essential for achieving high and sustained productivity. Feed accounts for nearly two-thirds of the total cost of livestock production, making the availability of quality green fodder crucial for reducing production costs and improving farmers' returns. Fodder trees and shrubs are valuable sources of nutrients for livestock; however, their potential remains underutilized, largely due to limited awareness of their nutritional benefits. Tree fodder can play a significant role in addressing the shortage of quality fodder in the country. More than 60 per cent of the fodder requirement of goats is normally met through shrubs

and tree leaves (Ally and Kunjikutty, 2000).

Under adverse environmental conditions, where natural grazing is insufficient to meet the maintenance requirements of livestock, fodder trees and shrubs become an important alternative feed resource. Their leaves are generally rich in crude protein, minerals, and vitamins, and many species possess high digestibility. They are readily accepted by livestock and, owing to their deep root systems, continue to produce foliage even during the dry season when herbaceous fodder becomes scarce (Khan et al., 2014).

Tree and shrub legumes, once

established, develop extensive root systems that enable them to utilize moisture and nutrients beyond the reach of most herbaceous plants (Topps, 1992). Consequently, they have been widely used as protein- and nitrogen-rich supplements in livestock feeding systems (Osuji and Odenyo, 1997). In addition to providing nutritious fodder, these species offer several ecological benefits. They help reduce soil erosion, improve soil moisture conservation, suppress weed growth, replenish soil fertility through biological nitrogen fixation, and provide additional products such as fuelwood. Fodder trees also enhance biodiversity, improve the microclimate, provide habitat and

forage for wildlife, and contribute to the conservation of soil macro- and micronutrients. Furthermore, they play an important role in the stabilization of degraded lands and sand dunes (Sharma, 2013). According to Alam and Djajanigra (1994), feeds containing less than 10 per cent crude protein may adversely affect rumen microbial activity and feed utilization. Most commonly used fodder tree leaves contain crude protein levels well above this threshold, making them excellent protein supplements capable of partially replacing expensive concentrate ingredients such as groundnut oil cake and gingelly (sesame) oil cake (Chithra, 2018).

Fodder trees are commonly integrated into agroforestry systems, silvipastures, farm boundaries, home gardens, community lands, and forest ecosystems rather than being cultivated as standalone crops. With the continuous decline in grazing lands and the increasing cost of commercial cattle feed, tree fodder has emerged as a dependable and sustainable feed resource. Besides supplying nutritious forage that supports better digestion, milk production, and overall livestock productivity, fodder trees also contribute to biodiversity conservation, environmental sustainability, and climate resilience. Some of the important tree fodder species suitable for cultivation under Kerala conditions are described below.

Subabul (*Leucaena leucocephala*)

Subabul (*Leucaena leucocephala*), also known as ipil-ipil, is a fast-growing evergreen perennial tree native to Mexico. It is widely cultivated in tropical and subtropical regions as an important fodder tree. It has a deep root system, making it highly drought-tolerant.

The tree has bipinnate leaves measuring 15–20 cm in length, globular inflorescences, and white flowers. It is highly nutritious, containing 27–34% crude protein, along with carotene and vitamins. It is particularly rich in provitamin A. Being a member of the Fabaceae family, it forms a symbiotic association with nitrogen-fixing bacteria, thereby improving soil fertility. It also serves as an effective windbreak or shelterbelt and thrives well under dry conditions.

Subabul is highly palatable to cattle and other livestock. However, it contains the antinutritional amino acid mimosine. Therefore, it should be fed in appropriate quantities and is generally mixed with other fodder crops rather than being used as the sole feed.



Subabul



Subabul

Varieties

(a) Hawaiian variety

- ▶ A valuable fodder resource for livestock.
- ▶ Short, dense-growing tree.
- ▶ Performs well under dry conditions.
- ▶ Produces numerous seeds.
- ▶ K-341 is a variety belonging to this type.

(b) Salvador variety

- ▶ Tall-growing variety with high biomass production.
- ▶ Produces relatively larger leaves and seeds than the Hawaiian type.
- ▶ Responds well to fertilizer application.
- ▶ K-8 is a popular fodder variety of this type.

(c) Peru variety

- ▶ Tall-growing tree with numerous branches.

- ▶ Mainly cultivated for fodder production.

(d) Cunningham variety

- ▶ A hybrid developed from the Salvador and Peru varieties.
- ▶ Grows well under hot climatic conditions (22–30°C) with an annual rainfall of 500–2000 mm.
- ▶ Possesses a deep root system that enables it to withstand drought.
- ▶ Not recommended for areas below 500 m above sea level or waterlogged/flood-prone areas, but performs well under other adverse climatic conditions.

Cultivation

Season of planting

Subabul is planted during:

- ▶ May–June, or
- ▶ September–October.

Seed treatment

Since the seeds have a hard seed

coat, pretreatment is necessary to improve germination. Seeds may be treated by either:

- ▶ Dipping them in concentrated sulphuric acid for 4 minutes, or
- ▶ Soaking them in hot water at 80°C, followed by sun drying.

Seed rate

- ▶ 3-4 kg of seed per hectare.

Method of sowing

Seeds can be:

- ▶ Directly sown in the field at a depth of 2-3 cm, or
- ▶ Raised in a nursery and transplanted to the main field after reaching the 6-8 leaf stage.

Spacing

Recommended spacing includes:

- ▶ 1.0 × 0.1 m, or
- ▶ 1.5 × 0.2 m when planted along coconut boundaries, or
- ▶ 2.0 × 0.2 m under other planting situations.

Subabul grows well on fallow lands and along roadsides.

Fertilizer recommendation

Apply fertilizers at 20:50:30 kg N₂O₅₂O per hectare.

Since the crop grows slowly during the initial stages, the first weeding should be carried out early to minimize weed competition.

Subabul can also be grown as a mixed crop with Guinea grass, Sangaranapier (Napier hybrid), and other fodder grasses.

Harvesting

Flowering begins about 125-150 days after sowing. Within 5-6 months, the plants attain a height of 1.5-1.75 m. At this stage, the branches should

be pruned at a height of 70-80 cm above ground level, without cutting the main stem.

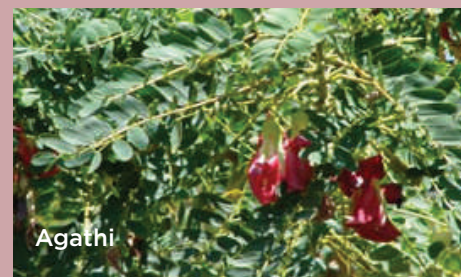
Yield

- ▶ Under low rainfall and gravelly lateritic soils, the yield is about 25-30 tonnes per hectare.
- ▶ Under irrigated conditions, after 7-8 harvests, yields of up to 100 tonnes per hectare can be obtained.

Agathi (*Sesbania grandiflora*)

Agathi (*Sesbania grandiflora*) is a leguminous nitrogen fixing tree fodder which is a rich source of various minerals and vitamins. The leaves contain as much as 25-30 percent crude protein, 30 mg phosphorous, 184 mg potassium, 15 mg sodium and 9600 IU vitamin A in every 100 g and it is an important food supplement to the cattle. The tree produces leaves for fodder within 4 months of establishment. For fodder production, the tree is cut when 90-120 cm tall (1.8 kg) and fed to animals mixed with rice straw (Pradip, 2016). It is a fast-growing tree that shows particularly vigorous growth during its first three to four years. It can be easily established through direct seeding and is known for its abundant root nodules, which are extremely large in size. It can be planted at high densities up to 3000 stems per hectare and produces vigorous regrowth after cutting. Its leaves and pods are palatable to cattle and are safe for livestock feeding. In an investigation conducted at Kerala Agricultural University on anti-nutritional factors and micro nutrient content in predominant tree fodders

and shrubs that locally available in southern Kerala have revealed that Banana (*Musa acuminata*) is nutritionally superior with respect to micro nutrients such as iron, zinc, manganese and copper. But the high content of oxalate may limit its utility as a fodder. Whereas agathi (*Sesbania grandiflora*) can be recommended as the best top feed due to negligible content of anti-nutritional factor, viz., oxalate and nitrates. (Mubeena et al, 2022).



Calliandra (*Calliandra calothyrsus*)

Calliandra is a multipurpose fodder tree that plays an important role in livestock production systems. It is especially useful in areas where environmental conditions or disease issues make it hard to grow other fodder tree species. This tree can tolerate acidic soils and grow well in humid regions. It can be grown from both seeds and stem cuttings and is often used as an intercrop in coconut and tapioca plantations. The leaves contain around 22% crude protein and are easily eaten by goats and dairy cattle. Although condensed

tannins may impact protein digestibility, fresh foliage has shown good taste and digestibility. These features make Calliandra a valuable fodder resource for boosting livestock nutrition and productivity.



Hedge lucerne – velimasal (*Desmanthus virgatus*)

Velimasal is a type of fodder crop that can be grown from stem cuttings. It is recommended to use a seed rate of 6 kg per hectare and space the plants 50 cm apart. The crop can reach a height of 2 to 3 meters and thrives in various growing conditions. It is a high-yielding fodder species producing 40 to 70 tonnes of green fodder per hectare. Because it produces a lot of biomass and no toxic substances are

detected, it is ideal for feeding dairy cattle and goats.



Mulberry (*Morus alba*)

Mulberry is a perennial shrub commonly grown for silkworm rearing and is also widely used as a fodder crop for livestock. It is usually propagated through stem cuttings. The leaves are highly nutritious, containing good amounts of protein, minerals, and essential amino acids. They are easily digested and readily accepted by animals because of their soft texture and palatability. Mulberry is a high-yielding fodder crop, producing about 35–45 tonnes of leaf fodder per hectare. Adult cattle can be supplemented with 2–3 kg of mulberry leaves per day. Because of its high leaf production, low tannin content, and excellent nutritive value, mulberry is considered a valuable feed resource for cattle, goats, and other ruminants.

Moringa

Fresh foliage of moringa (*Moringa oleifera*) can be included into the diet of different animals and it is able to produce and maintain high biomass yields over the years. Positive effects on feeding behaviour in goats (Manh et al., 2005), milk yield in dual purpose cows (Reyes-Sánchez et al., 2006) and growth rate in sheep (Salem and Makkar, 2009) have been reported.

Moringa is a fast-growing deciduous species, typically attaining a height of 9–15 m. It belongs to the family Moringaceae and is predominantly cultivated in tropical regions. Trees are drought-tolerant, capable of withstanding temperatures up to 48°C and thrive in areas receiving 250 - 1500 mm annual rainfall. The tree is multifunctional; it can be used for food, fodder, medicine, as a plant growth stimulant, in cosmetic formulations, for water treatment, and for biofuel generation. Nearly all parts of the tree are rich in essential nutrients, including proteins, carbohydrates, vitamins (A, B1, B2, B3, C, and E), and various minerals. Leaves and roots contain high concentrations of phytochemicals like total phenolics, tannins, and flavanols. Stem cuttings and seeds are used as planting material. It is one of the cheapest sources of protein. The moringa tree can be integrated as a component in hedgerow farming, intercropping and intensive farming.

When used as a fodder, it increases milk production by 43–65% and causes a reduction of up to 25%

in feed costs. It has excellent digestibility. Controls worm infestation in sheep. Used for low-cholesterol meat production. Harvesting can be done every 35-40 days.

Gliricidia

Native to Mexico and Central America, gliricidia is an arboreal leguminous species widely used as a livestock feed throughout the tropical and semi-arid regions. It is an excellent fodder source owing to its elevated dry matter yield and crude protein concentration. Planting materials used are stem cuttings and seeds. Thick stems should be chopped into smaller pieces and dried before feeding to livestock. The green leaf yield can be up to 15-17 tons per hectare per year.

Erythrina

Erythrina is a fast-growing, nitrogen-fixing leguminous tree widely distributed throughout the tropics. Typically attaining heights of 10-15 m, it grows best in tropical lowlands with annual rainfall ranging from 1000 to 1500 mm. Stem cuttings are used for propagation. Owing to its rapid growth and multifunctional nature, it is widely used in agroforestry as a windbreak, living fence, and trellis support, while also serving as a high-quality fodder source for livestock. Leaves of Erythrina contain approximately 16-18% crude protein. Depending on management, an average tree can be subjected to 3-4 pruning cycles per year and can produce 15-50 kg of green forage annually.

Conclusion

The livestock sector continues to face challenges of inadequate availability of quality fodder. Farmers are often forced to depend on low-quality feed supplements, leading to reduced productivity of livestock. This situation has intensified the search for a sustainable and nutritionally superior feed alternative. Tree fodder has gained attention as a valuable source of nutrients for livestock.

The declining availability of natural pastures has further increased the dependence on supplementary and manufactured feeds. In India, fodder trees play an important role in livestock nutrition by supplying cost-effective protein and essential micronutrients across various farming systems. Incorporating trees into agricultural landscapes supports fodder production while delivering ecological benefits like carbon sequestration, contributing to climate change mitigation.

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HYDROPONIC FODDER CULTIVATION

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Fodder cultivation plays a significant role in generating high returns for dairy farmers. However, producing high quality fodder at a low cost remains a major challenge. In Kerala, the availability of sufficient land for fodder cultivation is limited due to land fragmentation and the rapid expansion of residential and commercial buildings, which have reduced the area under agriculture. Hydroponic technology offers a promising solution to these challenges. Unlike conventional fodder cultivation, which requires 45-60 days for production, hydroponic fodder can be produced in a much shorter period while requiring minimal land.

ADVANTAGES OF HYDROPONICS FODDER

► Year-round availability of fodder can be ensured at a relatively low cost.

► Weather conditions do not pose a challenge, as hydroponic fodder is produced in a controlled environment.

► Under conventional cultivation, fodder generally requires 45-60 days to reach harvest. In contrast, hydroponically grown fodder can be harvested as early as the seventh day.

► Conventional fodder cultivation requires a substantial amount of water, with approximately 60-80 litres to produce one kilogram of green fodder, making it unsuitable for water scarce regions. In contrast, hydroponic fodder production requires only 2-3 litres of water per kilogram of fodder.

► Studies have shown that hydroponically grown fodder contains higher levels of fibre, protein and minerals. Therefore, hydroponic fodder production offers a practical solution to challenges such as limited agricultural land,

water scarcity and high labour costs.

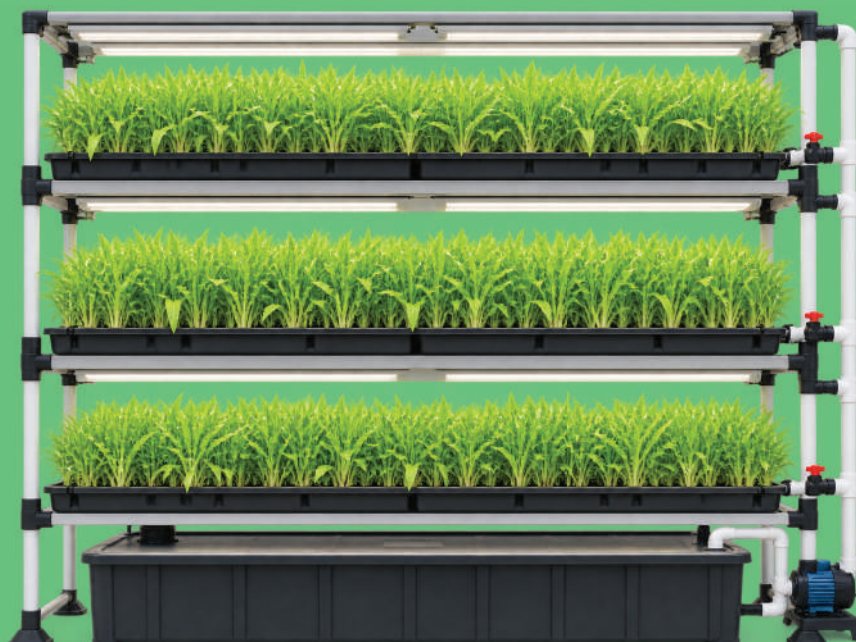
► Another advantage of hydroponic fodder production is its minimal incidence of pests and diseases.



Hydroponics machine



Hydroponics fodder



HYDROPONICS FODDER CULTIVATION METHOD

Many crops, including cereal grasses such as maize, barley, wheat, and millets, as well as legumes such as lentils, can be cultivated hydroponically for fodder production. The seeds are first soaked in water for 12 hours and then kept in a sack for an additional 24 hours to facilitate germination. The germinated seeds are subsequently spread evenly in trays. From the seventh day onwards, the dense green fodder is ready for harvest, with the plants attaining an average height of 20-25 cm. The entire fodder mat, comprising shoots, roots and germinated seeds can be removed from the trays and fed directly to livestock.

Hydroponic fodder production units are equipped with modern electronic automatic control systems. These units require only about 100 square feet of space and can be installed in open areas. A typical unit measures approximately 9 ft in length, 5 ft in width and 10 ft in height, with a production capacity of up to 120 kg

of green fodder per day. The main components include a chamber with shelves for holding the trays, a humidifier and a control panel. The chamber is fitted with a mist irrigation system and mechanisms for regulating humidity, temperature and light to maintain optimal growing conditions.

Despite their numerous advantages, the high initial investment and operating costs have limited the adoption of hydroponic fodder units by small and marginal farmers. To address this constraint, low-cost hydroponic fodder units are now available in the market, with prices generally ranging from ₹15,000 to ₹50,000.

HYDROPONICALLY GROWN MAIZE FODDER

Maize is the most widely cultivated crop for hydroponic fodder production worldwide. Approximately 200 g of seed is required per square foot of growing area. The fodder can be harvested on the eleventh day after sowing. One kilogram of maize seed produces approximately 6 kg of green fodder.

The harvested hydroponic fodder contains about 15% crude protein.

HYDROPONICALLY GROWN CHICKPEA FODDER

To produce nutrient rich fodder, chickpea or lentil seeds can be cultivated hydroponically. Approximately 200 g of seed is required per square foot of growing area. A major advantage of this system is that the fodder can be harvested as early as the seventh day after sowing. One kilogram of seed yields approximately 10 kg of green fodder. The harvested fodder contains about 20% crude protein. Fertilizer application is generally not required in hydroponic fodder production. However, in certain varieties, higher yields have been observed when a 0.5% solution of 19:19:19 NPK fertilizer is applied as a foliar spray. Soilless farming is practiced in many parts of the world to achieve high-quality forage production. Research findings indicate that this technology, which offers significant potential for dairy farmers, can also be successfully adopted in Kerala.

SILAGE AND HAY: EFFECTIVE METHODS FOR LEAN SEASON FEEDING

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INTRODUCTION

Livestock is an integral component of agriculture and plays a vital role in ensuring food security, generating employment, and improving the livelihoods of farming communities. The livestock sector contributes 30.87 per cent of the Gross Value Added (GVA) of agriculture and allied sectors and about 5.5 per cent of India's total economy at current prices during 2023-24 (DAHD, 2025). Kerala has been facing a continuous decline in its bovine population despite the predominance of high-yielding dairy animals. According to the 2019 Livestock Census, the state had a livestock population of 2908.66 thousands showing an increase of 6.34 per cent over

Livestock Census- 2012. Sustainable livestock production is heavily dependent on the regular supply of good-quality and nutritious fodder throughout the year. One of the major constraints affecting dairy production is the shortage of quality fodder. The feed resources available from existing agricultural practices satisfy only about 40 per cent of the requirement for green and dry fodder. Moreover, extensive crossbreeding has increased the average body weight of dairy animals to 325-350 kg, compared to the earlier average of around 150 kg, thereby substantially increasing their feed and fodder requirements (NDDDB, 2016).

However, fodder availability is not uniform across seasons. Therefore, effective techniques are needed to preserve surplus fodder produced during periods of abundance for use during fodder-scarce or lean periods. Under these circumstances, the production and utilization of silage and hay become highly important, as they provide a reliable supply of nutritious, good-quality conserved fodder throughout the year, particularly during periods of green fodder scarcity. This helps improve feeding efficiency, sustain milk production, and support the productivity of Kerala's dairy sector. Under these circumstances, the production and utilization

of silage and hay become highly important, as they provide a reliable supply of nutritious, good-quality conserved fodder throughout the year, particularly during periods of green fodder scarcity. This helps improve feeding efficiency, sustain milk production, and support the productivity of Kerala's dairy sector. Silage is produced by preserving succulent green fodder under anaerobic conditions and hay is produced by reducing the moisture content of green forage through drying.

SILAGE

Excess green fodder is preserved in pits for about three months without losing its nutritional quality. It can then be used as livestock feed during periods of green fodder scarcity. This preserved product is called **silage**. The fermentation and storage process is called *ensilage, ensiling, or silaging*. Silage is stored in different types of silos with various shapes and sizes. These include *pit silos, tower silos, trench silos, bunker silos*, etc.

A pit silo is more suitable for small-scale dairy farmers. It has a simple construction. A well-drained elevated site with firm soil, free from water stagnation during the rainy season and groundwater seepage, should be chosen for silo construction. The length, width, and depth of the pit are determined by the quantity of fodder used for silage making.

A silo pit designed for 5 tonnes of silage has a length of 3 m, a width of 1.5 m, and a depth of 2.5 m. The four sides and bottom of the pit are constructed with bricks and plastered with cement. A slope at the bottom of the pit and a drainage channel are provided to remove excess water from the fodder.

Not all green fodders are suitable for silage making. Leguminous fodders, fodders with low fibre content, and young fodders with high moisture content are generally not preferred for silage production. They are not preferred because they decay easily and contain low amounts of dry matter. Hybrid Napier grass, Guinea grass, maize, and similar fodder crops are suitable for silage making. The fodder grasses intended for silage making are harvested and wilted under the sun for about 2 hours to reduce the moisture content to approximately 60 per cent. They are then chopped into small pieces of about 1-1.5 inches in length and filled into the silo pit. Molasses or palm jaggery solution, at about 5 per cent of the dry matter, is added to improve the nutritional quality and palatability of the silage and to enhance its preservation. This solution is sprayed over each layer of fodder. A smaller quantity is applied to the lower layers of the pit, and the amount is gradually increased towards the upper layers. After the silo pit is filled, it is covered with a polythene sheet to prevent the entry of air and then sealed with a layer

of soil. While filling the silo pit, the fodder should be filled up to about 1.5 feet above the ground level. After filling, the sealed soil layer should be inspected regularly for cracks. If any cracks are observed, they should be repaired immediately by applying additional soil to maintain airtight conditions.

Silage is ready for use after three months of fermentation. It can be stored for up to one year without deterioration. When opening the silo pit, only one side should be opened. After removing the required quantity of silage, the pit should be covered again with a polythene sheet to prevent the dry out or deterioration of silage due to exposure to air. Good quality silage has a greenish-yellow to golden-brown colour and a mild fruity smell which is free from mold or slim. The silage should be highly palatable, soft textured and readily consumed by cattle.

BAG SILAGE

Fodder varieties commonly grown in Kerala, such as Hybrid Napier and Guinea grass, can be used for bag silage making. The first harvest is usually taken 75 days after planting, and subsequent harvests are carried out at intervals of 45-60 days. The fodder obtained from these harvests can be used for silage preparation. After harvesting, the fodder is chopped into small pieces of 2-3 cm length. To reduce the moisture content, it is wilted under the sun for

2-3 hours. A moisture content of 60-70 per cent is considered suitable for silage making.

Jaggery and urea are added to improve the nutritional quality and shelf life of silage. They are added at approximately 1-2 per cent of the weight of the green fodder. The chopped fodder is then filled into bags. The fodder is pressed after filling each layer, which helps to remove the air trapped between the layers of grass.

If the moisture content of the fodder is high, a layer of straw can be added to the top layer of the bag after filling. The bag should be filled in such a way that no air enters it, this is an important point that should be considered while making bag silage. After filling, the bag should be tied tightly and kept in a shaded place. The bag can be opened after 45-60 days. If stored properly under airtight conditions, the silage can be preserved for 1-2 years without deterioration.



Silage

CROPS SUITABLE FOR SILAGE

Crops with high water soluble carbohydrates, low to medium in protein content, low buffering capacity and adequate dry matter content are ideal for producing good quality silage. Maize, sorghum, oats, pearl millet, and hybrid napier are commonly used for ensiling. Among these, fodder maize is the most popular crop for silage making due to its high carbohydrate content and dry matter production.

NUTRIENT CONTENT OF SILAGE

Silage is considered almost as nutritious as fresh green fodder because most nutrients are preserved in their original form during the ensiling process. The fermentation process softens hard stems and reduces anti-nutritional factors, thereby improving palatability and digestibility. Maize is considered an ideal crop for silage making because it contains abundant fermentable sugars and

has a low buffering capacity. These characteristics promote rapid acid production, lowering the pH to about 3.5 and ensuring effective preservation of the fodder. Kumar et al. (2019) standardized the desirable nutrient composition for a good quality maize silage as follows.

- ▶ pH: 3.5 to 4.2
- ▶ Ammonical nitrogen of total N: less than 10%
- ▶ Lactic acid: Above 3 %
- ▶ Acetic acid : up to 5 %
- ▶ Butyric acid: less than 0. 2%
- ▶ Dry matter: 30-40%
- ▶ Crude protein: 7-9%

DISADVANTAGES

- ▶ High establishment and storage cost
- ▶ Requires airtight conditions to prevent spoilage
- ▶ Improper fermentation reduces feed quality
- ▶ Silage effluent may cause environmental pollution
- ▶ Heavy and expensive to transport
- ▶ Requires skilled management



Table 1: Comparative Nutritional characteristics of fresh maize fodder and silage (mean values)

CHARACTERISTIC	FRESH FODDER(MEAN)	SILAGE(MEAN)
Dry matter (DM,%)	32.63	31.94
Crude protein (CP,%)	9.39	9.40
Ash (%)	5.53	5.57
Acid Detergent Fiber (ADF,%)	32.88	32.58
Neutral Detergent Fiber (NDF,%)	61.91	61.81
Acid Detergent Lignin (ADL,%)	3.83	3.94
Ether Extract (EE,%)	2.24	2.17
Cellulose (%)	29.05	28.64
Hemicellulose (%)	29.03	29.24
Total Dietary Fiber (TDF,%)	64.83	65.04
Organic Matter Digestibility (OMD, %)	61.07	67.90
In vitro NDF Digestibility (IVNDFD, %)	45.10	50.12
In Vitro Dry Matter Digestibility (IVDMD,%)	61.69	68.24
Metabolizable Energy (ME, %)	7.25	7.60
Short-chain Fatty Acids (SCFA,%)	0.72	0.72

(Sharma et al., 2025)

HAY

Hay making is another important fodder preservation method used to preserve surplus forage for feeding livestock during periods of fodder scarcity. It is obtained by drying green forage to a safe moisture level for storage, usually containing less than 15-20 per cent moisture. Depending on the source of forage, hay can be classified as legume hay, non-legume hay or mixed hay.

During hay making, green forage is harvested and dried as quickly as possible to minimize nutrient losses and maintain quality. Drying can be carried out naturally by exposing the forage to sunlight on the ground and turning it regularly to facilitate aeration, or artificially by the active

circulation of air. Sun drying usually takes 2-3 days under rain-free conditions. Proper storage facilities, such as a covered and well-ventilated area, should be provided for storing hay. If the grass has matured and dried naturally in the field before harvesting, the harvested material is called straw rather than hay. Hay produced from grazing lands often has a nutritive value similar to that of straw because it is harvested when the plants have reached maturity. Such hay generally meets only the basic maintenance requirements of livestock and, in rare cases, supports only marginal production of milk and meat (FAO, 2002). It enables long-term storage of forage with minimal nutrient loss when properly prepared and stored. Hay helps ensure a continuous

supply of feed during periods of fodder scarcity, reducing seasonal fluctuations in feed availability. It can be prepared from a wide range of forage crops using simple techniques and equipment, making it suitable for both small-scale and commercial livestock farmers. In addition, hay is easy to transport, handle and feed, thereby contributing to improved livestock management and productivity.

NUTRITIVE CONTENT OF HAY

1.LEGUMINOUS HAY

Good-quality legume hay is highly valued in dairy cattle nutrition because of its superior nutritive properties. It contains a greater proportion of digestible nutrients and is especially rich in high-quality

digestible proteins compared to many other forage sources. Properly cured legume hay is also an excellent source of vitamins, particularly carotene, vitamin D and vitamin E. In addition, it is rich in calcium and is generally highly palatable to livestock. Among the various leguminous fodder crops used for hay production, lucerne, berseem, cowpea and soybean are considered the most important and preferred choices.

2. NON-LEGUMINOUS HAY

Compared with legume hays, non-legume or grass hays are less palatable and contain lower amounts of protein, minerals and vitamins. However, they are easier to cultivate and produce higher yields. Oat and barley hays harvested at the milk stage are considered good-quality grass hays and are particularly rich in carbohydrates.

3. MIXED HAY

Mixed hay is obtained from a combination of leguminous and non-leguminous fodder crops. Its nutritional composition depends on the proportion of the component species, and early harvesting of the mixture helps improve protein content, especially in the cereal component (NDDB, 2012)

DISADVANTAGES

- ▶ Highly dependent on favourable weather for drying
- ▶ Leaf shattering reduces nutritive value, especially in legumes
- ▶ Susceptible to mold if stored with high moisture
- ▶ Dusty hay can affect animal health
- ▶ Higher field losses during drying and handling
- ▶ Lower palatability if over-dried or weather damaged

CONCLUSION

Silage and hay are two important methods of fodder preservation which helps to ensure a continuous supply of feed for livestock during the periods of fodder scarcity. Silage is produced through anaerobic fermentation of green fodder and through this method the nutritional value, palatability, and moisture content is also retained. Hay is produced by drying of the forage to safe moisture level, which helps for long term storage. Methods such as pit silage and bag silage are cost effective options for farmers. These conservation methods will help to improve the livestock productivity, support sustainable dairy farming and reduce the seasonal fluctuations in fodder availability.

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MUGA SILK: GOLDEN THREADS, RURAL LIVELIHOODS AND WOMEN'S WORK

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Assam's Muga silk is instantly recognizable by its natural golden sheen. But its value lies far beyond appearance - it represents biodiversity, traditional knowledge, skilled craftsmanship and rural livelihoods, sustained for generations by families who rear the silkworm, reel the cocoons, spin yarn and weave garments.

Women are at the heart of this work. Yet those who contribute their labour do not always receive returns proportionate to the value they create. Recent evidence from Assam shows that improved equipment and appropriate training can substantially raise productivity and earnings - but the factors driving income differ between reelers, spinners and weavers. The lesson: technology, skills and market access must be

matched up to the specific activity and the people performing it.

THE GOLDEN SILK

Muga silk comes from the semi-domesticated silkworm *Antheraea assamensis* Helfer, endemic to Assam and reared outdoors on Som (*Persea bombycina*) and Soalu (*Litsea monopetala*) (Das, 2021). Around 3 lakh families across 8,722 villages in Assam are engaged in sericulture, including roughly 32,000 Muga rearers, 5,000 reelers and 10,000 weavers. Women make up about 65 per cent of this workforce (Government of Assam, 2026). Production, however, has slipped from 240.46 ton in 2020-21 to 181.32 ton in 2024-25, making livelihood security an urgent concern.

WOMEN AND THE VALUE CHAIN

Muga silk comes from the semi-domesticated silkworm *Antheraea assamensis* Helfer, endemic to Assam and reared outdoors on Som (*Persea bombycina*) and Soalu (*Litsea monopetala*) (Das, 2021). Around 3 lakh families across 8,722 villages in Assam are engaged in sericulture, including roughly 32,000 Muga rearers, 5,000 reelers and 10,000 weavers.

Women make up about 65 per cent of this workforce (Government of Assam, 2026). Production, however, has slipped from 240.46 ton in 2020-21 to 181.32 ton in 2024-25, making livelihood security an urgent concern.

WHEN TECHNOLOGY AND TRAINING CHANGE THE RETURN

Traditional Bhir reeling needs two workers and yields 50-100 g a day. An improved machine developed by the Central Silk Technological Research Institute can be run by a single trained worker and yields up to 150 g a day, with substantially higher earnings for those using it (Devi & Basumatary, 2022).



Muga sericulture farmer her spring rearing (Source: Jagrity Phukan, The Better India 2025)



Muga reeling and Eri silk spinning at a community cluster. (Source: Ron Bezbaruah, The Better India)

Muga sericulture farmer her spring rearing (Source: Jagrity Phukan, The Better India 2025)

Muga reeling and Eri silk spinning at a community cluster. (Source: Ron Bezbaruah, The Better India)

But the machine only helps if the worker is trained to use it. The same study found trained reelers earned about Rs. 265.51 more per day than untrained ones, and trained spinners using the CSTR wheel earned roughly Rs. 217.68 per day against an average of Rs. 41.06. Interestingly, training did not significantly affect weavers' income; design skill did. The lesson is not that everyone needs more training, but that training must match the occupation: reelers and spinners benefit from machine skills, while weavers gain more from design and market access.

Gender gaps persist too: male reelers earned about Rs. 32.83 more per day than female reelers, and male weavers about Rs. 10.10 more, after accounting for other factors (Devi & Basumatary, 2022). This doesn't prove unequal piece rates, but it does suggest that when women already do most of the work, improving their access to equipment, training and markets is what will raise their earnings, not simply their participation, which is already high.

A KERALA PARALLEL

Kerala has no Muga tradition, but it has its own women-dominated

processing economies facing near-identical dynamics. In coir processing, spinning and weaving remain largely women's work, often paid by piece-rate, with earnings tightly linked to access to motorized ratts and spinning units rather than to effort alone. In cashew processing, women shelling and grading cashew form the backbone of a sector where mechanization and training have repeatedly been shown to change take-home pay far more than experience does. And in Kerala's traditional handloom clusters, Balaramapuram, Chendamangalam, weavers navigate the same tension the Muga study found technical training helps spinners and pre-loom workers, while weavers' incomes hinge more on design innovation and market linkages than on training alone.

The pattern is the same one Assam's Muga economy reveals: women already anchor these value chains. What determines whether that translates into income is whether they can access the right equipment and the right kind of training for their specific task, not training in general, and not participation alone.

CONCLUSION

Muga silk's golden colour draws attention, but its deeper significance lies in the rural families - rearers, reelers, spinners, weavers - whose knowledge and labour create it. The evidence from Assam, and the parallel in Kerala's own coir, cashew

and handloom sectors, points to the same conclusion: preserving a traditional livelihood does not mean resisting change. The strongest traditions are the ones that adapt - matching technology, training and market access to the people who carry the work forward.

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Wild mung bean (*Vigna stipulacea* (Lam.) Kuntze) - A Potential New Pulse Crop for Sustainable Diversification

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INTRODUCTION

Legumes are an important component of sustainable agriculture and human nutrition due to their high protein content, essential minerals and ability to improve soil fertility through biological nitrogen fixation. Increasing the production and utilization of protein-rich pulse crops is essential to ensure nutritional security for the growing global population. Among the semi-domesticated wild legumes

identified in India, Minni payaru (*Vigna stipulacea* (Lam.) Kuntze) can be emerged as a valuable genetic resource with considerable potential for crop improvement and nutritional security. It belongs to the family Fabaceae and is known by several regional names, including Siru Payaru, Nari Payaru, Pillipesara, Chinnamesara, and Kattu Payaru, reflecting its regional importance and its small seed and pod size. It is primarily distributed across South- Asia, including peninsular

India (Akram et al., 2020), Indonesia (extending to Irian Jaya), Vietnam, Myanmar, Bangladesh, Sri Lanka, Yemen and Madagascar (Devanand et al., 2023). The crop is well adapted to diverse agro-climatic conditions ranging from arid to humid environments. Owing to its adaptability and agronomic potential, *V. stipulacea* was recognized as one of the most recent additions to the cultivated crop species of India through nationwide plant exploration conducted by

the ICAR-National Bureau of Plant Genetic Resources, New Delhi.

PLANT CHARACTERISTICS

V. stipulacea is an annual, short-duration legume that naturally occurs in open or lightly shaded habitats and in heavy clay paddy fields (Gore et al., 2021b), completing its life cycle within two to three months. The crop can be readily distinguished by several diagnostic morphological characteristics, including intermediate germination, angular stems, large stipules, canopy-elevated racemes, compact inflorescences, a purple keel pocket, long pods and rough-surfaced seeds with a slightly protruding oblong hilum (Plate 1.) (Gore et al., 2019). The crop is predominantly cultivated during the kharif season, is generally sown through broadcasting. It exhibits erect, semi-erect or spreading growth habits, developing as a trailing and twining herb with plant heights ranging from 4 to 28 cm and branch lengths of 45 to 152 cm. During the early seedling stage, the leaves are petiolate. Flowering commences between one to two months, with each inflorescence producing 4 to 12 bright yellow flowers. The fruits are linear, cylindrical pods measuring 4 to 5 cm in length, which turn blackish-brown upon maturity. The seeds are small, oblong and black in colour.

NUTRITIONAL COMPOSITION

Minni payaru is reported to contain moisture (15.04–17.01%), starch

(20.5%), sugars (8%), protein (20.23–24.88 g 100 g⁻¹), carbohydrates (30.62–56.60 mg 100 g⁻¹) and free amino acids (35.14–58.11 mg 100 g⁻¹) in dry seeds. The dry seeds are also rich in essential minerals, holding iron (Fe: 29.35–130.96 mg kg⁻¹), zinc (Zn: 19.44–74.20 mg kg⁻¹) and calcium (Ca: 251.50 mg kg⁻¹). Phytochemical analysis revealed high phenol (59.72 mg GAE g⁻¹), flavonoid (77.85 mg RE g⁻¹), and alkaloid (20.61 mg CoE g⁻¹) contents in different accessions. Antioxidant assays showed strong radical scavenging activity (63.27% RSA) and phosphomolybdenum antioxidant capacity. Studies have reported the presence of phytate in certain genotypes of Minni Payaru (65.13 mg AAE 100 g⁻¹) (Gore et al., 2021a; Gore et al., 2025; Gayacharan et al., 2026).

GENETIC RESOURCES

In India, *V. stipulacea* is widely distributed across several states, including Andhra Pradesh, Chhattisgarh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Odisha, and Tamil Nadu (Gore et al., 2021b). The species is extensively cultivated in Andhra Pradesh, particularly in the West Godavari district of the Eastern Ghats, where it has been traditionally grown for several generations (Fig 1.) (Tripathi et al., 2024). The Indian National Genebank (NGB) at ICAR-NBPGR, New Delhi, maintains 99 accessions collected from diverse agro-climatic regions of the country. At present, the ICAR-NBPGR, Regional Station, Thrissur, conserves 64 accessions

of Minni Payaru for future research, conservation, and crop improvement.

USES

Dry seeds of Minni Payaru are consumed either as whole grains or as split dhal and commonly used in the preparation of traditional dishes such as sambar and chutney. In rural parts of Andhra Pradesh, the crop is also utilized for preparing popular snacks, including vada and garelu. The seed flour is suitable for preparing dosa and idli without fermentation and can also be incorporated into bread formulations, highlighting its potential for the development of value-added food products.

In addition to its food uses, Minni Payaru serves as a valuable fodder crop due to its high forage quality. Erect and semi-erect genotypes are particularly suitable for fodder production and farmers have reported that feeding this crop to dairy cattle increased milk production by approximately 1.0 to 1.5 litres per day (Norihiko et al., 2011). It is also widely used as an in situ green manure and cover crop, contributing to improved soil fertility and soil health through the addition of organic biomass. Minni Payaru is commonly grown as a green manure crop before paddy cultivation to enhance soil productivity.

CULTIVATION PRACTICES

In Tamil Nadu, sowing is generally carried out during August, with flowering occurring from September

to October. For seed production, a seed rate of 10 kg ha⁻¹ is recommended, whereas 12-15 kg ha⁻¹ is sufficient when the crop is cultivated for green manuring. Seeds are sown in rows at a spacing of 30 cm × 10 cm and lightly covered with soil, while broadcasting is commonly adopted for green manure cultivation. A basal application of 10 t ha⁻¹ of farmyard manure, along with 30:60:40 kg ha⁻¹ of nitrogen, phosphorus and potassium is recommended to ensure optimum crop growth. To protect against soil-borne fungal diseases, seeds should be treated with Thiram or Captan at 3 g kg⁻¹ of seed before sowing. Although crop exhibits good resistance to most pests and diseases, insect infestations may occasionally occur in some locations. Under such circumstances, the plant protection practices recommended for pulse crops in the Package of Practices of Kerala Agricultural University can be adopted. Timely harvesting is essential, as the pods of wild forms are prone to shattering at maturity, resulting in seed loss. In contrast, the semi-domesticated form possesses reduced pod shattering and slightly larger seeds, facilitating easier harvesting by cutting the stems (Norihiko et al., 2011). After seed collection, the remaining crop residue can be incorporated into the soil. When cultivated exclusively as a green manure crop, the biomass is generally incorporated into the soil at approximately 60 days after sowing. Under good crop management, Minni Payaru produce

about 450-500 kg ha⁻¹ of seed and 5-6 t ha⁻¹ of green biomass.

CONCLUSION

V. stipulacea possesses several desirable attributes, including high nutritional value, resistance to major pests and diseases, tolerance to abiotic stresses, rapid growth, and a short life cycle, making it a promising crop for sustainable agriculture. At present, its cultivation is confined to only a few regions. Expanding its cultivation, developing efficient marketing networks and promoting value-added products could enhance income of farmers while contributing to food and nutritional security. Considering its adaptability and multiple uses, this crop has great potential for wider cultivation in Kerala.

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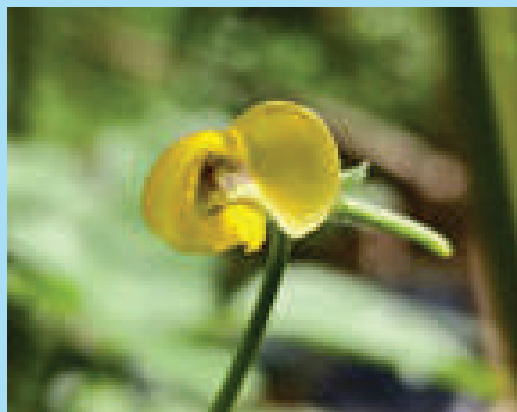
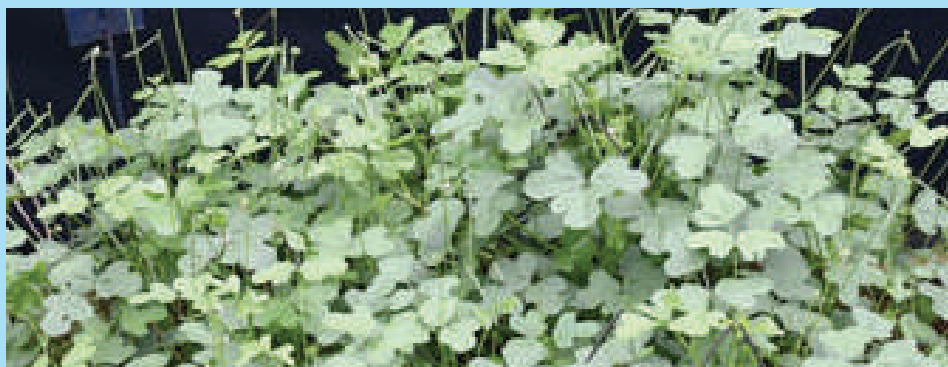


Plate 1. Morphology of Minni payaru (*Vigna stipulacea* (Lam.) Kuntze): (a) Plant; (b) Leaf; (c) Flower; (d) Stipule; (e) Pod; (f) Seed

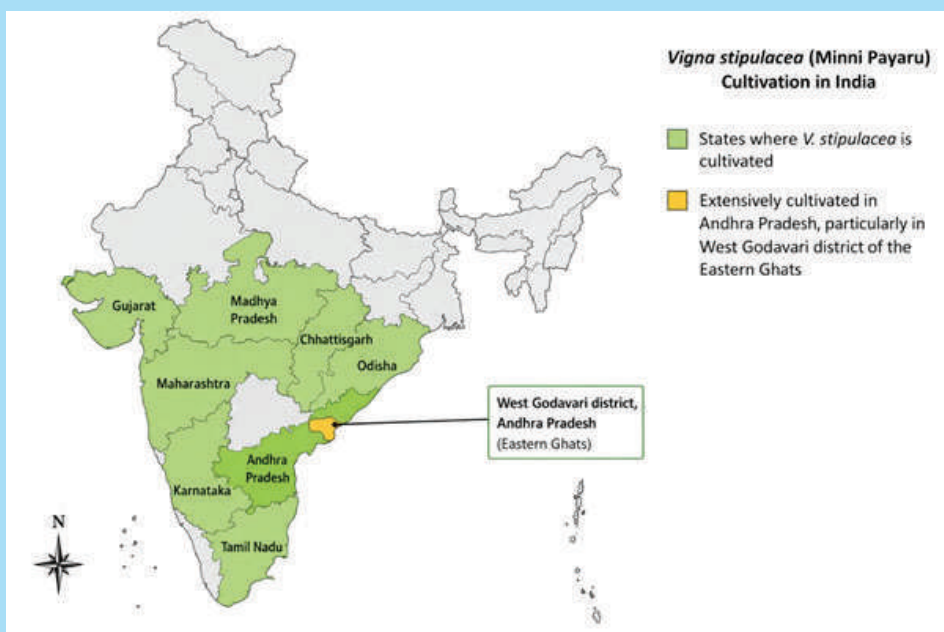


Fig 1. Distribution and cultivation of Minni payaru (*Vigna stipulacea* (Lam.) Kuntze) in India



Beyond the Weed: Exploring the Nutritional Potential of Weedy Rice

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Rice is one of the most important food crops of the world, but its production faces a persistent challenge from one of its closest relatives-weedy rice. Often referred to as red rice because of its frequently red-coloured pericarp, weedy rice competes strongly with cultivated rice and can cause considerable yield and quality losses. Its ability to produce numerous tillers, mature early, shatter seeds easily and persist in the soil makes it a difficult weed to manage. Recent outbreaks of weedy rice in Kerala's wet land paddy fields have caused

yield losses of 30-60%, depending on infestation severity, leading many farmers to abandon rice cultivation. Yet, hidden within this troublesome weed is an interesting nutritional story.

A COLOURFUL DIFFERENCE

A peculiar feature that can be found in many weedy rice varieties is the colour of pericarp of its grains. The colour may vary from red to dark red and is caused by the presence of anthocyanin and proanthocyanidin pigments. The latter are valuable

for the antioxidant properties of the pigment-containing rice. The red/dark red accessions of weedy rice contained cyanidin-3-glucoside or peonidin-3-glucoside with varied anthocyanin concentration.

MORE THAN CARBOHYDRATES

Like cultivated rice, weedy rice provides carbohydrates as a major component of the grain. What makes some weedy rice types particularly interesting, however, is the diversity of other nutritional constituents.

Weedy rice contains several beneficial trace elements, including minerals such as iron, calcium, magnesium, manganese and zinc, with some elements occurring at two to three times the levels observed in the cultivated-rice controls. The total concentrations of free amino acids in the weedy rice samples are also higher. Regarding the fatty acid composition, weedy rice are rich in greater quantities of unsaturated fatty acids. These suggest that the nutritional characteristics of weedy rice deserve greater attention, particularly from a crop-improvement perspective.



NUTRITIONAL TREASURE HIDDEN IN THE PERICARP

The grain pericarp is particularly important in understanding the nutritional potential of coloured rice. During domestication, many cultivated rice varieties were selected for traits such as white pericarp and improved eating quality. Weedy rice, in contrast, has retained considerable diversity in grain colour and related biochemical characteristics.

The red pigmentation is not merely a visual characteristic. Pigmented rice grains can contain phenolic compounds and other antioxidant-related substances. Research on traditional red-grained rice has also demonstrated substantially greater antioxidant capacity and phenolic

content in some red rice varieties compared with light-coloured varieties.

This makes the nutritional traits of weedy rice particularly interesting for plant breeders. Instead of viewing weedy rice only as a source of yield loss, researchers can explore its genetic diversity for traits that could potentially contribute to nutritionally improved rice varieties.



FROM FIELD MENACE TO GENETIC RESOURCE

A recent review has highlighted the emerging interest in weedy rice as a potential source of useful traits for crop improvement and functional-food research, particularly because of its nutritional and antioxidant characteristics.

This does not mean that weedy rice should simply be collected from fields and consumed. On the contrary, its aggressive weed characteristics make it a serious threat to cultivated rice. Any attempt to utilize weedy rice directly as a food resource would require appropriate identification, processing, food-safety evaluation and quality assessment. Its greater promise lies in its genes rather than the weed itself. Nutritional traits such as pigmentation, mineral accumulation, amino-acid composition and antioxidant-related compounds

could potentially be explored through breeding and biotechnology to develop rice with improved nutritional quality.

A WEED WORTH STUDYING

Weedy rice reminds us that agricultural biodiversity can contain unexpected possibilities. A plant that is undesirable in a rice field may nevertheless possess genetic and nutritional characteristics of value to crop improvement.

The challenge, therefore, is not to promote weedy rice as a crop, but to understand its diversity and identify useful traits hidden within it. With increasing interest in nutritious and functional foods, weedy rice may offer valuable genetic clues for developing the rice varieties of tomorrow.

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Nutrition & Health

Nutrition and Health

Importance of Fruit Crops

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ABSTRACT

Fruit crops are metabolically specialized plant organs that concentrate essential nutrients and bioactive phytochemicals within an intact cellular matrix. Rich in soluble sugars, dietary fiber, vitamins, minerals, carotenoids, and polyphenols, fruits function as biologically integrated dietary systems rather than mere energy sources. Their components modulate redox balance, inflammatory signaling (NF-KB), insulin sensitivity, endothelial function, and gut microbiota dynamics through coordinated molecular pathways. Epidemiological and clinical evidence consistently links regular fruit consumption with reduced risk of cardiovascular disease, metabolic syndrome, type 2 diabetes, and certain cancers. Thus, diversified

fruit intake represents a sustainable, evidence-based strategy for enhancing metabolic resilience, immune competence, and long-term public health.

Key words : Phytochemicals, Antioxidant Activity, Metabolic Regulation, Immune Support

Fruit crops represent one of the most metabolically dynamic and nutritionally concentrated components of the human diet. As highly specialized reproductive organs of angiosperms, fruits are physiologically programmed to synthesize and store a broad spectrum of primary metabolites—such as soluble sugars, organic acids, amino acids, vitamins, and minerals—alongside secondary metabolites including polyphenols, flavonoids, carotenoids, anthocyanins, and

other bioactive compounds. This integrated biochemical reservoir elevates fruits beyond mere caloric sources, positioning them as functional dietary matrices capable of influencing molecular signaling pathways, gene expression, and cellular homeostasis.

The health-promoting efficacy of fruits is fundamentally linked to their intact cellular architecture, wherein micronutrients and phytochemicals are embedded within complex fiber networks and vacuolar compartments. This structural organization modulates gastrointestinal transit, enzymatic accessibility, nutrient bioavailability, and postprandial glycemic dynamics. The synergistic interaction between antioxidants, dietary fiber, and

micronutrients enhances redox regulation, attenuates chronic low-grade inflammation, stabilizes endothelial function, and strengthens immunological defenses. Such mechanisms contribute to improved metabolic flexibility and systemic resilience against oxidative and inflammatory stressors.

Robust epidemiological investigations and clinical trials consistently demonstrate an inverse correlation between regular fruit consumption and the prevalence of non-communicable diseases. Recognizing this, global health authorities such as the World Health Organization emphasize diversified fruit intake as a central pillar of preventive nutrition strategies aimed at reducing cardiovascular disorders, type 2 diabetes mellitus, obesity, and certain cancers. In the context of contemporary dietary transitions characterized by increased consumption of ultra-processed foods, fruit crops assume critical importance at the intersection of agriculture, nutritional biochemistry, and public health, serving as natural modulators of metabolic integrity and long-term physiological sustainability.

COMPREHENSIVE NUTRITIONAL COMPOSITION

Fruits are distinguished by a high moisture content, typically ranging from 70–95%, which enhances hydration status and facilitates metabolic transport processes within the human body. They contain moderate concentrations of readily digestible carbohydrates—primarily fructose, glucose, and sucrose—while remaining naturally low in lipids and energy density. Importantly, the glycemic impact of intrinsic

sugars is physiologically moderated by the presence of dietary fiber and the intact plant cellular matrix, which slows gastric emptying and carbohydrate absorption, thereby preventing abrupt postprandial glucose fluctuations.

Dietary fiber in fruits exists in both soluble and insoluble forms, each exerting distinct physiological functions. Soluble fibers such as pectin, abundantly present in fruits like Apple and Pear, form viscous gels within the intestinal lumen, binding bile acids and reducing serum low-density lipoprotein (LDL) cholesterol concentrations. This mechanism also enhances glycemic control by modulating glucose diffusion and insulin response. In contrast, insoluble fibers contribute to increased fecal bulk, improved intestinal motility, and the prevention of constipation, thereby promoting gastrointestinal health and microbial balance (Masibo, M., and He, Q., 2008).

Beyond macronutrient contributions, fruits serve as critical sources of micronutrients including vitamin C (ascorbic acid), provitamin A carotenoids, folate, potassium, and magnesium. Vitamin C functions as a potent water-soluble antioxidant and cofactor in collagen biosynthesis, supporting connective tissue integrity and immune defense. Carotenoids contribute to epithelial maintenance and visual health, while folate plays an essential role in DNA synthesis, methylation reactions, and cellular replication. Potassium and magnesium are integral to electrolyte equilibrium, neuromuscular transmission, and enzymatic activation, collectively sustaining metabolic homeostasis

and cardiovascular stability. Through this multidimensional nutritional profile, fruits exemplify biologically optimized foods that integrate hydration, energy regulation, and micronutrient density within a single natural matrix.

PHYTOCHEMICALS AND MOLECULAR MECHANISMS

Fruits are abundant sources of structurally diverse phytochemicals, including polyphenols, flavonoids, anthocyanins, carotenoids, and tannins, which function as potent modulators of cellular redox and inflammatory pathways. These bioactive compounds are synthesized via secondary metabolic routes such as the phenylpropanoid pathway and accumulate in fruit peel and pulp as protective agents against environmental stress. Upon consumption, they exert antioxidant, anti-inflammatory, anti-atherogenic, and neuroprotective effects through well-characterized molecular mechanisms.

Polyphenol-rich fruits such as Strawberry and Blueberry are particularly notable for their high anthocyanin and flavonoid content. These compounds directly neutralize reactive oxygen species (ROS) by donating electrons and stabilizing free radicals, thereby limiting lipid peroxidation and oxidative DNA damage. Beyond direct scavenging, polyphenols activate endogenous antioxidant defense systems through the nuclear factor erythroid 2-related factor 2 (Nrf2) signaling pathway. Activation of Nrf2 promotes transcription of cytoprotective genes encoding enzymes such as superoxide dismutase (SOD), catalase, and glutathione peroxidase, strengthening intracellular

antioxidant capacity and preserving mitochondrial integrity.

In addition to redox modulation, fruit-derived phytochemicals regulate inflammatory signaling cascades. Chronic low-grade inflammation, a central feature of metabolic syndrome and cardiovascular disease, is attenuated through the inhibition of nuclear factor kappa B (NF- κ B) activation and the downregulation of pro-inflammatory cytokines such as tumor necrosis factor- α (TNF- α) and interleukin-6 (IL-6). By suppressing these mediators, phytochemicals reduce endothelial dysfunction, inhibit foam cell formation, and limit atherosclerotic plaque progression. Collectively, these molecular interactions position fruit phytochemicals as critical dietary regulators of oxidative balance and inflammatory homeostasis, thereby contributing significantly to the prevention of metabolic syndrome, atherosclerosis, and neurodegenerative disorders.

HEALTH IMPORTANCE OF SPECIFIC FRUIT GROUPS

Distinct fruit groups demonstrate characteristic biochemical compositions that correspond to measurable physiological benefits. Citrus fruits such as Orange and Lemon are particularly notable for their high ascorbic acid concentration. Fresh orange provides approximately 45–60 mg vitamin C per 100 g fresh weight, while lemon contains about 40–53 mg/100 g. This concentration fulfills nearly 50–80% of the recommended daily intake in a single serving. Vitamin C enhances neutrophil activity, supports collagen biosynthesis, and increases non-heme iron absorption by reducing ferric (Fe³⁺) to ferrous (Fe²⁺) iron, thereby improving iron bioavailability

by up to 2–3 fold.

Tropical fruits such as Mango and Papaya are rich in provitamin A carotenoids. Ripe mango contains approximately 540–1,100 μ g β -carotene per 100 g, contributing significantly to the recommended dietary allowance of vitamin A. Papaya supplies around 950 μ g β -carotene per 100 g along with 60–70 mg vitamin C per 100 g. Papaya also contains papain (0.1–0.5% in latex), a cysteine protease enzyme that hydrolyzes peptide bonds, enhancing protein digestibility and gastrointestinal function.

The Banana provides approximately 350–400 mg potassium per 100 g, representing about 10% of daily potassium requirements. Potassium plays a crucial role in maintaining membrane potential, neuromuscular excitability, and vascular tone. Increased potassium intake is associated with a measurable reduction in systolic blood pressure ($\approx$ 3–5 mmHg in hypertensive individuals). Bananas also contain 2–3 g dietary fiber per 100 g, including resistant starch (particularly in unripe fruit), which promotes short-chain fatty acid production in the colon and improves gut microbiota composition. Fruits such as Pomegranate and Guava exhibit exceptionally high antioxidant capacity. Pomegranate juice contains approximately 150–250 mg total polyphenols per 100 ml, including punicalagins and ellagic acid derivatives that inhibit LDL oxidation and improve endothelial nitric oxide bioavailability. Guava is one of the richest natural sources of vitamin C, providing 200–250 mg per 100 g, nearly four times higher than orange, along with 5–6 g dietary fiber per 100 g. The combined presence of vitamin C, carotenoids (lycopene

in pink guava $\approx$ 5–7 mg/100 g), and phenolic compounds confers strong cardioprotective, anti-inflammatory, and immunomodulatory effects. These quantitative nutritional profiles highlight the scientific basis for fruit-specific health benefits, demonstrating how precise micronutrient and phytochemical concentrations translate into measurable physiological and clinical outcomes.

ROLE OF FRUITS IN IMMUNE SYSTEM ENHANCEMENT

Fruits play a fundamental role in strengthening immune competence through synergistic actions of micronutrients, antioxidants, and bioactive phytochemicals. Vitamin C, abundantly present in fruits such as Guava, Orange, and Kiwi, acts as a critical regulator of innate and adaptive immunity. At the cellular level, ascorbic acid enhances neutrophil chemotaxis and phagocytosis, supports reactive oxygen species-mediated microbial killing, and promotes lymphocyte proliferation and antibody synthesis. Plasma vitamin C concentrations above 50 μ mol/L are associated with improved immune cell function and reduced oxidative damage during infections.

Carotenoid-rich fruits such as Mango and Papaya supply β -carotene and other provitamin A compounds that are enzymatically converted into retinol. Vitamin A regulates epithelial cell differentiation and maintains mucosal barrier integrity in respiratory and gastrointestinal tissues, which serve as the first line of defense against pathogens. Retinoic acid further influences T-cell differentiation, promoting balanced immune responses and preventing immune dysregulation.

Table 1. List of fruit crops with their major nutrients and health benifits

o n s	Fruit Crop	Major Nutrients	Important Bioactive Compounds	Key Health Benefits
1	Mango	Vitamin A, C, E, fiber, potassium	Mangiferin, carotenoids, polyphenols	Boosts immunity, improves vision, antioxidant, supports digestion
2	Banana	Carbohydrates, potassium, vitamin B6, fiber	Dopamine, resistant starch	Energy booster, regulates blood pressure, gut health
3	Apple	Fiber (pectin), vitamin C, potassium	Quercetin, flavonoids	Heart protection, lowers cholesterol, improves gut microbiota
4	Guava	Vitamin C (very high), fiber, folate	Lycopene, polyphenols	Strong immunity, anti-diabetic, improves digestion
5	Papaya	Vitamin C, A, folate, fiber	Papain enzyme, beta-carotene	Improves digestion, anti-inflammatory, skin health
6	Pomegranate	Vitamin C, K, potassium	Punicalagins, anthocyanins	Cardioprotective, anti-cancer potential, antioxidant
7	Grapes	Vitamin C, K, natural sugars	Resveratrol, flavonoids	Anti-aging, heart health, anti-inflammatory
8	Amla	Extremely high Vitamin C, iron	Tannins, gallic acid	Enhances iron absorption, immunity booster, anti-aging
9	Citrus	Vitamin C, folate, fiber	Hesperidin, limonoids	Immunity, prevents scurvy, improves skin health
10	Sapota	Carbohydrates, iron, fiber	Tannins	Energy source, digestive aid
11	Pineapple	Vitamin C, manganese	Bromelain enzyme	Anti-inflammatory, aids protein digestion
12	Strawberry	Vitamin C, manganese, fiber	Anthocyanins, ellagic acid	Anti-cancer potential, improves heart health
13	Custard Apple	Vitamin C, B6, magnesium	Acetogenins	Nervous system support, energy booster
14	Jackfruit	Carbohydrates, vitamin C, potassium	Lignans, isoflavones	Energy rich, digestive support

Polyphenols and flavonoids found in fruits such as Pomegranate and Blueberry modulate intracellular immune signaling pathways, including NF- B and MAPK cascades. By attenuating excessive pro-inflammatory cytokine production (e.g., TNF- , IL-6) while preserving necessary immune activation, these compounds reduce chronic inflammation without compromising host defense. Additionally, fruit-derived prebiotic fibers enhance gut microbiota diversity, increasing short-chain fatty acid production, which further supports immune regulation through gut-associated lymphoid tissue (GALT).

Clinical and epidemiological observations indicate that regular fruit consumption is associated with shorter duration and reduced severity of common infectious diseases, reflecting improved immune resilience and antioxidant protection. Through integrated micronutrient supply, epithelial maintenance, cytokine modulation, and microbiome support, fruits function as natural immunomodulatory agents essential for maintaining systemic immune homeostasis.

Fruits and Hormonal & Metabolic Regulation

Fruits exert significant regulatory effects on endocrine function and metabolic homeostasis through their mineral composition and bioactive phytochemicals. Potassium-rich fruits such as Banana and Orange, containing approximately 350-400 mg potassium per 100 g, play a critical role in modulating the renin-angiotensin-aldosterone system (RAAS). Adequate potassium intake suppresses excessive aldosterone secretion, promotes natriuresis, and maintains intracellular-extracellular fluid equilibrium. This mechanism contributes to blood pressure regulation, vascular relaxation, and overall cardiovascular stability.

Fruit-derived polyphenols have been shown to influence glucose metabolism at the cellular level. Compounds such as flavonoids and anthocyanins, present in fruits like Blueberry and Pomegranate, enhance insulin receptor phosphorylation and improve downstream signaling via the PI3K/Akt pathway. This activation increases the translocation of glucose transporter type 4 (GLUT4) to the cell membrane in skeletal muscle and adipose tissue, thereby facilitating glucose uptake and improving insulin sensitivity. Such modulation helps attenuate postprandial hyperglycemia and reduces the risk of insulin resistance.

Additionally, certain fruit components influence adipokine secretion and energy balance. Dietary fiber and polyphenols modulate the release of hormones such as leptin and adiponectin, which regulate appetite, lipid metabolism, and inflammatory status. Increased adiponectin levels are associated with enhanced fatty acid oxidation and improved metabolic flexibility, while adequate fiber intake promotes satiety through delayed gastric emptying and stimulation of gut-derived hormones such as glucagon-like peptide-1 (GLP-1).

Through integrated effects on electrolyte regulation, insulin signaling pathways, adipokine balance, and gut-hormone interactions, fruits contribute substantially to hormonal equilibrium and metabolic stability. These mechanisms collectively reduce the risk of obesity, type 2 diabetes mellitus, and metabolic syndrome, reinforcing the central role of fruit consumption in preventive metabolic health.

CONTRIBUTION TO NUTRITIONAL SECURITY AND SUSTAINABLE DIETS

Fruit crops play a pivotal role in advancing nutritional security, particularly in developing and tropical regions where micronutrient malnutrition—often termed “hidden hunger”—remains prevalent. Regular access to diverse fruits provides essential vitamins such as vitamin C, provitamin A carotenoids, folate, and minerals including potassium and magnesium, which are frequently deficient in cereal-dominated diets. For instance, fruits like Guava and Mango offer high concentrations of vitamin C and β -carotene, contributing substantially to recommended dietary allowances and supporting immune competence, visual health, and cellular growth. Diversified fruit production systems therefore enhance dietary diversity, a key indicator of nutritional adequacy and long-term health outcomes. From an agricultural perspective, horticultural intensification and varietal improvement in fruit crops strengthen resilience within food systems. Perennial fruit orchards contribute to soil conservation, carbon sequestration, and improved agro-ecosystem stability compared to annual monocropping systems. The cultivation of locally adapted fruit species reduces input dependency, enhances climate adaptability, and supports sustainable land-use practices. Moreover, fruit production often generates higher economic returns per unit area, thereby improving farmer livelihoods, rural employment, and value-chain development. Integrating a variety of seasonal and regionally adapted fruits into daily dietary patterns aligns human health objectives with environmental sustainability. Such integration promotes nutrient-rich, plant-forward

diets with lower ecological footprints while preserving agrobiodiversity. In this context, fruit crops occupy a strategic position at the intersection of public health nutrition, sustainable agriculture, and socio-economic development, reinforcing their indispensable role in building resilient and health-oriented food systems.

CONCLUSION

Fruit crops function as metabolically active, nutrient-dense biological systems that deliver essential macro- and micronutrients within an intact phytochemical matrix. Their compositional synergy—comprising dietary fiber, ascorbic acid, carotenoids, polyphenols, potassium, folate, and diverse secondary metabolites—facilitates coordinated regulation of cellular redox balance, inflammatory signaling, glucose homeostasis, lipid metabolism, and immune competence. Through activation of endogenous antioxidant pathways, modulation of NF- κ B-mediated inflammation, enhancement of insulin sensitivity, and support of gut microbiome-derived short-chain fatty acid production, fruits exert measurable protective effects against cardiometabolic and degenerative disorders.

Substantial epidemiological and clinical evidence supports regular fruit intake as a determinant of reduced incidence of cardiovascular disease, type 2 diabetes mellitus, obesity, and certain malignancies. Consequently, diversified consumption of seasonal and regionally adapted fruits represents a scientifically substantiated, sustainable nutritional strategy for maintaining metabolic integrity, physiological resilience, and long-term health across the human lifespan.



Policies of Pollution: Global Promises, National Realities, and the Long Road to Cleaner Air, Water, and Soil

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The Periyar river, which winds through the industrial corridor of Ernakulam in Kerala, was once a lifeline - drinking water, fish, livelihoods. Today, stretches of it run with effluents from chemical

factories, and the fishermen who depended on it speak of a river they no longer recognise. Thousands of kilometres away, in the Czech Republic, Jana Dvořák describes the same quiet

grief: "We stopped letting our children swim in it fifteen years ago. Nobody came to fix it. Nobody was held responsible."

These are not isolated tragedies. Across six continents, communities are living downstream, literally and figuratively, from industries that pollute freely, governments that regulate slowly, and policies that look bold on paper but collapse in practice.

So what does effective pollution policy actually look like? What have the world's major frameworks set out to achieve and how much has actually been delivered?

THE SCALE OF THE PROBLEM

Pollution is not a future threat. It is a present emergency. According to the World Health Organization (WHO), air pollution alone kills approximately 7 million people every year, which is more than AIDS, malaria, and tuberculosis combined. Soil and water contamination affect billions more, quietly poisoning food supplies and drinking water in ways that rarely make headlines.

The sources are well known: industrial manufacturing, fossil fuel combustion, agricultural runoff, plastic waste, and vehicle emissions. What is less understood is why, given this knowledge, policy responses remain so fragmented and so weak.

GLOBAL POLLUTION POLICIES: GOALS, GAINS, AND GAPS

Over the past five decades, the international community has attempted to bring pollution under collective

control through a series of binding and non-binding agreements. Each represented a milestone. None has been fully delivered upon.

The Paris Agreement (2015)

Goal: Limit global temperature rise to 1.5-2°C above pre-industrial levels by achieving net-zero greenhouse gas emissions by mid-century. Each signatory nation submits Nationally Determined Contributions (NDCs) - pledges to reduce emissions.

What was achieved: 196 nations signed the agreement, representing near-universal participation. Renewable energy deployment has accelerated globally, and several major economies, including the EU, UK, and Japan, have enshrined net-zero targets in law.

The stumbling blocks: NDCs are voluntary. There is no legal mechanism to compel compliance. A 2023 UN analysis found that if current pledges were fully implemented, the world would still be on track for 2.5-2.9°C of warming, well above the 1.5°C target. The United States' withdrawal under one administration and re-entry under another exposed the fragility of political commitment.

The Stockholm Convention on Persistent Organic Pollutants (2001)

Goal: Eliminate or restrict the production and use of twelve highly toxic chemicals, the "dirty dozen",

including DDT, dioxins, and PCBs, which persist in ecosystems and accumulate in the food chain.

What was achieved: Ratified by over 180 countries, the Convention has successfully banned most of its original target chemicals. Concentrations of several POPs have measurably declined in human tissue and wildlife across monitored regions.

The stumbling blocks: The list of regulated substances has been slow to expand. Many newly developed industrial chemicals with similar properties escape regulation for years before being added. In developing nations, enforcement infrastructure is often absent.

The Minamata Convention on Mercury (2013)

Goal: Phase out mercury-added products, control mercury emissions from coal combustion and industrial processes, and remediate contaminated sites, named after the Japanese city devastated by industrial mercury poisoning in the 1950s.

The stumbling blocks: Artisanal gold mining - one of the largest sources of mercury pollution, has proven extremely difficult to regulate, particularly in remote regions of Sub-Saharan Africa and Latin America.

Emission Reduction Policies:

The Frontline of the Fight

Emission reduction sits at the heart of modern pollution policy. Three approaches have shown the most promise and revealed the most friction.

Cap-and-Trade Systems. The EU Emissions Trading System (ETS), launched in 2005, is the world's largest carbon market. Polluters are given a cap on emissions and can trade allowances with others. Over time, the cap tightens. The system has delivered measurable reductions in power sector emissions, down over 40% since 2005, but has been criticised for setting initial caps too generously, allowing industries to profit without cutting pollution.

Carbon Taxes. A direct tax on carbon emissions, championed by economists as the most efficient tool. Sweden introduced a carbon tax in 1991; its emissions have fallen significantly while its economy has grown. Canada's federal carbon price, introduced in 2019, covers all fossil fuel combustion. The political challenge is stark, carbon taxes are visible to consumers and easy to campaign against, as France's 'Yellow Vest' protests demonstrated.

Vehicle Emission Standards.

The EU's Euro standards, progressively tightened since 1992, have dramatically reduced nitrogen oxides and particulate matter from vehicles. India's Bharat Stage (BS) emission norms, modelled on the Euro system, leapt from BS-

IV to BS-VI in 2020, bypassing an intermediate standard. Studies show this single step has reduced vehicle NOx emissions by up to 68% in tested models.

National Policies: The View from India

India presents one of the most complex pollution governance challenges in the world, home to 14 of the 20 most polluted cities globally, yet also the site of some of the most ambitious recent policy action.

National Clean Air Programme (NCAP, 2019).

Goal: Reduce particulate matter (PM2.5 and PM10) concentrations by 20-30% in 122 non-attainment cities by 2024, with a revised target of 40% reduction by 2026. Progress has been uneven, some cities like Varanasi and Agra have seen improvements, while others remain far above safe limits. Critics point to weak monitoring networks and insufficient funding as key barriers.

Water Pollution - The Ganga and Beyond.

The Namami Gange Mission, launched in 2014, allocated over 20,000 crore for the rejuvenation of the Ganges, India's most sacred and most polluted river. Sewage treatment capacity has improved in several towns. Yet industrial discharge, untreated municipal waste, and agricultural runoff continue to compromise water quality. The pattern repeats across the country. In Punjab, heavy pesticide and fertiliser use in the

agricultural heartland has severely contaminated groundwater, with studies reporting alarmingly high nitrate and arsenic levels in villages of Malwa - a region now associated with unusually high rates of cancer, locally called the "cancer belt." In Maharashtra, the Ulhas river near Mumbai receives untreated effluents from over 700 industries, making it one of the most polluted rivers in the state despite years of court-ordered clean-up drives. In Tamil Nadu, industrial clusters around Tiruppur, the knitwear capital, discharged textile dye effluents into the Noyyal river for decades, devastating downstream agriculture and prompting the Supreme Court to order factory closures in 2011. The Periyar in Kerala tells a similar story: decades of effluents from the Eloor industrial belt have made it one of India's most contaminated rivers, despite repeated legal interventions by the Kerala High Court.

The stumbling blocks in India:

Enforcement remains the Achilles heel. India has a robust legislative framework - the Environment (Protection) Act, the Air Act, the Water Act - but implementation is hampered by understaffed pollution control boards, poor real-time monitoring, and political reluctance to penalise large industrial employers.

The Policy Landscape Globally: What Works

Where policies have genuinely worked, they share common features.

Clear, enforceable standards.

London's Ultra Low Emission Zone (ULEZ) - tied to specific, time-bound targets with real financial penalties - reduced nitrogen dioxide by 46% in central London within a year of launch.

Polluter pays principle. When industries bear the financial cost of the pollution they generate-through carbon taxes, remediation levies, or strict liability - frameworks incentives to clean up shift fundamentally.

Community-level monitoring.

Citizens equipped with real-time data become the most effective enforcement mechanism. Low-cost air quality sensors in cities like Beijing and Delhi have driven accountability where formal inspections have failed.

Cross-border cooperation.

Pollution does not respect national boundaries. The EU's success in reducing trans boundary acid rain through binding Gothenburg Protocol targets offers a model for regions where rivers, winds, and ocean currents carry pollution across borders.

The Human Cost of Inaction

Behind every policy gap is a human story. In Lagos, children in low-income neighbourhoods have blood lead levels that would trigger a public health emergency in Europe. In the industrial belt of Jharkhand, India, communities report cancer clusters near unregulated mining operations. In California's Central Valley, farmworkers breathe

air that regularly exceeds federal safety limits, yet enforcement actions remain rare.

These are not accidents. They are the predictable outcome of systems that treat pollution as an acceptable cost of economic growth, and that consistently place that cost on the shoulders of those least able to fight back.

A Way Forward

The solutions are not mysterious. The science is settled, the policy models exist, and the economic case for action - when long-term health costs, lost productivity, and climate feedback loops are counted - is overwhelming. What is missing is political will, equitable enforcement, and the recognition that pollution policy is not an environmental issue separate from everything else. It is a public health issue, an economic issue, a justice issue, and a question of what kind of world we are willing to leave behind.

The Periyar did not turn grey overnight. Neither did Jana's river. And they will not run clear overnight either. But they can, if the policies we write finally match the promises we make.

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OCTOBER 2026
VOLUME 14 ISSUE 5

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