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Inland Fisheries in the Indian Context: Emerging Challenges and Strategic Solutions

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ABSTRACT

Inland fisheries in India play a vital role in ensuring food security, livelihood generation, and nutritional support, particularly for rural and economically weaker communities. The country's extensive inland water resources contribute nearly three-fourths of total fish production, highlighting their immense potential. However, the sector faces significant challenges, including habitat alteration from damming and water abstraction, sedimentation and siltation, introduction of exotic species, pollution, and climate change impacts. Addressing these issues requires an integrated and sustainable management approach. Key strategies include developing time-series databases on ecological parameters, utilizing advanced tools such as remote sensing and GIS, and identifying critical habitats for conservation. The formulation and effective implementation of a national open water fisheries policy is crucial for sustainable utilization and equitable benefit sharing. A participatory, ecosystem-based approach is necessary to balance ecological, economic, and social priorities for present and future generations.

Keywords: Inland fisheries, Sustainability, Biodiversity conservation, Climate change, Habitat restoration, Ecosystem-based fisheries management

Introduction

India currently ranks third in total global fish production and holds the second position in aquaculture output. During 2024-25, the country's total fish production reached 18.40 million metric tonnes (MMT), of which 13.91 MMT was contributed by the inland sector and 4.49

Volume 3 – Special Issue 1-May, 2026

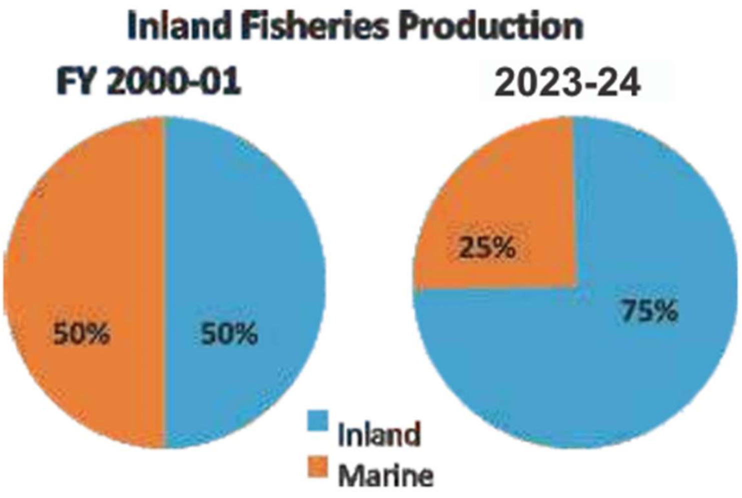
MMT by the marine sector (Annual Reports, 2024-25, DoF). Inland fish production accounts for around 75 percent of the nation's total fish output, with a significant yearly increase rate in production. The fisheries sector in India is an emerging industry, contributing around 1.10% to the national economy and 6.72% to the agricultural economy, with yearly export earnings at Rs. 60,523.89 Crores. Historically, the contribution from inland fisheries has been nearly three times greater than that of the sea industry. The use of resources from inland fisheries (25%) was significantly lower than that of the marine industry (75%) (Figure 1). Inland fisheries are a diversified and dynamic sector that provides food, income, and benefits to rural people, including those in low-income regions.

Inland fisheries are vital for ensuring food security, sustaining livelihoods, and preserving cultural traditions throughout India. The country is endowed with extensive and diverse inland water resources, including more than 29,000 km. rivers, 3.15 million hectares of reservoirs, 2.9 million hectares of ponds and tanks and about 1.2 million hectares of floodplain wetlands (Sugunan, 2010) (Figure 2). These ecosystems harbor significant biodiversity and have long been managed by indigenous and local communities through traditional ecological knowledge and customary governance practices. The sector offers both direct and indirect employment to millions, especially in rural regions. India generates foreign cash through fish and seafood exports, with aquaculture playing a substantial role.

However, Inland fisheries in India are becoming increasingly threatened by factors such as overfishing, habitat degradation, pollution, invasive species, and the consequences of climate change (Vass et al. (2009). Traditional, top-down management styles are being acknowledged for their shortcomings, and the importance of indigenous knowledge is being acknowledged as well.

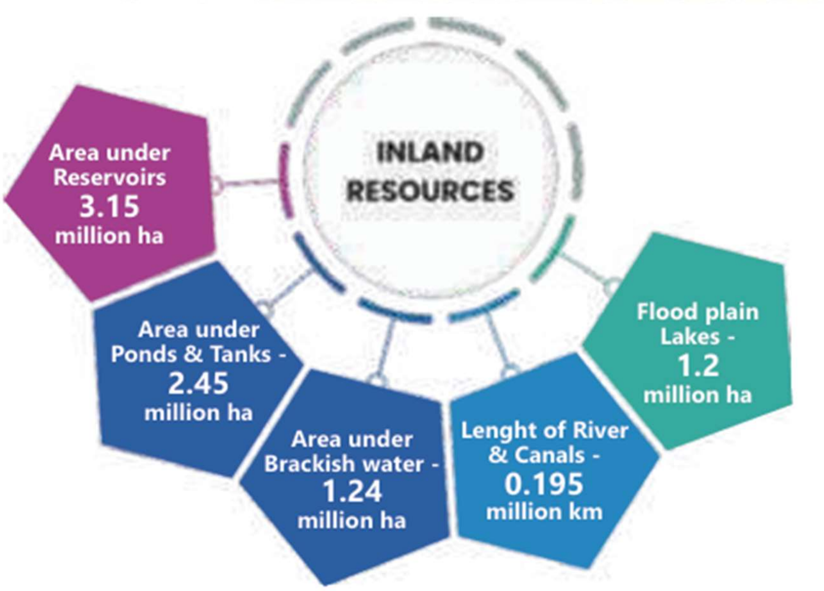
When it comes to developing sustainable fisheries, community-based systems and other similar initiatives can provide invaluable insights (Berkes et al., 2000).

Volume 3 – Special Issue 1-May, 2026



Source: Annual Report 2024-25

Figure 1. Inland fish production in India



Source: Annual Report 2024-25

Figure 2. Inland water resources of India

COMPLEX CHALLENGES IN THE MANAGEMENT OF INLAND FISHERIES

The sector currently confronts numerous challenges, including the degradation and over-exploitation of finite open water resources, agricultural expansion accompanied by persistent chemical and pesticide usage, and heightened domestic and industrial pollution, all of which will negatively affect the sustainability of inland fish production. The principal difficulties are being addressed here-

Habitat alteration

Damming and water abstraction cause changes in water quantity and environmental flow. Variations in river flow regimes negatively impact biodiversity and put strain on fish supplies, especially when demand for seafood increases. Dams and barrages have fragmented rivers and are expected to further impair flows, resulting in a shift in fish species composition, decreased catch, and habitat loss, particularly for Indian major carps, Mahseers, and Hilsa.

Introduction of exotic species

Exotic species have a significant impact on inland fisheries, as demonstrated by the introduction of silver carp (*Hypophthalmichthys molitrix*) in the Gobindsagar reservoir, which significantly reduced the local fish population. Increased abundance and range extension of *C. carpio* pose a significant danger to native species (Lakra et al., 2018).

Sediment deposition and silt accumulation

Environmental abnormalities, including elevated sedimentation rates, augmented water extraction, alterations to river courses, and indiscriminate fishing of brooders and juveniles, pose significant difficulties to India's inland fisheries. The elevated rate of siltation, caused by deforestation and soil erosion in the catchment region, has induced sedimentation in the water body and created a blanketing effect on the soil-water interface, leading to a decline in productivity. Moreover, the abstraction of water for diverse reasons, such as irrigation, residential use, and power production, exerts additional strain on inland resources by diminishing water volume, resulting in habitat loss for biotic populations, including fish and their food species. Siltation and reduced water volume adversely impact the feeding and possible breeding habitats of fish in inland water resources.

Volume 3 – Special Issue 1-May, 2026

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Impact on Climate change

The effect is evident in the inland aquatic resources and associated fisheries, resulting in the reproductive failure of Indian Major Carps (IMCs) and a subsequent reduction in fish spawn availability in the Ganga River. on recent years, the climate on the Indian subcontinent has exhibited significant alterations, including elevated water temperatures, variations in regional monsoons, increased frequency of droughts, a rise in severe storms, and the shrinkage of Himalayan glaciers. The current temperature variation has led to a significant biogeographical spread of the Gangetic fish fauna, since temperature is a crucial element that profoundly affects reproductive activity in fish. The freshwater ecosystem, susceptible to climate change, may be disrupted by water fluctuation and warming, leading to diminished fish capture, changed species composition, reduced abundance, and changes in regional ranges. Consequently, it may be asserted that inland resources, particularly the productivity and sustainability of riverine fisheries, may be significantly affected by climate change.

Water pollution

Water pollution is characterized by any adverse alterations in the standard state and composition of water, which may compromise its quality, rendering it unsuitable for human or animal consumption and posing health risks. Urbanization and industrialization are the primary causes contributing to significant pollution in inland waters, which poses a severe threat to inland fisheries resources. Moreover, the biogenic capacity and productivity of inland fisheries resources are diminishing due to the increasing issues of siltation and macrophyte infestation.

Strategies to manage and address these challenging issues

Holistic management of the inland fisheries sector can be achieved by effectively managing its three key components: fisheries resources, fish, and fishers. According to the Central Inland Fisheries Research Institute (CIFRI), the goals and targets for inland open water fisheries can be attained through conservation and management of natural resources, adoption of fish production–oriented technologies, and the development of effective policies and governance frameworks (CMFRI, 2025). The key need-based strategic actions to achieve these targets are outlined below-

- Development of a time-series database on ecological parameters and fish biodiversity in open water systems.

ISSN:3107-4200

- Development of effective mitigation plans in accordance with identified risks to restore habitats and degraded ecosystems, along with measures for pollution control and prevention.
- Assessment of yield and productivity of open waters through modern tools like remote sensing and Geographic Information Systems (GIS).
- Survey and recording of fish diversity in riverine, estuarine, and reservoir ecosystems for improved management of capture fisheries.
- Promoting self-sustaining fish populations through the establishment of protected areas, habitat restoration, pollution control, seasonal fishing bans, and mesh size regulations.
- Identification of potential river stretches, including deep pools and fish breeding grounds, and development of sanctuaries/protected habitats for the conservation of fish germplasm.
- To support ranching and restocking for stock improvement in natural water bodies, hatchery development is necessary for the supply of high-quality fish seed.
- Planning and execution of conservation and habitat restoration programs with active community involvement.
- Developmental and promotional initiatives, awareness programs, and capacity building for inland fishers.

Conclusions

The vast inland aquatic resources of the country present significant scope for sustainable fish production, as well as diverse opportunities for livelihood generation and nutritional support for underprivileged communities. The development and implementation of a national policy for open water fisheries has become an urgent necessity to ensure sustainability and maximize benefits. Such a policy would facilitate effective governance and management of inland waters, considering their multi-user nature and the responsibilities of all stakeholders. Furthermore, capacity building and participatory management approaches, supported by interdisciplinary and inter-institutional collaboration, are strongly recommended to address the challenges of inland open waters, ensuring their sustainable use and conservation while maintaining a balance among economic, social, and environmental priorities.

Volume 3 – Special Issue 1-May, 2026

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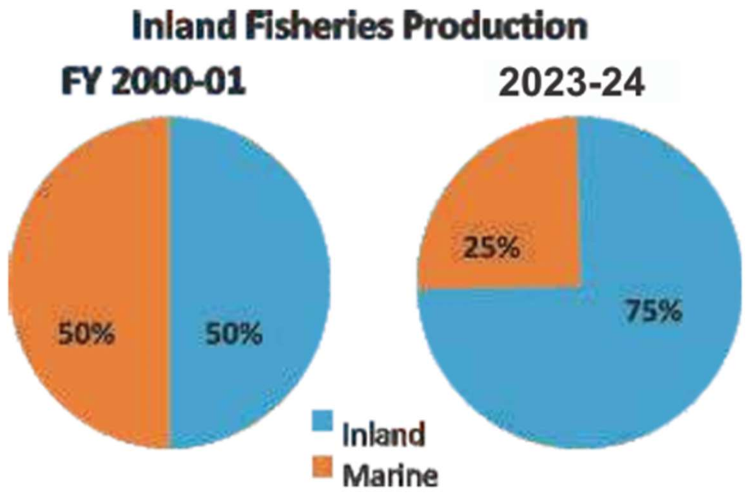

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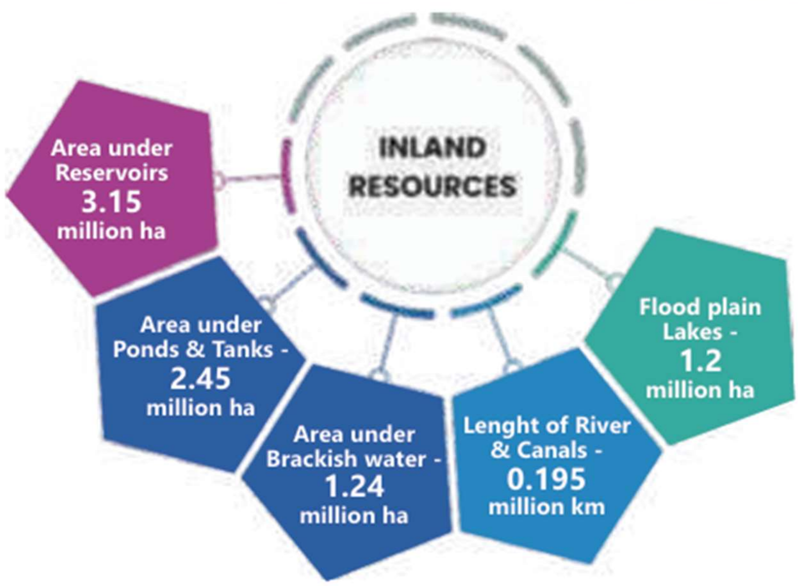

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Volume 3 – Special Issue 1-May, 2026

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Tomato Pomace Utilization in Aquafeeds: A Sustainable Waste-to-Wealth Approach

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ABSTRACT

The tomato processing industry generates large quantities of tomato pomace, a by-product consisting mainly of peels, seeds, and residual pulp, which poses environmental disposal challenges. At the same time, aquaculture faces rising feed costs and sustainability concerns due to dependence on conventional feed ingredients. Tomato pomace has emerged as a promising waste-to-wealth resource for aquafeed formulation owing to its nutritional value and presence of bioactive compounds such as lycopene and polyphenols. Studies indicate that low to moderate dietary inclusion of tomato pomace can support fish growth, enhance antioxidant capacity, improve immune responses, and contribute to flesh quality without negative effects. Furthermore, its utilization in aquafeeds supports circular economy principles by minimizing organic waste and reducing feed production costs. This article highlights the potential of tomato pomace as a sustainable ingredient in aquafeeds, discusses its practical applications and limitations, and outlines future prospects for its wider adoption in the fish feed industry.

1. Introduction

Tomato (*Solanum lycopersicum*) is one of the world's most widely cultivated vegetables, and its processing industry produces large quantities of tomato products such as juices, paste and sauces. During processing, a significant amount of tomato pomace consisting mainly of peels, seeds, and leftover pulp is generated as a by-product. Improper disposal of this waste contributes to environmental pollution, due to its high moisture content and rapid spoilage limit its direct use (Sharma et al., 2020).

Volume 3 – Special Issue 1-May, 2026

At the same time, aquaculture is expanding rapidly to satisfy the rising demand for fish protein. However, the industry's dependence on conventional feed ingredients such as fishmeal and soybean meal, rising feed costs, and the requirement for more sustainable practices pose significant challenges (Kari et al., 2023). In this context, the use of agro-industrial by-products as alternative feed ingredients has gained attention. Tomato pomace, rich in protein, lipids, dietary fibre, and bioactive compounds such as lycopene and polyphenols, offers potential as a low-cost, sustainable ingredient for aquafeeds (Del Valle et al., 2006; Knoblich et al., 2005). This article explores the utilization of tomato pomace in fish diets, its nutritional benefits, practical applications, and the challenges associated with its adoption in the fish feed industry.

2. Tomato Pomace as an Agro-Industrial By-product

Tomato pomace is the major by-product of tomato processing industries, produced during the preparation of products such as tomato paste, puree, ketchup, sauces, and juice. It mainly consists of peels, seeds, and residual pulp, which remain after removing the liquid and solid fractions. Globally, tomato processing generates a large amount of pomace, and its disposal is a major environmental concern due to high moisture content and rapid spoilage (Del Valle et al., 2006).

Pomace is rich in dietary fibre, and also contains protein, lipids, minerals, and bioactive compounds such as lycopene, carotenoids, and phenolic acids (Azevedo et al., 2018). These bioactive compounds possess strong antioxidant properties, which can benefit animal health. However, the high fibre content and variability in nutrient composition are limiting factors for its direct use in animal feeds. Despite this, tomato pomace is considered a valuable resource for developing sustainable feed ingredients due to its availability, low cost, and potential functional benefits (Del Valle et al., 2006).

3. Application in Fish Feed Formulation

Tomato pomace can be used in fish feed formulation as a partial substitute for conventional ingredients such as fishmeal, soybean meal, and cereal grains. Its inclusion is mainly determined by its nutritional composition, high fibre content, and the specific nutritional requirements of the cultured fish species. As shown in **Figure 1**, the utilization of tomato pomace in aquafeed formulation involves several processing methods such as drying, grinding, and fermentation, which enhance its nutritional value and storage stability. The figure also illustrates the functional roles of tomato pomace in fish diets, including its contributions as an energy and fiber source, protein supplement, and functional additive.

Volume 3 – Special Issue 1-May, 2026

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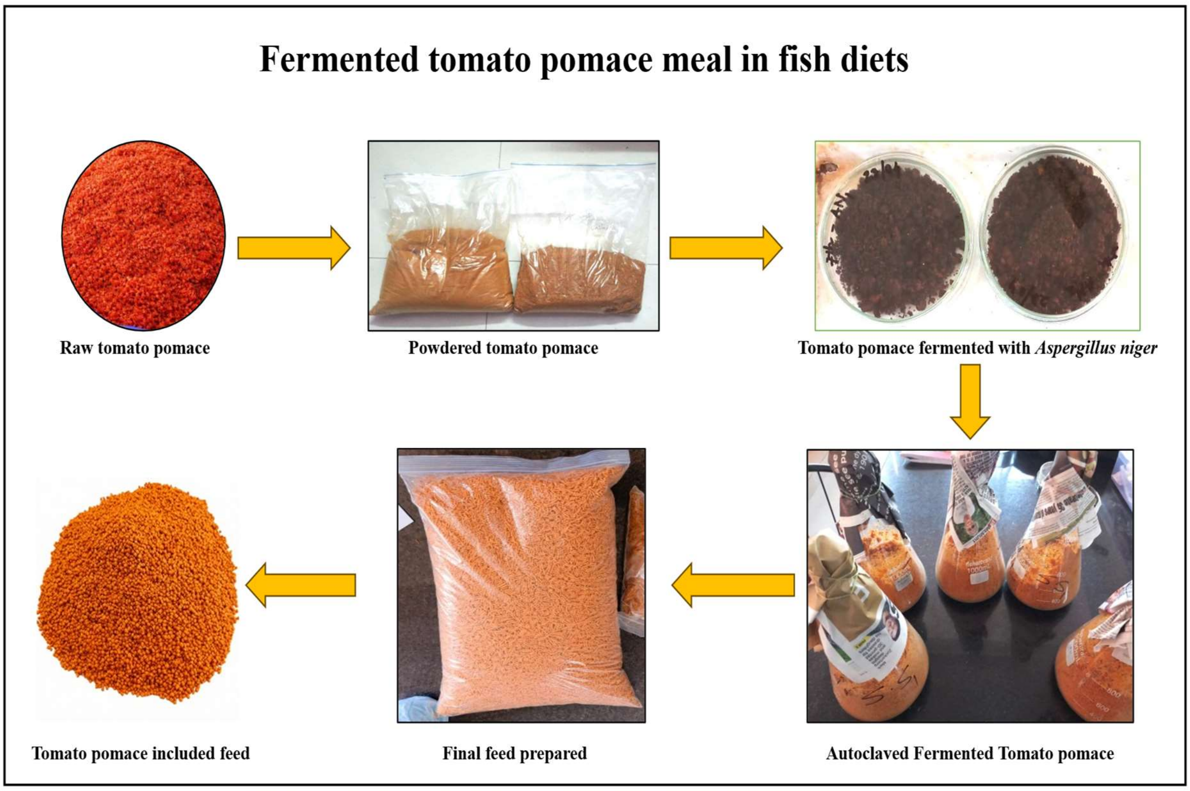

Figure 1: Tomato Pomace Utilization in Aquafeed Formulation

3.1 Inclusion Level

Most studies recommend low to moderate inclusion levels (2–10%) in fish diets. Higher levels may reduce nutrient digestibility and growth performance due to the high fiber content and the presence of anti-nutritional factors (NRC, 2011).

3.2 Processing for Feed Use

To improve its nutritional value and storage stability, tomato pomace is often processed before feed formulation:

- Drying (sun drying, oven drying) to reduce moisture and prevent spoilage
- Grinding to improve digestibility and mixing
- Fermentation or enzyme treatment to enhance nutrient availability and reduce fibre effects (Ibarruri and Hernandez, 2018)\

3.3 Functional Role in Feed

Volume 3 – Special Issue 1-May, 2026

Tomato pomace can be used as:

- Energy and fibre source
- Protein supplement
- Functional additive due to antioxidants like lycopene and polyphenols
- Pigmentation agent enhancing flesh color in some fish species (Sahin et al., 2014)

3.4 Species-specific Application

The suitability of tomato pomace depends on fish species and feeding habits. Herbivorous/omnivorous fish tolerate higher fibre levels, whereas carnivorous species require more digestible protein and may show better results at lower inclusion levels (NRC, 2011).

4. Practical Challenges

Although tomato pomace has promising potential as an alternative ingredient in aquafeeds, several practical challenges must be addressed for its successful implementation.

4.1 High Fibre Content

Tomato pomace contains a large proportion of dietary fibre, which may reduce nutrient digestibility and feed efficiency, especially in carnivorous fish.

4.2 Nutritional Variability

The nutrient composition of tomato pomace can vary depending on tomato variety, processing methods, and moisture content. This variability makes it difficult to standardize feed formulation and achieve consistent growth results.

4.3 Moisture and Storage Issues

Fresh tomato pomace has high moisture content, making it prone to microbial spoilage and fungal contamination. Proper drying and storage facilities are necessary to prevent deterioration and maintain feed quality (Del Valle et al., 2006).

4.4 Anti-nutritional Factors

Some tomato pomace samples may contain anti-nutritional compounds such as tannins and phytates, which can interfere with mineral absorption and digestion (Del Valle et al., 2006).

4.5 Limited Industrial Adoption

Despite research evidence, the large-scale adoption of tomato pomace in commercial aquafeeds is still limited due to lack of awareness, processing infrastructure, and standardized supply chains.

5. Future Outlook

The utilization of tomato pomace in aquafeeds presents a promising pathway toward sustainable and cost-effective fish production. Future research should focus on improving its nutritional value through advanced processing techniques such as Solid-state fermentation, enzyme treatment, and biofortification. These approaches can reduce fibre content, enhance digestibility, and increase the availability of valuable nutrients and bioactive compounds ((Meshram et al, 2018).

Integration of tomato pomace with probiotics or prebiotics may further improve gut health, immunity, and nutrient utilization in fish. Additionally, developing standardized processing and quality control protocols is essential to ensure consistent feed formulation and product performance. Large-scale industrial trials and collaboration between tomato processing industries and aquafeed manufacturers will be crucial for establishing reliable supply chains.

Conclusion

Tomato pomace is a valuable agro-industrial by-product that offers significant potential as a sustainable ingredient in aquafeeds. It is readily available, cost-effective, and rich in nutrients and bioactive compounds such as lycopene and polyphenols, which can enhance fish health and product quality. Incorporating tomato pomace into fish diets supports circular economy principles by converting waste into a useful resource, thereby reducing environmental pollution and lowering feed costs.

However, its successful implementation depends on proper processing, quality standardization, and appropriate inclusion levels to overcome challenges related to high fibre content and nutritional variability. With further research on processing techniques, species-specific feeding trials, and industry collaboration, tomato pomace can become an important component of sustainable aquaculture nutrition, contributing to both economic and environmental benefits.

Volume 3 – Special Issue 1-May, 2026

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Tomato Pomace Utilization in Aquafeeds: A Sustainable Waste-to-Wealth Approach

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ABSTRACT

The tomato processing industry generates large quantities of tomato pomace, a by-product consisting mainly of peels, seeds, and residual pulp, which poses environmental disposal challenges. At the same time, aquaculture faces rising feed costs and sustainability concerns due to dependence on conventional feed ingredients. Tomato pomace has emerged as a promising waste-to-wealth resource for aquafeed formulation owing to its nutritional value and presence of bioactive compounds such as lycopene and polyphenols. Studies indicate that low to moderate dietary inclusion of tomato pomace can support fish growth, enhance antioxidant capacity, improve immune responses, and contribute to flesh quality without negative effects. Furthermore, its utilization in aquafeeds supports circular economy principles by minimizing organic waste and reducing feed production costs. This article highlights the potential of tomato pomace as a sustainable ingredient in aquafeeds, discusses its practical applications and limitations, and outlines future prospects for its wider adoption in the fish feed industry.

1. Introduction

Tomato (*Solanum lycopersicum*) is one of the world's most widely cultivated vegetables, and its processing industry produces large quantities of tomato products such as juices, paste and sauces. During processing, a significant amount of tomato pomace consisting mainly of peels, seeds, and leftover pulp is generated as a by-product. Improper disposal of this waste contributes to environmental pollution, due to its high moisture content and rapid spoilage limit its direct use (Sharma et al., 2020).

Volume 3 – Special Issue 1-May, 2026

At the same time, aquaculture is expanding rapidly to satisfy the rising demand for fish protein. However, the industry's dependence on conventional feed ingredients such as fishmeal and soybean meal, rising feed costs, and the requirement for more sustainable practices pose significant challenges (Kari et al., 2023). In this context, the use of agro-industrial by-products as alternative feed ingredients has gained attention. Tomato pomace, rich in protein, lipids, dietary fibre, and bioactive compounds such as lycopene and polyphenols, offers potential as a low-cost, sustainable ingredient for aquafeeds (Del Valle et al., 2006; Knoblich et al., 2005). This article explores the utilization of tomato pomace in fish diets, its nutritional benefits, practical applications, and the challenges associated with its adoption in the fish feed industry.

2. Tomato Pomace as an Agro-Industrial By-product

Tomato pomace is the major by-product of tomato processing industries, produced during the preparation of products such as tomato paste, puree, ketchup, sauces, and juice. It mainly consists of peels, seeds, and residual pulp, which remain after removing the liquid and solid fractions. Globally, tomato processing generates a large amount of pomace, and its disposal is a major environmental concern due to high moisture content and rapid spoilage (Del Valle et al., 2006).

Pomace is rich in dietary fibre, and also contains protein, lipids, minerals, and bioactive compounds such as lycopene, carotenoids, and phenolic acids (Azevedo et al., 2018). These bioactive compounds possess strong antioxidant properties, which can benefit animal health. However, the high fibre content and variability in nutrient composition are limiting factors for its direct use in animal feeds. Despite this, tomato pomace is considered a valuable resource for developing sustainable feed ingredients due to its availability, low cost, and potential functional benefits (Del Valle et al., 2006).

3. Application in Fish Feed Formulation

Tomato pomace can be used in fish feed formulation as a partial substitute for conventional ingredients such as fishmeal, soybean meal, and cereal grains. Its inclusion is mainly determined by its nutritional composition, high fibre content, and the specific nutritional requirements of the cultured fish species. As shown in **Figure 1**, the utilization of tomato pomace in aquafeed formulation involves several processing methods such as drying, grinding, and fermentation, which enhance its nutritional value and storage stability. The figure also illustrates the functional roles of tomato pomace in fish diets, including its contributions as an energy and fiber source, protein supplement, and functional additive.

Volume 3 – Special Issue 1-May, 2026

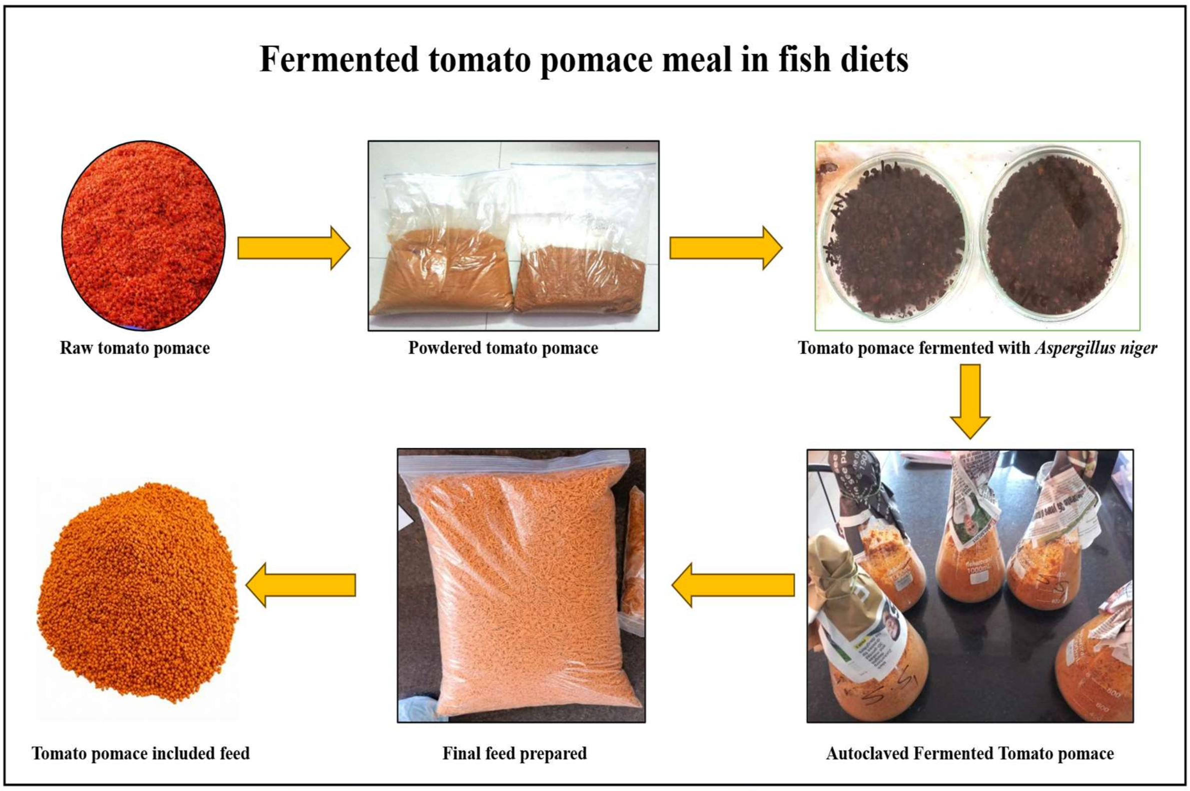

Figure 1: Tomato Pomace Utilization in Aquafeed Formulation

3.1 Inclusion Level

Most studies recommend low to moderate inclusion levels (2–10%) in fish diets. Higher levels may reduce nutrient digestibility and growth performance due to the high fiber content and the presence of anti-nutritional factors (NRC, 2011).

3.2 Processing for Feed Use

To improve its nutritional value and storage stability, tomato pomace is often processed before feed formulation:

- Drying (sun drying, oven drying) to reduce moisture and prevent spoilage
- Grinding to improve digestibility and mixing
- Fermentation or enzyme treatment to enhance nutrient availability and reduce fibre effects (Ibarruri and Hernandez, 2018)\

3.3 Functional Role in Feed

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Tomato pomace can be used as:

- Energy and fibre source
- Protein supplement
- Functional additive due to antioxidants like lycopene and polyphenols
- Pigmentation agent enhancing flesh color in some fish species (Sahin et al., 2014)

3.4 Species-specific Application

The suitability of tomato pomace depends on fish species and feeding habits. Herbivorous/omnivorous fish tolerate higher fibre levels, whereas carnivorous species require more digestible protein and may show better results at lower inclusion levels (NRC, 2011).

4. Practical Challenges

Although tomato pomace has promising potential as an alternative ingredient in aquafeeds, several practical challenges must be addressed for its successful implementation.

4.1 High Fibre Content

Tomato pomace contains a large proportion of dietary fibre, which may reduce nutrient digestibility and feed efficiency, especially in carnivorous fish.

4.2 Nutritional Variability

The nutrient composition of tomato pomace can vary depending on tomato variety, processing methods, and moisture content. This variability makes it difficult to standardize feed formulation and achieve consistent growth results.

4.3 Moisture and Storage Issues

Fresh tomato pomace has high moisture content, making it prone to microbial spoilage and fungal contamination. Proper drying and storage facilities are necessary to prevent deterioration and maintain feed quality (Del Valle et al., 2006).

4.4 Anti-nutritional Factors

Some tomato pomace samples may contain anti-nutritional compounds such as tannins and phytates, which can interfere with mineral absorption and digestion (Del Valle et al., 2006).

Volume 3 – Special Issue 1-May, 2026

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4.5 Limited Industrial Adoption

Despite research evidence, the large-scale adoption of tomato pomace in commercial aquafeeds is still limited due to lack of awareness, processing infrastructure, and standardized supply chains.

5. Future Outlook

The utilization of tomato pomace in aquafeeds presents a promising pathway toward sustainable and cost-effective fish production. Future research should focus on improving its nutritional value through advanced processing techniques such as Solid-state fermentation, enzyme treatment, and biofortification. These approaches can reduce fibre content, enhance digestibility, and increase the availability of valuable nutrients and bioactive compounds ((Meshram et al, 2018).

Integration of tomato pomace with probiotics or prebiotics may further improve gut health, immunity, and nutrient utilization in fish. Additionally, developing standardized processing and quality control protocols is essential to ensure consistent feed formulation and product performance. Large-scale industrial trials and collaboration between tomato processing industries and aquafeed manufacturers will be crucial for establishing reliable supply chains.

Conclusion

Tomato pomace is a valuable agro-industrial by-product that offers significant potential as a sustainable ingredient in aquafeeds. It is readily available, cost-effective, and rich in nutrients and bioactive compounds such as lycopene and polyphenols, which can enhance fish health and product quality. Incorporating tomato pomace into fish diets supports circular economy principles by converting waste into a useful resource, thereby reducing environmental pollution and lowering feed costs.

However, its successful implementation depends on proper processing, quality standardization, and appropriate inclusion levels to overcome challenges related to high fibre content and nutritional variability. With further research on processing techniques, species-specific feeding trials, and industry collaboration, tomato pomace can become an important component of sustainable aquaculture nutrition, contributing to both economic and environmental benefits.

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Status of Smart Farming Technologies in Nagaland

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INTRODUCTION

Nagaland is a beautiful state in the hills near the north eastern corner of India. Famous for its biodiversity, beautiful plains and farming methods passed down from generation to generation. Agricultural industry is of greatest importance economically. It is estimated that roughly seventy percent of the population depends on agriculture as a main source of subsistence. For a fairly long period, Nagaland has been farming horticultural crops including oranges, pineapples. It also has a tradition of growing vital crops including rice, maize and millets. The continued enactment of these rites has helped the local people to survive greatly and has been an important factor in conserving the cultural legacy of the respective region. Nagaland is rich in natural resources, but has not been able to develop a sustainable and profitable agriculture industry, which has a number of problems for its production. The big problem is that agriculture is very fragmented. The hills are dotted with farms, mainly peaceful and unobtrusive. Mechanisation is complicated and there is no possibility for economies of scale. Droughts, floods and changes in precipitation patterns have become increasingly unpredictable and agricultural productivity much more uncertain. There are many benefits to traditional practices in agriculture, which have been passed down from generation to generation. But these procedures can lack the accuracy needed to improve production or respond rapidly to changing market conditions. The problem is due to the scarcity of modern agricultural research and the tendency of farmers to depend on their instinct and traditional knowledge. Digital agriculture and intelligent technology are among the drivers of progress and this is widely acknowledged. In the agricultural industry, digital agriculture means the employment of Information and Communication Technology (ICT). This agricultural technique offers farmers access to marketplaces commercially, data in real time and the backing

Volume 3 – Special Issue 1-May, 2026

of industry professionals. Today, farmers can use the latest technology, including sensors, drones, satellite photos and the Internet of Things (IoT), to analyse their crops development, soil quality and environmental conditions with an unparalleled level of precision. These advancements are ushering change in the agricultural scenario of Nagaland. It is assisting farmers to move from reactive farming practices, that involves a lot of human effort, to data-driven proactive farming approaches. There are several initiatives going in Nagaland right now that can demonstrate the prospective repercussions of this transformation. Mobile applications enable farmers to access services such as agronomic consulting, meteorological predictions and pest alarms from their devices. The Internet of Things (IoT) can be applied to monitor the amounts of moisture and nutrients in the soil for irrigation and fertilization. Drones, from an overhead perspective, may monitor broad regions of land and have the ability to operate as a potential early warning system for problems before they become more severe. These technologies bring a range of benefits including higher productivity, decreased prices, less waste and more ecologically responsible farming practices. Digital markets provide direct communication between consumers and producers, removing the need for middlemen and enabling better prices for agricultural products. Nagaland's digital agriculture is not about technology but a shift of thinking. Farmers are no longer passive users of agricultural inputs but ever more active decision makers who employ a broad range of technology and information to optimize all dimensions of crop output. At the same time, governments and industry are also realizing that investment in infrastructure, training and support systems is a crucial part of making new technology available to the most remote communities and individuals. Therefore, with the support of digital agriculture and new technology, Nagaland can develop a more efficient, sustainable and resilient agricultural industry than what it has now. The state has been facing many problems for long and these problems can be solved by increasing the quality of life of farmers in the state, by merging the traditional wisdom with modern research and development and by being a role model for other hilly and rural portions of India. Nagaland is poised for a change that will usher in a new era of exceptional wealth for its agriculture sector. The journey will incorporate cultural, technological and food production aspects within the community. Nagaland is looking at the possibilities of using advanced technology including Internet of Things (IoT) devices, drones and sensors to track soil moisture, agricultural growth and climate factors. They can easily evaluate broad agricultural areas and detect insect infestations or water stress in a timely manner. Sensors that are IoT-enabled enable farmers to collect real-time data, which allows them to optimize the use of irrigation and fertilizers, resulting in increased yields and reduced wastage of resources.

The adoption of digital and smart technologies offers multiple advantages:

- The employment of precision farming technologies results in the rise of the agricultural yield per hectare and, respectively, in the increase of the total productivity.
- Sustainable agriculture means utilizing water, fertilizers, and pesticides in such a way as to do the least possible damage to the environment.
- Market Access: Digital platforms enable farmers to access wider markets and secure higher incomes.
- Empowerment: The appropriate information at the right time allows farmers to make decisions and manage risk.

Success Story: Reviving Traditional Crops with Digital Tools in Nagaland

For years, a group of small-scale farmers in the rural village of Pfutsero, Nagaland, have been striving to overcome a range of problems including unpredictable weather, diminished harvests and limited access to markets. Conventional crops such as maize, rice and millets were mostly cultivated and heavy losses were regularly incurred due to weather conditions, disease and pest infestation.

In 2021, the Nagaland State farming Department, working in conjunction with a digital agriculture project, was able to offer the community with smart farming equipment. The farmers were provided with mobile applications to assist them access weather forecasts, pest alarms and soil health assessments. Farmers were told to install affordable Internet of Things (IoT) sensors to measure soil moisture and nutrients.

The transformation was remarkable:

- Farmers utilized real-time soil and weather data to optimize irrigation and fertilizer use, which saved costs by more than twenty percent. Mobile alerts for early pest detection and crop saving, protecting a big portion of the harvest.
- Farmers chose to sell their produce through online platforms and to reach consumers outside the local marketplaces and experienced an increase of thirty to forty percent in income.

T. Koso, a farmer who has been battling persistent problems of low corn yields for several years. He said the mobile application and the sensors have provided us with the possibility of having precise knowledge about the needs our crops have at the moment. I was able to get a better yield last year and sell it straight to the clients that bought online.

Today, Pfutsero is a model of smart agriculture in the state and is encouraging its neighbouring districts to embrace similar technologies.

Source: Nagaland State Action Plan on Climate Change, Govt. of Nagaland

Challenges

There is a prospect of 100 per cent adoption of digital agriculture in Nagaland if restrictions are crossed. There are many potential barriers to expansion, including poor internet access in distant places, low levels of digital literacy among farmers, and the upfront expenditures of adopting technology. These problems will have to be addressed by government involvement, partnerships with Information and Communications Technology corporations and capacity building measures. Educating farmers in digital technologies and promoting community-oriented technology can speed the shift.

Conclusion

In conclusion, digital agriculture and smart technologies can be the key to transforming Nagaland's agriculture sector. This would enable them to solve a range of challenges facing farmers today, including the fragmentation of landholdings, climate variability, low productivity and limited market access. The traditional agricultural knowledge of Nagaland can be combined with modern technologies like Internet of Things (IoT) sensors, drones, mobile applications and digital marketplace to build a better, sustainable and resilient agricultural system. Technology may help farmers make educated decisions, enhance crop yields, cut production costs and improve their revenues. This change requires the improvement of the digital infrastructure, the rise of Internet connectivity and the regular training and access to these advancements of the farmers living in rural areas. Nagaland has the capacity to successfully combine tradition and technology through the collaborative efforts of the government, the private sector and the local community. It would provide a sustainable agricultural future and would be a model for other hilly and rural portions of India.

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Role of Robotics and Automation in farming

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ABSTRACT

This article explores the role of robotics and automation in modern agriculture and their potential to transform traditional farming practices. It highlights how technologies such as autonomous tractors, drones, robotic harvesters, and automated irrigation systems are improving efficiency, accuracy, and productivity in agricultural operations. These innovations enable precision farming by ensuring optimal use of resources like water, fertilizers, and pesticides, thereby reducing waste and environmental impact. The study also emphasizes the integration of Artificial Intelligence (AI) with robotics, which enhances decision-making through data analysis related to soil conditions, weather patterns, and crop health.

The article further discusses the growing need for robotics in agriculture due to labor shortages, increasing food demand, and the need for sustainable farming practices. Despite the numerous advantages, several challenges hinder widespread adoption, including high initial costs, lack of technical knowledge, and inadequate infrastructure in rural areas. The paper concludes that while robotics and automation hold great promise for the future of agriculture, effective implementation requires proper training, financial support, and policy interventions to ensure accessibility for all farmers.

Introduction

Agriculture is the backbone of our country. For many years, farmers have depended on manual labor and traditional methods to grow crops. But today, farming is changing fast because of new technologies. One of the most important changes is the use of robotics and automation in

Volume 3 – Special Issue 1-May, 2026

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agriculture. Robotics and automation help farmers do their work more easily, quickly, and accurately. These technologies reduce human effort, save time, and improve crop production. In this article, we will discuss how robotics and automation are used in farming, their advantages, challenges, and future scope.

Robotics and Automation in Farming

Robotics in farming refers to the use of machines (robots) that can perform agricultural tasks with little or no human involvement. Automation means using technology to carry out tasks automatically without continuous human control. In simple words, these technologies help farmers by doing repetitive, difficult, and time-consuming work.

For example, machines can now plant seeds, water crops, spray fertilizers, detect pests, and even harvest crops. These tasks were traditionally done by farmers manually, but now machines can do them faster and more accurately.

Need for Robotics in Agriculture

There are many reasons why robotics and automation are needed in farming today.

First, there is a shortage of labor in agriculture. Many people are moving from villages to cities, so fewer workers are available for farming. This makes it difficult for farmers to manage large fields. Second; farming requires a lot of time and physical effort. Tasks like planting, weeding, and harvesting can be tiring and time-consuming. Machines can reduce this burden. Third; farmers need to increase production to meet the food demand of a growing population. Robotics helps in improving productivity and reducing wastage. Finally, modern farming also needs to be environmentally friendly.

Volume 3 – Special Issue 1-May, 2026

Role in Crop Monitoring

Robotics and automation help farmers monitor their crops more effectively. Drones and sensors collect data about soil moisture, temperature, and crop growth. This information helps farmers understand the condition of their fields. With the help of AI, farmers can identify diseases early and take action quickly. This reduces crop loss and improves yield. Continuous monitoring also helps in making better decisions about irrigation and fertilizer use.

Precision Farming

One of the biggest advantages of robotics and automation is precision farming. This means applying the right amount of water, fertilizer, and pesticides at the right time and place. Automated systems use sensors and GPS technology to ensure accuracy. This reduces waste and saves money. It also helps protect the environment by reducing the excessive use of chemicals. Precision farming leads to better crop quality and higher productivity.

Role in Irrigation

Water management is very important in agriculture. Automated irrigation systems help farmers provide water only when needed. Sensors detect soil moisture levels and control water supply accordingly. This prevents overwatering and saves water. In areas facing water scarcity, such systems are very useful. They ensure that crops get enough water without wasting this valuable resource.

Role in Harvesting

Harvesting is one of the most labor-intensive activities in farming. Robotic harvesters can perform this task quickly and efficiently. They use cameras and sensors to identify ripe crops and pick them carefully. This reduces the need for manual labor and saves time. It also helps reduce post-harvest losses by ensuring proper handling of crops.

Types of Agricultural Robots

There are different types of robots used in farming, each designed for a specific purpose.

Autonomous tractors are one of the most important machines. These tractors can work without a driver and perform tasks like ploughing, planting, and spraying. Harvesting robots are used

Volume 3 – Special Issue 1-May, 2026

to pick fruits and vegetables. They are designed carefully so that they do not damage the crops while harvesting. Weeding robots help in removing unwanted plants (weeds) from fields. They reduce the need for chemical herbicides. Drones are also widely used in agriculture. They can fly over fields and collect information about crop health, soil condition, and water levels. They can also spray fertilizers and pesticides. Irrigation systems are automated to supply water to crops at the right time and in the right quantity. This helps in saving water and improving crop growth.

Role of Artificial Intelligence (AI)

Robotics in farming is often supported by Artificial Intelligence (AI). AI helps machines to make decisions based on data.

For example, AI can analyze soil conditions and weather patterns to decide the best time for planting or harvesting. It can also detect diseases in plants by analyzing images and suggest proper treatment. With the help of AI, robots become smarter and more efficient. They can adapt to different farming conditions and improve their performance over time

Advantages of Robotics and Automation

Robotics and automation provide many benefits in agriculture. One major advantage is increased efficiency. Machines can work faster than humans and can operate for longer hours without getting tired. Another benefit is accuracy. Robots can perform tasks like planting seeds at the exact depth and distance, which improves crop growth. Labour cost is reduced because fewer workers are needed. This is especially helpful in areas where labour is expensive or not easily available. Automation also helps in better use of resources. Water, fertilizers, and pesticides can be used in precise amounts, reducing waste and protecting the environment. It also improves safety. Farmers do not have to expose themselves to harmful chemicals or heavy physical work.

Challenges in Using Robotics

Even though robotics has many advantages, there are also some challenges. One major issue is the high cost. Many small farmers cannot afford advanced machines and technology. Another challenge is the need for technical knowledge. Farmers need training to operate and maintain these machines. In some areas, infrastructure like electricity and internet connectivity may not be sufficient for using automated systems. There is also a concern that increased use of machines may reduce job opportunities for farm workers.

Role in Sustainable Agriculture

Robotics and automation play an important role in making agriculture more sustainable. They help in reducing the use of chemicals by applying them only where needed. This protects soil health and reduces pollution. Water management becomes better with automated irrigation systems, which helps in conserving water. Precision farming techniques ensure that crops get exactly what they need, improving yield and reducing waste. Overall, these technologies support environmentally friendly farming practices.

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Future of Robotics in Farming

The future of robotics in agriculture looks very promising. With continuous advancements in technology, machines are becoming more affordable and efficient. In the future, we may see fully automated farms where most of the work is done by robots. Farmers will mainly supervise and manage operations. Integration of technologies like AI, Internet of Things (IoT), and data analytics will further improve farming practices. Governments and organizations are also supporting the use of modern technology in agriculture through subsidies and training programs.

Conclusion

Robotics and automation are transforming agriculture in a positive way. They help farmers overcome challenges such as labour shortage, low productivity, and resource wastage. By improving efficiency and sustainability, these technologies are shaping the future of farming. However, proper support, training, and investment are needed to ensure that all farmers can benefit from these advancements. With the right approach, robotics and automation can lead to a more productive and sustainable agricultural system.

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AI Adoption and Challenges among Indian Farmers

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ABSTRACT

This paper examines the adoption and challenges of Artificial Intelligence (AI) in Indian agriculture, with a focus on its potential to enhance productivity and decision-making. AI technologies, including machine learning and rule-based systems, enable real-time monitoring of key agricultural parameters such as soil moisture, crop health, pest incidence, and nutrient management. Despite these advantages, the adoption of AI among Indian farmers—particularly smallholders—remains limited due to several structural, economic, and technological barriers. Major challenges include high initial investment costs, lack of supportive regulatory frameworks, poor internet connectivity in rural areas, and the complexity of integrating diverse agricultural conditions into digital systems. Additionally, low digital literacy and limited technical knowledge among farmers further hinder effective implementation. The study also highlights the importance of explainable and user-friendly AI systems in building trust among farmers. Capacity-building initiatives, including training programs and institutional support, are essential for improving adoption rates. The paper concludes that while AI holds significant promise for transforming Indian agriculture, addressing these challenges through policy support, infrastructure development, and farmer education is crucial for achieving sustainable and widespread adoption.

Introduction

Although artificial intelligence (AI) is not a novel idea, it has been rapidly evolving in recent years and is being more widely used in both social and economic spheres. As a title, artificial intelligence (AI) encompasses a variety of sophisticated digital technological systems, such as rule-based systems, which use human-crafted sets of rules to manipulate information and produce outputs, and machine learning (ML) systems, which rely on algorithms and statistical models to carry out pattern identification and inference, producing predictions, decisions, and actions for a particular task. In many different businesses, rule-based AI, machine learning, and other AI techniques are employed, often in tandem.(Tzachor, 2021) Rule-based systems rely extensively on domain-specific expertise throughout both their development and deployment. Consequently, implementing these systems typically demands extra digital support, such as well-prepared labeled and unlabeled datasets, appropriate computing resources, sensors to capture input data, and actuators to carry out actions. In addition, skilled human knowledge is crucial for properly using AI systems and understanding their constraints.(Tzachor, 2021).

The integration of advanced technologies facilitates real-time monitoring of agricultural conditions, encompassing critical parameters such as soil moisture content, irrigation efficiency, pest dynamics, and nutrient availability. Nevertheless, in rural and resource-constrained contexts, farmers may exhibit reluctance toward the adoption of AI-enabled systems, particularly when the underlying rationale of algorithmic recommendations is not sufficiently transparent or interpretable. In this regard, fostering trust becomes essential, which necessitates the development of explainable AI systems that provide clear, interpretable, and contextually relevant outputs to end users.(Mane et al., 2024).

Furthermore, the effective deployment of artificial intelligence in agriculture is contingent upon comprehensive capacity-building initiatives targeting farmers, agricultural extension personnel, and other stakeholders within the agricultural value chain. Such initiatives should include the design of intuitive and user-centric digital interfaces, the implementation of structured hands-on training programs, and the establishment of robust technical support frameworks. Enhancing digital literacy and reinforcing institutional support mechanisms are therefore fundamental to promoting user confidence and enabling the sustainable and widespread adoption of AI-driven agricultural technologies.(Mane et al., 2024)

Challenges of AI adoption

The adoption of Artificial Intelligence (AI) in Indian agriculture holds great promise, but its diffusion among farmers especially smallholders face multiple structural, socio-economic, and technological challenges. These challenges can be explained as follows:

Volume 3 – Special Issue 1-May, 2026

- **Lack of supportive regulations:**

Inadequate regulatory support poses a significant challenge to the adoption of AI in agriculture. Agricultural policies in India, including the farm laws introduced in September 2020, have drawn global scrutiny due to limited public and parliamentary discussion. Moreover, even with improvements in financial services, the formal banking system has not effectively reached many small farmers, limiting their access to resources needed for adopting advanced technologies. To address these issues, governments, financial institutions, researchers, and experts must work together to make regulatory systems more accessible and supportive for farmers.(Hota & Verma, 2022).

- **High capital cost:**

The adoption of AI in agriculture is hindered by the high initial investment required. Traditional farming already involves significant expenses related to energy use, fertilizers, labor, and overall production costs, along with the need for technical expertise to manage operations effectively. These financial burdens make it difficult for farmers to invest in advanced technologies such as AI. Therefore, government bodies, financial institutions, and researchers need to develop affordable funding options and cost-reduction strategies to support technological adoption in agriculture.

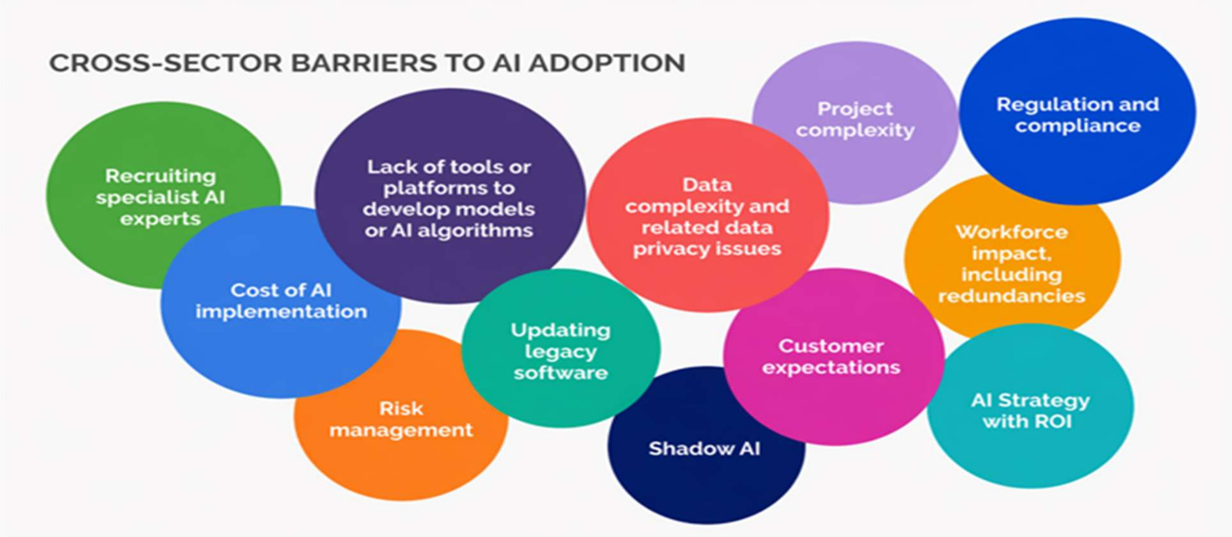
- **Complexity in integrating agricultural diversity:**

A key challenge in adopting digital agriculture, including AI-based systems, is the difficulty of digitally capturing and managing the wide variation in crops, climate conditions, and soil types. The diversity of environmental and farming conditions makes it hard to develop unified digital systems that accurately reflect real-world agricultural settings, thereby limiting the effective implementation of advanced agricultural technologies

- **Poor access to network and internet connectivity:**

Limited internet and communication infrastructure in rural farming areas significantly restricts the adoption of AI and digital agriculture. Many farms are located in remote regions where connectivity is weak, and physical barriers such as crops and farm structures can further disrupt signal transmission. These issues increase the cost of data transfer and slow down the

Barriers in AI Adoption



implementation of precision agriculture technologies. Additionally, insufficient telecom infrastructure, limited government support, and low investment in rural development continue to hinder reliable communication access for farmers.

Future scope of AI

Agriculture faces several challenges such as poor irrigation, climate change, groundwater issues, food shortages, and waste. Although some digital tools exist, the sector is still in an early stage of adopting advanced technologies like AI. AI is being used in farming for tasks such as pest detection, disease identification, and nutrient management. It also supports agricultural robotics, crop monitoring, and predictive analysis using data from drones, sensors, and imaging systems.

Despite these advancements, widespread adoption is still limited, and agriculture remains underdeveloped in terms of autonomous and data-driven decision-making. However, AI has strong potential to improve productivity and help address future food demand by enabling better crop prediction, monitoring, and resource management. (kumar et al,2023)

Conclusion:

Artificial Intelligence (AI) has the potential to bring significant transformation to the agricultural sector by enabling data-driven decision-making and real-time monitoring of farming activities. It supports essential functions such as crop surveillance, pest and disease identification, irrigation optimization, and predictive analytics. However, the adoption of AI in

Volume 3 – Special Issue 1-May, 2026

agriculture remains limited, particularly in rural regions, due to challenges such as lack of transparency in AI systems, low digital literacy, and insufficient infrastructure. Additional barriers, including high implementation costs, weak policy and regulatory support, and inadequate internet connectivity, further restrict its widespread use. The inherent diversity of agricultural conditions also complicates the development of standardized AI solutions. Therefore, overcoming these challenges is essential for effective integration. Strengthening farmer training programs and developing user-friendly technologies can enhance adoption. Moreover, explainable AI systems are critical for building trust among end users. With appropriate policy interventions and infrastructural improvements, AI can play a vital role in improving agricultural productivity and sustainability.

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Impact of Crop Rotation on Sustainable Agriculture Production

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INTRODUCTION

Crop rotations date back as far as the Roman Empire. European farmers used to follow a crop rotation system created by the Romans called, "food, feed, fallow." Farmers using this cropping system divided their farm into three sections, rotating the sections to the next category the following year. In the "food" section, farmers used to plant a food grain such as wheat, in the "feed" section other cereals like barley or oats would be planted for their livestock and in "fallow" the ground kept empty so it could recover some of its organic matter and nutrients that was lost in previous years. As European farms increased in size during the 15th century, farmers were able to carry out with their crop rotation schedules, which lead to the development of the four-year crop rotation. This rotation was introduced in Great Britain by Viscount Charles "Turnip" Townshed in the mid-1700s and rotated wheat, barley, a root crop like turnips and a nitrogen fixing crop like clover. Crop rotation use by farmers has gone through cycles throughout history.

To assist home gardeners with rotating vegetables, a list of commonly grown vegetables and their plant families is provided.

Apiaceae (Carrot Family): Celery, carrot, fennel, parsnip, parsley.

Alliaceae (Onion Family): Onion, garlic, leek, shallot, chive.

Brassicaceae (Mustard Family): Broccoli, Brussels sprout, cabbage, cauliflower, kale, horseradish, kohlrabi, mustard, radish, rutabaga, turnip, collards.

Chenopodiaceae (Goosefoot Family): Beet, Swiss chard, spinach.

Volume 3 – Special Issue 1-May, 2026

Cucurbitaceae (Gourd Family): Cucumber, muskmelon, watermelon, squash, pumpkin, gourd, zucchini.

Fabaceae (Pea Family): Garden pea, snap bean, lima bean, soybean.

Solanaceae (Nightshade Family): Tomato, pepper, potato, eggplant.

Crop rotation

Crop rotation is the growing of two or more crops sequentially on the same plot of land to improve soil health, optimize nutrients, and combat insect pests and weed pressure. Simple rotation involves two or three crops, while a complex rotation may have a dozen or more. Crops can be rotated on a field within the same year, over two years, or more extended periods. Crop rotation requires the succeeding crops to be of a different species or subspecies (variety) than the previous crop, such as legumes grown after wheat and cereals, however, cereal-cereal crop rotations are predominant in the country with farmers growing green manure before sowing rice for building soil health.

Tropical and subtropical climate of India offers scope for growing two or more crops per year. However, Crop rotations are location-specific depending on their economic utility, which varies under diverse socioeconomic and agroecological conditions.

Effective implementation of crop rotations

- **Rotation by plant family.** This is the most common method, which involves planting different plant families on a field in a seasonal, sequential fashion, often over the course of four years.
- **Rotation by plant parts harvested.** It is the standard practice to alternate between picking legumes, leaves, fruits, and roots throughout this cycle. Plants of different families and with varying rooting depths are typically used, and legumes are often planted as restorative plants.
- **Rotation by plant compatibility.** It is important to consider which plants complement one another when planning a rotation cycle. For example, maize is highly recommended as a pre-potato plant due to its significant positive impact on potato growing and yield.
- **Rotation by nutrient requirements.** Typically, this approach entails planting legumes first, followed by heavy feeders such as tomatoes or maize the following year.

- **Rotation by rooting depth and type.** This technique requires to alternate between growing plants with deep and shallow roots, such as beets and cauliflower, on a single plot.
- **Inclusion legumes and cover plants.** A grass or minor cereals planted will use unused nitrogen from the preceding maize or soybeans. Though legumes aren't as good as grasses at reusing nitrogen, they enrich the soil so that the next plant can benefit. Combinations of legumes and grasses perform admirably in both settings.

Types of Crop Rotation

The number of different plants chosen to grow will determine the type of rotation. One can grow a new plant in the same field each season, or one can divide the field into zones and grow different plants in each zone. Let's consider the most typical 1- to 5-year sequences.

1-Year Crop Rotation Plans

- Maize- mustard.
- Rice- wheat.
- Rice-mustard.

2-Year Crop Rotation Plans

- Maize- mustard- sugarcane- fenugreek.
- Maize- potato- sugarcane- peas.
- Oat- clover- spelt.

3-Year Crop Rotation Plans

- Rice- wheat- mung- mustard.
- Cotton- oats- sugarcane- peas- maize- wheat.
- Roots and potatoes- greenery, and miscellaneous plants.
- Roots and potatoes- brassicas and bean family- and any other plant.

4-Year Crop Rotation Plans

- Potatoes- legumes- brassicas- onions/roots.
- Tomatoes- roots- brassicas- legumes.

- Onions-grazing rye/phacelia-winter tares, - winter brassicas.

5-Year Crop Rotation Plans

- Potatoes- mustard- legumes- brassicas- sweetcorn/cucurbits- roots- onion family.
- Brassicas- legumes- fruiting vegetables- onion family- root and stem vegetables.

Crop rotations in India

North India

Unirrigated: Maize-wheat, Maize-barley, Maize-Safflower, Urd-wheat, Jowar-gram, Paddy-pulses, Groundnut-wheat, Bajra-wheat, Mung-wheat

Irrigated: Paddy- wheat-mung, Maize-potato-mung, Maize-potato-sunflower, Paddy-potato-wheat-mung

Eastern India: Rice-wheat-rice, Rice-potato-rice, Jute-rice-maize, Jute-potato-rice

Central India: Rice-wheat, Rice-potato, Cotton-wheat-mung, Jowar-wheat-mung, Jowar-wheat-cowpea, Jowar-potato-groundnut

Southern India: Rice-rice-mung, Rice-rice-groundnut, Rice-rice-sesamum

Benefits of Crop Rotation

Enhance Soil Structure: Plant growth is inhibited by soil compaction, which is when the pores in soil are pressed so tightly together that they leave little room for water and nutrients to reach a plant's root, killing the plant. Crop rotation improves soil's physical texture by rotating different plants whose roots reach various soil depths instead of leaving the soil in its compressed state.

Boost Soil Fertility: Continuous planting decreases vital nutrients in the soil. Crop rotation revitalize soil by putting some of those lost nutrients back into the ground. For instance, certain crops can increase potassium levels in the soil, which can then be used by peas or corn. Manure can also be used to improve soil fertility and bacterial diversity levels by enriching soil better than inorganic fertilizer. Microorganisms like fungi and earthworms increase in the soil after manure application. These organisms assist the nutrient cycle process, which can be applied to plants for increased yield.

Prevent Soil Erosion: Nature is unpredictable and heavy rainfall or wind can erode the top layer of soil, impacting crops. Crop rotation with cereal rye, oats, and certain strains of wheat protect topsoil and almost acts as a blanket for crops. These cover crops also provide roots to the soil so they can continue to gain nutrients for optimal conditions. Plants like vetch, rye, and clover can also be used as cover crops. Implementing crop rotation practices can help combat this issue by improving soil structure and reducing erosion. Research indicates that up to 60 percent of eroded soil is carried into streams, lakes, and rivers, contributing to water pollution. By integrating crop rotation methods, farmers can not only reduce soil erosion but also promote healthier, more sustainable farmland.

Improved Soil Nutrients and Nutrient Uptake Regulation: Crop rotation helps the soil renew its nutrients so that less fertilizer is needed. Planting legumes, for instance, boosts soil nitrogen fixation because these plants harbour nitrogen-fixing bacteria. Also, farmers can reduce their use of fertilizer and improve carbon sequestration by adding grasses, cereals, and oil plants to their rotations.

Rotations that include both deep-rooted and nutrient-poor plants are particularly helpful. Growing sorghum, soybeans, alfalfa, potatoes, wheat, and oats — deep-rooted plants that draw water and nutrients up from the soil's depths.

More Efficient Water Use: Crop rotation improves water use efficiency by increasing the amount of organic matter in the soil, which can improve soil structure and water-holding capacity. Also, this method helps to preserve moisture in deep soil layers, which plants can use during droughts. This way, farmers can reduce irrigation water usage.

Decrease Pollution: Crop rotation allows plants to receive optimal nutrients from the soil, which can result in a reduction in fertilizer use – especially if crops are able to effectively utilize the nutrients in and around them. More nutrients in the plant means less in streams and lakes.

Prevents the Concentration of Pests and Diseases: Crop rotation is useful to prevent plants succumbing from insect pests and diseases. Insect pests and diseases can live in the soil, which is why changing the crops each season can deter them. Certain plants are resistant to pathogens called non-host plants that could be used to assist in limiting the spread of diseases and pests.

Crop rotation is used either to starve the pathogen or to kill it with toxic root exudates. To be most effective, rotations between susceptible crops should be three to seven years. A number of soil borne pathogens like *Fusarium* spp., *Verticillium* spp. and *Ralstonia* spp causing wilts can effectively managed by crop rotation. In fields, where rice-solanaceous crop rotation is followed the severity of bacterial wilt is reduced. In sorghum and pigeon pea mixed cropping helps in reducing *Fusarium* wilt because of toxic exudates of sorghum plant parts which eventually reduces the inoculum load and hence the disease.

Reduces Weed Growth: Crop rotation creates a constantly changing environment, so weeds have very little time to adapt to the new conditions. Weeds are opportunistic and seek to steal nutrients from crops and plants. Over time, weeds have become adaptable as some survive with minimal water. Crop rotation allows plenty of crops to grow and creates less space for weeds to inhabit the soil.

Raises Crop Yield: Crop rotation can lead to more yield and profitability. Monocropping involves using a field for one type of crop every single year, which can increase pollution and depletes the soil of nutrients. Ditching this practice in favour of crop rotation can create a better return on investment. Ine one study it was found that a 29 percent improved corn yield compared to continuous cropping when done in a two-year rotation. This yield increased to 48 percent during a four-year crop rotation with the use of a legume cover crop in the winter season for one of the four years. Implementing crop rotation can positively affect farmers' bottom lines, especially during turbulent times as many family farms continue to struggle financially and take on unsustainable levels of debt.

Lower Production Costs and Crop Variety: Food costs are rising due to a variety of external pressures. One of the many crop rotation benefits includes decreased input costs. Crop rotation leads to better soils, fewer weeds, and lower pathogens. According to one survey, farmers who used crop diversity with three or four crops for a period of ten years said they had higher profits and crop yields.

Disadvantages of Crop Rotation

Although crop rotation, as a practice of sustainable agriculture, shows great potential for positive change in farming, it is a resource-intensive process that highly demands competent implementation.

Volume 3 – Special Issue 1-May, 2026

Potential Harm from Inappropriate Implementation: Incorrect application of the crop rotation method does more harm than good. For success, an agriculture producer should have knowledge of what plants can be grown after others. Farmers should be cautious with this method if they have no idea how to keep soil from becoming overloaded with nutrients.

Obligatory Diversifying Crops: Crop rotation is only effective if different plants are grown each time. Diversifying plants necessitates spending time and money on acquiring and mastering various planting techniques, as each plant has specific needs.

Demand For Specific Knowledge and Skills: Crop rotation means a variety of plants; therefore, it demands a deeper set of skills and knowledge regarding each plant type. It also requires different types of machinery and operating them also calls for knowledge.

Impact of crop rotation

Yields: According to the literature, crop yield improvements are one of the immediate economic benefits of crop rotation. As continuous monocropping on the same area of land tends to deplete soil health and reduce yields, these practices alongside other measures (weed control, application of secondary and micronutrients) — are said to bridge yield gaps mostly in dryland rainfed areas with low productivity. For example, an analysis done in dryland zone indicated over 50 percent of the yield could be increased by following crop rotation for major crops (finger millet, pigeon pea, maize, cowpea, horse gram, groundnut, sunflower).

An experiment was conducted to observe crop rotation performance in leguminous and non-leguminous crops in arid zones. In the winter, cumin and psyllium were grown in rotation with sesame and cluster beans. Results showed that yields of 566 kgs/hectare for cumin and 808 kgs/hectare for psyllium were obtained in the treatments of organic inputs and cluster beans in rotation. Here the legumes were found to play a key role, contributing 20-25 percent in yield growth for the next crop of cumin. Another study that evaluated the gross productivity across several locations showed that rice rotations with oilseed, wheat, pulse, and maize gave a rice equivalent yield (REY) of between 7.0 to 10.2 tonnes/ hectare.

Income: The crop rotation practices suggest the practices offer much potential to enhance farmers' income and profitability by diversifying crops over time or space. Crop rotation provides a steady and assured income in times of crop failure, as the next harvest can yield some of the income. A study conducted to determine the gross return of different rice-based

Volume 3 – Special Issue 1-May, 2026

cropping systems across the country found that rice rotations with oilseed, wheat, pulse, and maize gave returns of between INR 40,472/ hectare and 59,110/ hectare.

Gender: A study conducted on crop rotation in a Central Himalayan ecosystem village (Garhwal Himalayas) found it increased women's contribution in terms of working hours, accounting for over 75 percent of total labour (farm and off-farm activities). This shows the increasing role of women in the practice, which is encouraging, but simultaneously it also increases the workload for women farmers.

Soil and Nutrients: Crop rotation mitigates soil health problems by controlling weeds and insect pests, decreasing soil run-off, and building soil health and structure through root systems and plants that have different nutrient demands. In general, sowing restorative crops that build soil health has immense importance in crop rotation practices. Crops with different rooting systems absorb essential nutrients from various soil depths utilizing nutrients more efficiently than sole cropping. Mainly, alternating shallow and deep-rooted crops restores soils. Generally, crops which demand high nutrients should both precede and follow legume-dominated crop combinations. Topographical features also affect crop selection; for instance, alternate cropping of erosion-promoting crops (millet) and erosion-resistant crops (legumes) can be adopted on erosion-prone sloping lands.

Water: With proper planning, resources like water, space, and land are used efficiently in crop rotation practices. The crop types rotated tend to depend on the availability of water and usually two or three crops are taken on a similar field in a year under irrigated conditions. But one of the crops rotated should be a dry one or one that requires less water to avoid damage to the soil by continuous watering. In rainfed areas, after the harvest of Kharif crops, crops requiring less moisture are sown like pulses and cereals. This crop rotation involving less water-intensive successive crops helps balance water requirements. When rotated, crops with different root depths tend to use soil moisture more efficiently. For example, sunflower extracts water from deeper soil layers, while shallow-rooted crops (cole crops) draw it from nearer the surface. Greater water percolation occurs in these systems due to the varied root structure.

Emissions: It seems that certain crop rotations tend to reduce emissions more than monocropping. For example, field experiments in the Indo-Gangetic plains found lower average annual CO_2 emissions in wheat crop rotations (wheat-fallow-paddy, wheat-fallow, wheat-maize, wheat-pulses, wheat-sugarcane, wheat-sorghum, and wheat-vegetable) than from

Volume 3 – Special Issue 1-May, 2026

vegetable crops, which showed higher emission rates. In a similar study, compared to sole wheat (0.71 grams per m^2 per hour), sorghum-berseem rotation (fodder crops) had the highest rate of CO_2 emissions (0.75 grams per m^2 per hour), followed by vegetables grown alone (0.72 grams per m^2 per hour) and vegetables in rotation with mustard (0.72 grams per m^2 per hour). In these crops, the moisture seemed to be responsible for higher emissions rates.

Biodiversity: Introducing a range of varieties to an agroecosystem leads to an increase in natural biodiversity and strengthens the agroecosystem's ability to respond to the stresses created by monocropping. Rotating crops lead to diverse soil biodiversity (flora and fauna) as the leguminous roots excrete organic substances attracting bacteria and fungi. Intercropping and mixed cropping can promote on-farm biodiversity by supporting more organisms than is possible in a single-crop environment.

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Sericulture in Transition: A Decadal Analysis of Production Growth, Technological Change, and Policy Impact in South India (2015–2025)

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ABSTRACT

Sericulture in South India has undergone a significant transformation over the period 2015–2025, driven by technological advancements, expansion of mulberry cultivation, and targeted policy interventions. The present study analyzes decadal trends in raw silk production, changes in cultivation area, employment generation, and the impact of institutional support mechanisms, particularly the Silk Samagra Scheme. Secondary data from government reports and industry sources indicate that raw silk production increased from 28,708 MT in 2014–15 to over 41,000 MT in 2024–25, reflecting substantial gains in productivity and efficiency. The dominance of mulberry silk, accounting for more than 75% of total production, underscores the importance of South India in the national sericulture economy. Technological interventions such as bivoltine hybrid adoption, precision farming practices, mechanization, and digital advisory tools have contributed significantly to improved cocoon quality and yield. Furthermore, the Silk Samagra Scheme has strengthened the sericulture value chain through investments in seed infrastructure, farmer support systems, and post-cocoon processing units. The study concludes that sericulture has evolved into a sustainable and technology-driven rural enterprise, although challenges related to climate variability, disease incidence, and market

Volume 3 – Special Issue 1-May, 2026

fluctuations persist. Future growth will depend on the integration of climate-resilient technologies and strengthening of institutional frameworks.

Keywords

Sericulture; Mulberry cultivation; Bivoltine silk; Silk Samagra Scheme; Rural livelihoods; South India; Agricultural technology; Silk production trends; Value chain development; Sustainable agriculture

Growth Trends in Raw Silk Production (2015–2025)

Year	Raw Silk Production (MT)
2014–15	28,708
2017–18	31,906
2020–21	33,739
2022–23	36,582
2023–24	38,913
2024–25	41,121

Table 1: Growth of Raw Silk Production in India

The data presented in Table 1 reveal a consistent upward trend in raw silk production over the last decade. Production increased by nearly 40–45%, from 28,708 MT in 2014–15 to over 41,000 MT in 2024–25. This growth is largely attributed to improved silkworm hybrids, better farm management practices, and strong institutional support under various government schemes. The steady increase also reflects the growing adoption of scientific sericulture practices among farmers (Economic Times, 2025, 2025).

Composition of Silk Production

Silk Type	Production (MT)
Mulberry	29,892
Eri	7,183
Tasar	1,586

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Silk Type	Production (MT)
Muga	252
Total	**38,913**

Table 2: Production of Different Types of Silk (2023–24)

Table 2 indicates that mulberry silk contributes more than 75% of total production, highlighting its dominance in the Indian sericulture sector. This is primarily due to its large-scale cultivation in South India and the availability of advanced technologies for mulberry-based sericulture. Other silk types such as eri, tasar, and muga contribute relatively smaller shares, reflecting their regional and specialized nature (2024).

Expansion of Mulberry Area and Employment

Parameter	2017–18	2023–24 / 2025
Mulberry Area (ha)	2,23,926	2,63,352
Employment (persons)	~78 lakh	~97.6 lakh

Table 3: Growth in Mulberry Area and Employment

As shown in Table 3, the area under mulberry cultivation increased significantly, accompanied by a rise in employment. The expansion from 2.23 lakh hectares to 2.63 lakh hectares and the increase in employment to nearly 9.76 million persons demonstrate the sector's contribution to rural livelihoods. This growth reflects the labour-intensive nature of sericulture and its suitability for small and marginal farmers (2024, 2025).

Technological Advancements and Productivity Enhancement

The improvement in sericulture productivity over the last decade is largely driven by technological advancements. The introduction of high-yielding bivoltine hybrids and disease-resistant silkworm races has enhanced cocoon quality and silk output. Improved mulberry cultivation practices, including drip irrigation, fertigation, and scientific pruning, have increased leaf yield and quality. Mechanization in rearing and reeling processes has reduced labor dependency and improved efficiency. Additionally, digital innovations such as mobile advisory services and artificial intelligence-based disease detection tools have improved farm-level decision-making and reduced crop losses (2024, 2025).

Policy Support and Silk Samagra Scheme

Government policy interventions have played a pivotal role in the development of sericulture, particularly through the Silk Samagra Scheme implemented by the Central Silk Board. The scheme adopts an integrated approach covering seed production, farm support, infrastructure development, and capacity building. With an estimated outlay of ₹2,161 crore over its implementation phases, the scheme has significantly strengthened the sericulture value chain (Central Silk Board, 2024).

Component	Achievement / Progress
Total Outlay	~₹2,161 crore
Raw Silk Production	Increased from 31,906 MT to ~41,121 MT
Mulberry Area	Increased from 2.23 to 2.63 lakh ha
Employment	Increased from ~78 lakh to ~97.6 lakh
Bivoltine Silk	Significant increase in production and quality
Seed Infrastructure	Strengthened grainages and CRCs
Farmer Support	Subsidies for irrigation, housing, and equipment
Infrastructure	Silk parks, reeling units, clusters
Capacity Building	Training and extension services
Technology	Promotion of mechanization and digital tools

Table 4: Key Achievements under Silk Samagra Scheme (2017–2025)

The achievements summarized in Table 4 demonstrate the comprehensive impact of the Silk Samagra Scheme. The increase in production, area, and employment highlights its effectiveness in enhancing both productivity and livelihoods. The strengthening of seed infrastructure and post-cocoon facilities has improved silk quality and market competitiveness. Overall, the scheme has played a critical role in transforming sericulture into a more organized and technology-driven sector (2024, 2025).

Socio-Economic Impact

Sericulture has emerged as a sustainable livelihood option in South India, providing employment to nearly 10 million people. The sector supports small and marginal farmers due to its low investment requirements and short production cycles. It also promotes women's participation in rural economies. The steady growth in production and expansion of cultivation area have contributed to increased income levels and improved living standards (2025; Kumaresan et al., 2022).

Challenges and Future Prospects

Despite significant progress, the sector faces challenges such as climate variability, disease outbreaks, and price fluctuations. Addressing these challenges requires continued investment in research and development, adoption of climate-resilient technologies, and strengthening of market linkages. The future of sericulture in South India remains promising, with increasing domestic demand and export potential expected to drive further growth (2025).

Conclusion

The decade from 2015 to 2025 marks a period of substantial growth and transformation in sericulture in South India. Technological advancements, expansion of mulberry cultivation, and strong policy support, particularly through the Silk Samagra Scheme, have significantly improved production, productivity, and rural livelihoods. Sustained efforts in innovation and infrastructure development will be essential to ensure long-term sustainability and global competitiveness.

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