AGRIALLIS

SCIENCE FOR AGRICULTURE AND ALLIED SECTOR

VOLUME 8 ISSUE 4

Apr. 2026

A Monthly Magazine

Online ISSN 2582-368X

www.agriallis.com

Growing seed

Editorial Board

Contents

www.agriallis.com

AGRIALLIS

Science for Agriculture and Allied Sector: A Monthly Magazine

Volume 8, Issue 4

Article Id
AL04507

SPEED BREEDING IN VEGETABLES: ACCELERATING GENETIC GAINS FOR THE FUTURE

Email

kousihort1998@gmail.com

R. Kousalya

Department of Vegetable Science, RVS Padmavathy College of Horticulture, Sempatti, Tamil Nadu, India

Vegetable crops are an important component of human nutrition and food security as they provide essential vitamins, minerals, fiber, and antioxidants. The demand for vegetables is increasing rapidly due to population growth, urbanization, and rising awareness about healthy diets. To meet this demand, the development of improved vegetable varieties with high yield, better quality, and resistance to pests, diseases, and abiotic stresses is essential.

Conventional plant breeding methods have successfully contributed to crop improvement; however, these methods are often time-consuming. The development of a new variety through traditional breeding may require 6–12 years or more**,** depending on the crop and breeding objectives. With the increasing challenges posed by climate change, emerging pests and diseases, and the need for sustainable agricultural production, faster breeding approaches have become necessary.

Speed breeding is an innovative technique that accelerates plant growth and shortens the breeding cycle by manipulating environmental conditions such as photoperiod, temperature, and light intensity. This approach enables breeders to grow multiple generations of crops within a single year, thereby significantly reducing the time required for variety development (He *at al.* 2024). Speed breeding is gaining importance in modern crop improvement programs and is being applied to several crops, including vegetable crops.

Principles of Speed Breeding

The goal of speed breeding is to accelerate plant development from germination to seed set (Blinkov *et al.* 2025). Key principles includes:

1. **Extended Photoperiod** – Providing 20–24 hours of light/day to promote early flowering and rapid growth.
2. **Temperature Optimization** – Adjusting day/night temperatures to maximize vegetative growth without causing stress.
3. **Early Seed Harvesting** – Collecting seeds before full maturity for the next generation.
4. **Controlled Environment Facilities** – Using growth chambers, greenhouses, or vertical farms to maintain ideal growth conditions year-round.

Application of Speed Breeding in Vegetable Crops

Tomato (*Solanum lycopersicum*)

Tomato is one of the most extensively studied vegetable crops in speed breeding programs due to its relatively short life cycle and high adaptability to controlled environmental conditions**.** The use of extended photoperiods and optimized temperature regimes significantly accelerates flowering and fruit development.

Hu *et al.*, (2025) Speed breeding of tomato was evaluated in a plant factory using cultivars Zuanhongmeili and Xiaokeai. Under a 12 h photoperiod**,** light intensities of 300–400 $\mu mol \cdot m^{-2} \cdot s^{-1}$ accelerated development, enabling flower bud emergence at ~25 DAS and germinable seed harvest at 60–63 DAS**.** Using 350 $\mu mol \cdot m^{-2} \cdot s^{-1}$**,** photoperiod optimization showed that a 20 h photoperiod further promoted growth and reproductive development. Under these conditions, seeds were harvested at 72–76 DAS. Overall, optimized light regimes can enable up to six tomato generations per year in controlled environments, supporting rapid breeding

Speed breeding in tomato has been widely used for the rapid development of disease-resistant varieties**,** particularly against pathogens such as bacterial wilt and late blight. Additionally, it facilitates the improvement of fruit quality traits**,** including firmness, soluble solids content, and shelf life. The approach is also useful in developing heat-tolerant and climate-resilient tomato cultivars**.**

Capsicum (*Capsicum annuum*)

Capsicum, including both sweet pepper and chilli pepper, generally exhibits a longer reproductive phase compared to other vegetable crops. However, speed breeding techniques can significantly reduce the time required for generation advancement.

In a study by Liu *et al.*, (2022)**,** two hot pepper varieties (Xiangyan 55 and Xiangla 712) grown under controlled light conditions flowered at about 39.9 days after sowing under PPFD 420 μmol m^{-2} s^{-1} with a 12-h photoperiod, producing viable seeds by 82 days; supplementation with far-red light (R:FR = 2.1) accelerated fruit ripening and improved seed germination, enabling up to four generations per year. Similarly, Choi *et al.*, (2023) demonstrated that a 20-h photoperiod combined with far-red light reduced the time to first harvest to about 95 days compared with 170 days in control conditions and enabled a seed-to-seed cycle of ~110 days, while genetic analysis identified flowering-related genes such as AP2, WOX4, FT, and GI**,** highlighting the effectiveness of speed breeding in accelerating pepper breeding and genetic improvement.

The technology has proven particularly useful for the rapid development of virus-resistant cultivars, including resistance to tomato leaf curl virus and other economically important pathogens. Speed breeding also facilitates the development of high-yielding hybrid parental lines and the improvement of fruit quality and capsaicin content in chilli peppers**.**

Lettuce (*Lactuca sativa*)

Lettuce is well suited for speed breeding because of its short life cycle and rapid transition from vegetative growth to reproductive development under extended photoperiod conditions**.** The crop shows strong responsiveness to controlled environmental manipulation.

Optimal conditions for lettuce speed breeding include a photoperiod of 20–22 hours and temperatures maintained between 20–24°C**.** Under conventional breeding systems, lettuce generally requires 3–4 months to complete a generation**.** Speed breeding can reduce this duration to approximately 30–40 days, allowing five to six generations per year. Zhang *et al.*, (2024) reported that Plant Factory Technology (PFT) provides a controlled agricultural environment where factors such as light regimes, temperature, CO_2 concentration, and nutrient supply can be precisely managed. Using lettuce as a model crop, their study demonstrated that PFT can accelerate breeding processes and improve vegetable nutritional quality within a shorter production period compared with conventional open-field cultivation.

This rapid cycling greatly enhances breeding efficiency for traits such **as** bolting resistance, leaf morphology, color development, and nutritional quality. Additionally, speed breeding is useful for developing functional lettuce varieties with enhanced levels of vitamins and antioxidants**.**

Spinach (*Spinacia oleracea*)

Spinach is another leafy vegetable crop that responds well to extended photoperiod conditions. The crop is particularly sensitive to day length, which can be exploited to accelerate flowering and seed production.

Ibrahim *et al.,* (2025) reported that LED-based speed breeding with extended photoperiods (13–19 h) significantly enhanced spinach vegetative growth, with a 19-h photoperiod producing the highest stem length, root length (≈30% increase), leaf area, and plant weight while reducing necrosis and chlorosis.

Speed breeding has been effectively applied to accelerate the development of spinach cultivars with improved nutritional quality, including higher iron and folate content, as well as resistance to diseases such as downy mildew**.**

Brassica Vegetables (Cabbage, Cauliflower, and Broccoli)

Brassica vegetable crops generally have longer breeding cycles due to their requirement for vernalization to induce flowering**.** However, modified speed breeding protocols that incorporate controlled temperature treatments and extended photoperiods can significantly shorten the breeding cycle.

Typical speed breeding conditions include a photoperiod of approximately 20 hours, with temperatures maintained around 22–24°C during vegetative growth, followed by appropriate vernalization treatments to induce flowering. While traditional breeding cycles for Brassica crops may require 6–8 months per generation, speed breeding can reduce this period to approximately 90–120 days, allowing three to four generations per year**.**

Speed breeding in Brassica vegetables has been used to accelerate the development of biofortified varieties, climate-resilient cultivars, and pest-resistant lines. The approach is particularly valuable in hybrid breeding programs where rapid development of parental lines is required.

Advantages and Limitations

Speed breeding offers several advantages in vegetable crop improvement. The most important advantage is the reduction in breeding time, as multiple generations can be grown within a single year. This significantly accelerates the development of new varieties with desirable traits.

Another advantage is the rapid development of pure lines in self-pollinated crops using techniques such as single seed descent. Speed breeding also enhances research in plant genetics, physiology, and molecular breeding by enabling faster generation turnover.

Furthermore, speed breeding allows breeders to respond quickly to emerging agricultural challenges such as new pests, diseases, and climate stresses. When combined with modern genomic tools, it can greatly improve the efficiency and precision of breeding programs.

Despite its advantages, speed breeding also has certain limitations. Establishing controlled environment facilities such as growth chambers and glasshouses requires significant investment. The cost of artificial lighting and temperature control may also be high due to energy requirements (Samantara *et al.*, 2022).

In addition, not all vegetable crops respond equally to extended photoperiods and controlled conditions. Some crops may require specific environmental conditions or may exhibit physiological stress under prolonged lighting. Therefore, careful optimization of growth conditions is necessary for successful speed breeding.

Future Prospects

Speed breeding is expected to play an increasingly important role in vegetable crop improvement in the future. Advances in controlled environment agriculture, energy-efficient lighting systems, and automation technologies are making speed breeding more accessible and cost-effective.

The integration of speed breeding with modern molecular breeding techniques such as marker-assisted selection, genomic selection, and genome editing will further enhance its potential in developing improved vegetable varieties.

Speed breeding can also support research on climate-resilient crops by enabling rapid evaluation of plant responses to environmental stresses. In addition, it can facilitate the development of nutrient-rich vegetable varieties that contribute to improved human health and nutrition.

As global demand for vegetables continues to increase, speed breeding will become an essential tool for accelerating crop improvement and ensuring sustainable agricultural production.

Conclusion

Speed breeding is a promising and innovative approach for accelerating vegetable crop improvement. By manipulating environmental factors such as photoperiod, temperature, and light intensity, this technique enables rapid plant growth and multiple generations within a year.

The adoption of speed breeding in vegetable breeding programs can significantly reduce the time required to develop new varieties with improved yield, quality, and stress resistance. Although certain limitations exist, ongoing technological advancements and integration with modern breeding tools are expected to enhance its efficiency and applicability.

Overall, speed breeding represents a powerful strategy for meeting the growing demand for vegetables and addressing future challenges in agriculture.

Reference

Blinkov, A. O., Kroupin, P. Y., Dmitrieva, A. R., Kocheshkova, A. A., Karlov, G. I., & Divashuk, M. G. (2025). Speed Breeding: Protocols, application and achievements. *Frontiers in Plant Science*, *16*, 1680955.

Choi, H., Back, S., Kim, G. W., Lee, K., Venkatesh, J., Lee, H. B., ... & Kang, B. C. (2023). Development of a speed breeding protocol with flowering gene investigation in pepper (Capsicum annuum). *Frontiers in Plant Science*, *14*, 1151765.

He, R., Ju, J., Liu, K., Song, J., Zhang, S., Zhang, M., ... & Liu, H. (2024). Technology of plant factory for vegetable crop speed breeding. *Frontiers in Plant Science*, *15*, 1414860.

Hu, Y., He, X., Ju, J., Zhang, M., Yang, X., Song, J., & Liu, H. (2025). A Scheme for Speed Breeding of Tomato Through Modification of the Light Environment. *Horticulturae*, *11*(12), 1488.

Ibrahim, M. S., Ikhajiagbe, B., & Enerijiofi, K. E. (2025). Photoperiodic influence of light-emitting diode (LED) on vegetative parameters of Spinacia oleracea L.(Spinach). *Studia Universitatis Babeş-Bolyai, Biologia*, *70*(2).

Liu, K., He, R., He, X., Tan, J., Chen, Y., Li, Y., ... & Liu, H. (2022). Speed breeding scheme of hot pepper through light environment modification. *Sustainability*, *14*(19), 12225.

Samantara, K., Bohra, A., Mohapatra, S. R., Prihatini, R., Asibe, F., Singh, L., ... & Varshney, R. K. (2022). Breeding more crops in less time: A perspective on speed breeding. *Biology*, *11*(2), 275.

Zhang, L., Huang, T., Zhang, Q., Wei, S., Contreras, V. H. E., Peng, J., ... & Yang, X. (2024). Plant factory technology as a powerful tool for improving vegetable quality: lettuce as an application example. *Vegetable Research*, *4*(1).

Article Id
AL04508

IMPROVING FARMERS' INCOME THROUGH SCIENTIFIC CROP PLANNING: ROLE OF AGRONOMY AND VEGETABLE SCIENCE

Email

drvgp126@gmail.com

[1]Mala Dasari Pavan and [2]G Prameela*

[1]Department of Vegetable Science, IGKV, Raipur, Chattisgarh-492012, India

[2]Department of Agronomy, OUAT, BBSR, Odisha-751003, India

Boosting farmers' incomes is a key goal in sustainable agriculture, especially in nations like India, where smallholder operations dominate. Strategic crop planning, guided by agro-climatic zones, soil testing, market trends, and efficient resource use, greatly elevates productivity and earnings. Agronomy advances through optimised cropping patterns, balanced nutrient and irrigation strategies, conservation techniques, and resilient methods that stabilise yields and reduce costs. Vegetable science amplifies gains through superior hybrids, greenhouse systems, counter-seasonal harvests, precision techniques, and holistic pest control. Incorporating high-value vegetables, streamlining inputs and embracing cutting-edge methods markedly boost efficiency and profitability. Merging agronomic expertise with innovative vegetable technologies fosters enduring growth, lowers risks and bolsters livelihoods. Thus, evidence-based crop strategies powered by agronomy and vegetable science offer a clear route to double the farm income alongside ecological balance and food nutrition.

Strategic crop planning significantly boosts farmers' earnings by directing thoughtful crop choices and sequencing based on soil quality, precipitation patterns, available farm inputs, and market prospects. Studies in semi-arid conventional farming areas reveal that growers routinely employ organised rotations like cereal-legume or cereal-oilseed setups to sustain soil nutrients, curb pests and diseases, and optimise limited water supplies. These deliberate cropping arrangements steady production amid unpredictable weather while regulating dependence on costly off-farm resources. Meanwhile, growers' choices adapt to irregular rains, intensifying land use from population growth, and shifting demand signals, responsive planning tactics. Integrating evidence-based agronomic expertise with on-farm insights, this approach advances land efficiency, crop variety, and hazard mitigation-ultimately elevating output and livelihoods, especially in India. (Kumar *et al*.,2019).

Scientific Crop Planning: Concepts, Principles and Practical Approaches

Scientific crop planning draws on proven agronomic practices like crop rotation, diversified cropping patterns, and optimal resource use-techniques deeply embedded in India's traditional agriculture. Field studies over extended periods show that growers deliberately follow sequences such as cereal-legume, cereal-oilseed, or crop-fallow to preserve soil nutrients, suppress pests and diseases, retain moisture, and align food security with commercial demands. Yet, real-world rotations frequently adapt to erratic rainfall, volatile prices, land scarcity from population growth, and innovations, leading to briefer, more versatile cycles. Growers often favour integrated systems, shifting between monocropping, mixed cropping, and fallow periods, to counter weather variability and uphold yields. Notably, legumes in these cycles cut reliance on synthetic fertilisers by naturally replenishing soil fertility. Overall, such planning fuses age-old wisdom with contemporary agronomic insights to deliver tailored, resilient, and input-saving methods that boost output, environmental health, and farm earnings. (Jodha *et al*.,1990).

Role of Agronomy in Enhancing Productivity and Profitability

Agronomy drives higher productivity and profits by ramping up cropping density and ensuring consistent yields via research-backed rotations and holistic systems. Findings reveal that time-tested sequences of one to three years preserve soil health and moisture levels while limiting pest and disease pressures. Incorporating legumes into cereal frameworks substantially boosts nutrient profiles, decreasing dependence on commercial fertilisers and trimming expenses. Growers apply versatile patterns-mixing solo crops, intercrops, and rest periods-to cope with unpredictable precipitation, bolstering output reliability and hazard mitigation. These measures maximise land productivity and slash operational costs, yielding stronger margins and enduring financial uplift for farming communities. (Xing *et al*.,2024).

Contribution of Vegetable Science in Income Diversification

Vegetable science significantly boosts farmers' earnings through diversification into premium vegetable crops, counter-seasonal yields, and cutting-edge growing techniques. Structures like polyhouses, net houses, and low-cost tunnels let growers extend production beyond standard seasons, capturing higher market rates. These setups deliver ideal environments that lift output, upgrade produce quality, and streamline water and nutrient application. Year-round vegetable farming generates steady revenue streams while buffering against price swings in glut periods. Enhanced cultivars combined with holistic management further amplify efficiency and returns. Overall, vegetable science charts a resilient course for elevating farm profits and securing rural livelihoods.

Integrated Approaches: Sustainable Practices for Higher Returns

Combining agronomic fundamentals with cutting-edge vegetable growing methods creates resilient routes to elevated farm profits. Research highlights how rotation systems, legume integration, water-saving techniques, and varied cropping boost soil health while curbing external input needs, as protected structures and refined management deliver superior yields and produce standards. These unified tactics optimise land, water, and fertiliser use, counter weather uncertainties, and support ongoing revenue. Linking evidence-driven planning, conservation efforts, and demand-focused output helps growers secure consistent production, trim expenses, and lift earnings-fostering enduring viability and financial stability. (Anjanappa *et al*.,2014)

Future Strategies and Policy Support for Doubling Farmers' Income

Evidence-based crop planning shifts farmers from subsistence to market-focused farming, with agronomy boosting yields via optimized rotations, nutrient balance, smart irrigation, timely sowing, and climate-resilient varieties. Vegetable science enhances income through high-value crops, protected cultivation, off-season hybrids, and value-added products for steady returns. Future success hinges on precision tech, digital tools, FPOs, and policies for irrigation, credit, insurance, and extension driving sustainable productivity and financial security.

Summary

Raising farm incomes demands a deliberate move to data-driven crop strategies tailored to terrain, weather, and sales potential. Implementing rotations, mixed cropping patterns, pulse crops, targeted fertilisation, and optimised watering elevates soil quality, evens out harvests, and trims operational outlays. Expanding into lucrative vegetables via non-traditional seasons, covered farming, and elite hybrids ramps up efficiency and earnings from limited plots. Fusing time-honoured practices with today's agronomy and vegetable innovations heightens resource

effectiveness, dampens threats, and fosters reliable cash generation. Ultimately, yield boosts paired with variety expansion build robust operations and lasting fiscal security.

Conclusion

Lasting gains in farmers' earnings emerge from blending proven agronomic methods with state-of-the-art vegetable growing practices. Smart resource handling, crop variety expansion, and uptake of weather-adaptive, demand-driven tactics deliver elevated and reliable profits. Bolstering producer groups, broadening tech access, and upgrading facilities, loans, coverage, and advisory support prove vital for this shift. A unified strategy of research, novelty, and enabling policies drives superior outputs, lower hazards, and enduring economic resilience for rural growers.

Reference

Anjanappa, M., Venkatesha, J., & Kumara, B. S. (2014). Protected cultivation technologies for off-season vegetable production: A review. *Journal of Horticultural Sciences, 9*(1), 1-14.

Jodha, N. S., & Singh, R. P. (1990). Crop rotation in traditional farming systems in selected areas of India. *Economic and Political Weekly*, A28-A35.

Kumar, R., Kumar, S., Yashavanth, B. S., & Meena, P. C. (2019). Natural Farming practices in India: Its adoption and impact on crop yield and farmers' income. *Indian journal of agricultural economics*, *74*(3), 420-432.

Xing, Y., & Wang, X. (2024). Precision agriculture and water conservation strategies for sustainable crop production in arid regions. *Plants*, *13*(22), 3184.

AGRIALLIS
Science for Agriculture and Allied Sector: A Monthly Magazine
Volume 8, Issue 4

Article Id
AL04509

AQUAMIMICRY: NATURE-BASED SELF-SUSTAINING AND CLOSED-LOOP AQUACULTURE ECOSYSTEMS

Email

gokul.aqcpb204@cife.edu.in

Gokul S

Aquaculture Division, ICAR-Central Institute of Fisheries Education, Off Yari Road, Panch Marg, Mumbai – 400 061, MS, India

Aquaculture is growing fast to meet the world's demand for fish and shrimp to fulfil the protein requirements of the world. World fish per capita consumption rate increased in last two decades in twofold. Global fisheries and aquaculture produced a record 223.2 million tonnes in 2022. About 185.4 million tonnes of aquatic animals and 37.8 million tonnes of algae. In that, 89% of all aquatic animal production is used for human food (about 20.7 kg per person), with the rest used for non-food items like fishmeal and oil. Aquaculture alone hit 130.9 million tonnes, worth $312.8 billion, making up 59% of all production. Aquaculture overtook capture fisheries for the first time, producing 94.4 million tonnes of aquatic animals (51% of the world's total and 57% of food-grade production). In this, most of the production comes from the modern semi-intensive and intensive aquaculture technologies like biofloc, aquaponics, RAS, IMTA etc compare to traditional fish farming. However, traditional fish farming often faces challenges such as poor water quality, disease outbreaks, and high feed costs. A new method called aquamimicry is helping solve these issues by working with nature instead of against it.

What is Aquamimicry?

Aquamimicry is a mimicking natural estuarine conditions by creating zooplankton diversity (mainly copepods) by addition of fermented carbon source such as rice bran is used with some probiotics like bacillus species *B. subtilis* and *B. licheniformis*, Lactobacillus species (*L. acidophilus*, *L. plantarum*, *L. fermentum*) and etc. that create phytoplankton and zooplankton population considered as supplemental nutrition and beneficial bacteria improve water quality in fish and shrimp cultures and mimic natural pond conditions.

History

In 1990s, mass mortality and disease outbreaks occurred in shrimp industry of Thailand. At that time, in some extensive shrimp ponds, they were growing healthy and disease-free. As the farmers, had limited resources available, so using these practices formulation of feed as a substitute by only rice bran. Because of its impending reason for the enhanced performance in the pond ecosystem. Over time, this protocol gradually developed after extensive trial and error. Two shrimp farmers (Sutee Prasertmark and Veerasan Prayotamornkul) in Thailand were who established this scientific aquamimicry technique in 2013.

Aquamimicry vs Biofloc

Although similar to biofloc technology, aquamimicry has some differences:

Feature	Aquamimicry	Bio floc
Main food	Zooplankton (copepods)	Microbial flocs
Aeration	Moderate	High
Feed input	Low	Moderate
System type	Natural-based	Microbial-based

Step-by-step Process

1. **Pond Preparation -** Pond filled with clean water about 80-100 cm depth. Add probiotics (e.g., Bacillus and Lactobacillus spp.). Drag chains for 7 days to mix soil well. Apply tea seed cake (~20 ppm) and fermented rice bran (50-100 ppm). Keep aeration running. Plankton (like copepods) develop in ~2 weeks.

2. **Carbon Source Preparation** - Mix rice/wheat bran with water (1:5-10 ratio) and probiotics. Ferment for 24 hours (pH 6-7).

3. **Application in Pond -** Add fermented rice bran (FRB) about 500-1000 kg/ha, adjusting for turbidity (Secchi disk: 30-40 cm ideal). Add probiotics monthly. Phytoplankton, zooplankton, and biocolloids grow.

4. **Stocking Phase** - Stock post-larvae (10–20/m^2) after ~1 week. System turns biologically active.

5. **Natural Food Production** - Copepods and zooplankton take over; minor biofloc (<25 mL/L) forms.
6. **Grow-Out Pond System -** Use paddlewheels for continuous water circulation. Stock fish such as catfish or milkfish to stir detritus. Worms and benthic organisms offer additional nutrition.
7. **Sedimentation Pond** - Solids settle (4 m deep at center, 2m at edges). Low-density bottom feeders clean debris and waste reduced.
8. **Biofilter Pond** - Water flows in from sedimentation pond. Fish like tilapia absorb excess nutrients and purified with low nitrogen waste.
9. **Water Recirculation** - Clean water loops back to grow-out pond. Closed-loop system.
10. **System Output -** Stable water quality, lower feed costs, natural plankton nutrition, fewer diseases/chemicals.

Advantages of Aquamimicry

- This method enhancements productivity and sustainability in aquaculture. It keeps water clean by using microbes to break down waste, while balancing pH and oxygen levels. It reduces feed costs by cultivating natural plankton in the pond, thereby reducing reliance on expensive commercial feeds.
- This system fights against diseases too, as good bacteria stop harmful pathogens, often skipping antibiotics altogether and enhance immunity and health
- Environmentally, it uses little water and cuts pollution. Overall, fish grow faster, survive better, stay healthier, and resist stress due to balanced natural nutrition.
- Natural live feed is rich in proteins, fatty acids, and vitamins, it improves growth and survival of fish larvae and reducing the need for expensive artificial feed.
- Self-sustaining aquaculture ecosystem and Closed-loop system.

Conclusion

Conclusively, aquamimicry is a basic, environmentally friendly and sustainable alternative to intensive aquaculture systems like biofloc technology. It creates a self-regulating and balanced culture environment by imitating natural processes of aquatic ecosystems and improving the microbial and planktonic food webs. The system enhances recycling of nutrients, bioremediation of microbes and natural feeds which in effect enhance water quality, lowering the input cost and dependency on artificial feeds. Moreover, the simulation of natural pond conditions can enhance the growth performance, survival and health of cultured organisms due to the alleviation of stress levels and development of immunity. Hence, aquamimicry is an emerging, low-input aquaculture method that is consistent with the principles of ecological sustainability and ecosystem-based management.

Reference

Khanjani, M. H., Mozanzadeh, M. T., & Fóes, G. K. (2022). Aquamimicry system: a sutiable strategy for shrimp aquaculture–a review. *Ann. Anim. Sci*, *22*(4), 1201-1210.

Deepti, M., Meinam, M., Devi, N. C., Singh, S. K., & Devi, W. M. (2024). Aquamimicry (Copefloc technology): an innovative approach for sustainable organic farming with special reference to shrimp aquaculture. *Blue Biotechnology*, *1*(1), 5.

Romano, N. (2017). Aquamimicry: A revolutionary concept for shrimp farming. *Global aquaculture advocate*, *10*, 1-6.

Khanjani, M. H., da Silva, L. O. B., Fóes, G. K., do Nascimento Vieira, F., Poli, M. A., Santos, M., & Emerenciano, M. G. C. (2023). Synbiotics and aquamimicry as alternative microbial-based approaches in intensive shrimp farming and biofloc: Novel disruptive techniques or complementary management tools? A scientific-based overview. *Aquaculture*, *567*, 739273.

Islam, M. S., Das, M., Chakroborty, K., Lee, J. M., Islam, M. R., & Rafiquzzaman, S. M. (2024). Aquamimicry improves the growth performance and immunity of black tiger shrimp (Penaeus monodon) in low saline ponds. *Aquaculture Reports*, *36*, 102082.

Ghosh, A. K., & Hasanuzzaman, A. F. M. (2025). Aquamimicry in aquaculture: a nature-based approach to improve growth, immunity, and environmental sustainability. *Aquaculture International*, *33*(6), 421.

www.agriallis.com

AGRIALLIS

Science for Agriculture and Allied Sector: A Monthly Magazine

Volume 8, Issue 4

Article Id
AL04510

BIOTECHNOLOGY AT THE SUSTAINABILITY CROSSROADS: RE-ENGINEERING INDIAN AGRICULTURE FOR PRODUCTIVITY, RESILIENCE AND NUTRITION

[1]Sourav Mandal* and [2]Ayushi Choudhary

Email

sourav1999mandal@gmail.com

[1]Odisha University of Agriculture and Technology, Bhubaneswar, Odisha, India

[2]Hemvati Nandan Bahuguna Garhwal University, Srinagar, Uttarakhand, India

Indian agriculture faces the dual challenge of feeding a rapidly growing population while conserving natural resources under increasing climate variability. Biotechnology has emerged as a powerful enabler of sustainable agricultural intensification through genetic improvement, microbial interventions, and integration with precision technologies. This review critically synthesizes evidence from three recent peer-reviewed review articles to present a coherent, plagiarism-free, and scientifically grounded analysis of how modern biotechnology contributes to sustainable agriculture, with special reference to India. The paper integrates advances in genetic engineering, CRISPR/Cas genome editing, tissue culture, molecular breeding, biofertilizers, biofortification, and data-driven precision agriculture. Emphasis is placed on productivity gains, environmental sustainability, nutritional security, and socio-economic implications. Regulatory, ethical, and adoption challenges are discussed, followed by future research priorities. The review concludes that biotechnology, when aligned with sound policy and farmer-centric deployment, can act as a cornerstone for climate-resilient and nutrition-sensitive agriculture in India.

Agriculture remains central to India's economy, livelihoods, and food security, employing a significant share of the population while supplying food to over 1.4 billion people (Okechukwu *et al*., 2024). However, conventional input-intensive farming systems have resulted in declining soil health, groundwater depletion, biodiversity loss, and increased greenhouse gas emissions (Singh *et al*., (2025). Simultaneously, climate change has intensified abiotic stresses such as drought, heat, and salinity, threatening crop productivity and stability (Singh *et al*., 2025).

Sustainable agriculture seeks to balance productivity, environmental stewardship, and socio-economic equity. Biotechnology, broadly defined as the application of biological systems and processes for practical use, offers tools to achieve this balance (Singh *et al*., (2025). Recent advances in plant, microbial, and digital biotechnology provide opportunities to enhance yields, reduce chemical inputs, improve nutritional quality, and strengthen resilience to climate stress (Okechukwu *et al*., 2024). This review synthesizes insights from three contemporary review papers to provide an integrated and original assessment of biotechnology's role in sustainable agriculture, with a particular focus on the Indian context.

Conceptual Framework: Biotechnology and Agricultural Sustainability

Sustainability in agriculture is commonly evaluated across three interlinked dimensions: productivity, environmental integrity, and social viability. Biotechnology contributes to each dimension through distinct yet interconnected pathways:

- **Productivity:** Genetic improvement, molecular breeding, and tissue culture enhance yield potential and yield stability.
- **Environmental sustainability:** Biofertilizers, biopesticides, and stress-tolerant crops reduce reliance on synthetic agrochemicals and conserve natural resources.
- **Social and nutritional sustainability:** Biofortification and nutraceutical crops address hidden hunger, while income gains from improved technologies support rural livelihoods.

The reviewed literature consistently emphasizes that biotechnology should complement, not replace, agroecological principles and traditional knowledge systems.

Evolution of Agricultural Biotechnology

From Conventional Breeding to Molecular Approaches: Early agricultural biotechnology involved domestication and selective breeding. The Green Revolution marked a major milestone by introducing high-yielding varieties, but it also increased dependence on external inputs. The emergence of molecular biology enabled marker-assisted selection (MAS), genomic selection, and transgenic approaches, allowing precise manipulation of traits such as pest resistance and nutrient use efficiency.

Contemporary Biotechnological Tools: Modern agricultural biotechnology encompasses genetic engineering, CRISPR/Cas-based genome editing, tissue culture, microbial biotechnology, and bioinformatics. These tools shorten breeding cycles, increase precision, and expand the genetic base available for crop improvement.

Genetic Engineering and Genetically Modified Crops

Genetically modified (GM) crops represent one of the most visible applications of biotechnology. Traits such as insect resistance and herbicide tolerance have contributed to yield gains and reduced pesticide use. In India, Bt cotton remains the only GM crop approved for commercial cultivation and has demonstrated substantial benefits in terms of productivity and income.

However, the adoption of GM crops has been uneven due to regulatory delays, public perception issues, and biosafety concerns. The literature highlights that while GM technology has strong scientific backing, transparent risk assessment, public engagement, and context-specific policy frameworks are essential for wider acceptance.

CRISPR/Cas Genome Editing: Precision for Sustainability

CRISPR/Cas9 technology represents a paradigm shift in crop improvement by enabling targeted genome modifications without introducing foreign DNA. Compared to earlier gene-editing tools, CRISPR is faster, more precise, and cost-effective.

Applications in Crop Improvement: Studies reviewed report successful applications of CRISPR in enhancing yield, disease resistance, drought tolerance, and nutritional quality in major crops such as rice, wheat, and maize. Genome editing has also been used to knock out negative regulators of stress tolerance, improving crop performance under adverse conditions.

Regulatory and Ethical Considerations: Despite its potential, the deployment of CRISPR-edited crops in India depends on regulatory clarity. Distinguishing genome-edited crops from transgenic organisms in policy frameworks is critical to accelerate innovation while ensuring biosafety.

Tissue Culture and Micropropagation

Plant tissue culture plays a crucial role in producing disease-free, uniform, and high-quality planting material. Micropropagation has been widely adopted in horticultural crops, ornamentals, and plantation crops, contributing to higher productivity and rapid dissemination of elite genotypes.

In the Indian context, tissue culture has supported the second Green Revolution by enabling large-scale multiplication of improved varieties and conserving valuable germplasm.

Molecular Breeding and Marker-Assisted Selection

Marker-assisted selection bridges conventional breeding and modern biotechnology. By using DNA markers linked to desirable traits, breeders can select superior genotypes at early growth stages, reducing time and cost.

The reviewed literature documents successful use of MAS in developing disease-resistant and nutrient-efficient varieties of rice, wheat, and millets in India. Integration of genomic selection further enhances breeding efficiency for complex traits such as yield and climate resilience.

Microbial Biotechnology: Biofertilizers and Biopesticides

Biofertilizers: Biofertilizers based on nitrogen-fixing, phosphate-solubilizing, and potassium-mobilizing microorganisms improve nutrient availability and soil health. Evidence indicates that biofertilizers can enhance yields while reducing dependence on chemical fertilizers, particularly in resource-constrained farming systems.

Biopesticides: Biopesticides derived from bacteria, fungi, and plant extracts offer environmentally friendly alternatives to chemical pesticides. Their role in integrated pest management supports biodiversity conservation and reduces residue risks.

Biofortification and Nutritional Security

Malnutrition, particularly micronutrient deficiency, remains a major public health challenge in India. Biofortification through conventional breeding, transgenics, and genome editing enhances the nutrient content of staple crops.

The reviewed studies highlight the development of iron-, zinc-, and vitamin-rich varieties of rice, wheat, and millets. Biofortified crops provide a sustainable, cost-effective approach to improving nutrition among vulnerable populations.

Integration with Precision Agriculture and Digital Technologies

The convergence of biotechnology with precision agriculture and big data analytics enables site-specific crop management. Sensors, remote sensing, and decision-support systems optimize input use, while biotechnological innovations ensure that crops respond efficiently to managed environments.

This integration enhances resource-use efficiency, reduces environmental footprints, and improves farm profitability.

Socio-Economic and Policy Dimensions

While biotechnology offers significant benefits, its impact depends on accessibility, affordability, and farmer awareness. Smallholder-centric approaches, capacity building, and public-sector research are essential to avoid technological exclusion.

Robust regulatory systems, transparent communication, and stakeholder engagement are repeatedly emphasized in the literature as prerequisites for responsible biotechnology deployment.

Challenges and Limitations

Key challenges identified across the reviewed studies include:

- Regulatory uncertainty and lengthy approval processes
- Public perception and misinformation
- Intellectual property and seed sovereignty concerns
- Infrastructure and funding constraints

Addressing these challenges requires coordinated efforts among scientists, policymakers, industry, and farming communities.

Future Research Directions

Future research should prioritize:

- Climate-resilient and low-input crop ideotypes
- Integration of genome editing with conventional breeding
- Expansion of microbial consortia for soil health
- Digital-biotechnology convergence for smallholder farming
- Long-term sustainability and impact assessments

Conclusion

This review highlights that biotechnology provides a comprehensive toolkit for advancing sustainable agriculture in India by improving crop productivity, resilience, and nutritional security. Genetic improvement strategies, microbial inputs, and the integration of digital and precision technologies collectively contribute to efficient resource use and reduced environmental impacts. However, biotechnology should not be considered a standalone solution. Its effectiveness depends on supportive policies, robust biosafety regulations, farmer awareness, and alignment with agroecological practices and local farming conditions. When implemented responsibly and inclusively, biotechnology can play a pivotal role in strengthening climate-resilient and sustainability-oriented agricultural systems in India.

References

Okechukwu F, Nwawuba SU. Biotechnology for sustainable agriculture in India: Promise and challenges. *Journal of Emerging Technologies and Innovative Research*. 2024;11(8):383–402. ISSN: 2349-5162.

Singh M, Singh RP, Patra A, Singh H, Ram RM. Application and recent trends of biotechnology in sustainable agriculture: A brief review. *Journal of Advances in Biology & Biotechnology*. 2025;28(1):846–858.

Singh S, Ravikumar B, Singh K. Biotechnology and technological advancements in agriculture: A review. *International Journal of Research in Agronomy*. 2025;8(5):328–338.

Article Id
AL04511

BLUE CARBON ECOSYSTEMS AS A TOOL FOR AQUATIC ENVIRONMENT MANAGEMENT

Email
vishnupriyashanmugam16@gmail.com

S.Vishnupriya
Department of Aquatic Environment Management, Kerala University of Fisheries and Ocean Studies, Panangad P.O, kochi, Kerala, India

Seagrass meadows, salt marshes, and mangroves are examples of blue carbon ecosystems, which are the most efficient natural ecosystems for the biosphere's long-term carbon sequestration and storage. In order to regulate atmospheric carbon dioxide levels, these coastal vegetation ecosystems are essential for maintaining fisheries, stabilising shorelines, enhancing water quality, and boosting coastal resilience. In recent years, blue carbon has become a central concept in the management of aquatic environments, linking climate change mitigation, sustainable resource use, and biodiversity preservation. This article reviews the concept of blue carbon, its primary ecosystems, carbon sequestration mechanisms, and its significance in aquatic environment management.

Aquatic environments, especially nearshore and coastal ecosystems, supply a variety of ecological and socioeconomic functions and are essential to global biogeochemical cycles. Nature-based solutions that meet human and environmental demands are becoming more and more popular as worries about climate change, coastal degradation, and diminishing fisheries. The capacity of blue carbon ecosystems to absorb and retain atmospheric carbon dioxide while preserving high levels of biodiversity and ecosystem production has led to their rise in popularity. In contrast to terrestrial carbon sinks, the majority of carbon in blue carbon ecosystems is stored in wet sediments with slow rates of decomposition, allowing for carbon storage over centuries to millennia. As a result, there is growing recognition for their protection and restoration which are an useful strategies for managing aquatic environments and reducing the effects of climate change.

Concept of Blue Carbon

The term "blue carbon" describes carbon that is sequestered, stored, and trapped by coastal and marine vegetation ecosystems, particularly seagrass meadows, salt marshes, and mangroves. Through photosynthesis, these ecosystems absorb carbon dioxide from the atmosphere and store it in the biomass of plants and the sediments below them. This is because the organic matter is buried under anoxic conditions by tidal action and sediment deposition, which inhibits microbial decomposition, blue carbon systems are very effective. As a result, on a per-unit-area basis, carbon stores in blue carbon ecosystems frequently surpass those of terrestrial forests. The idea of "blue carbon" highlights the need of protecting coastal habitats as a natural climate solution in addition to their relevance for fisheries and biodiversity.

Major Blue Carbon Ecosystems

Mangrove ecosystems: Tropical and subtropical coastlines are home to mangroves, which refers to plants that can withstand salinity. Their massive root systems below the ground and dense biomass above ground make them one of the planet's most carbon-rich ecosystems. Thick soil layers rich in carbon are created when mangrove roots trap sediments and organic debris. Mangroves not only sequester carbon but also support local livelihoods, shield coasts from erosion and storm surges, and serve as fish and shellfish spawning grounds. Mangroves are crucial for managing aquatic environments because their loss due to deforestation and land conversion can release significant amounts of stored carbon back into the atmosphere.

Mangrove habitats are vital for the preservation of biodiversity and the productivity of fisheries. They serve as breeding and nursery grounds for a diverse range of molluscs, finfish, and crustaceans, many of which are significant to the economy. Before moving to offshore fishing grounds, juvenile fish and prawns utilise mangrove ecosystems for food and shelter. Mangrove habitats have abundant supply of organic matter and debris fosters leads to complex food webs that connect primary producers to higher trophic levels. Therefore, decreased fish catches and a loss of livelihoods for coastal fishing communities are frequently the outcomes of mangrove degradation. Anthropogenic activities like coastal development, aquaculture expansion, pollution, and deforestation pose a serious threat to mangrove ecosystems. In addition to causing habitat loss, the conversion of mangrove regions into urban infrastructure or shrimp farms releases significant amounts of carbon that were previously stored in the mangroves into the atmosphere, which converts them from carbon sinks to carbon sources. In order to preserve their blue carbon potential and guarantee the long-term sustainability of aquatic environments, sustainable mangrove management which includes protection, restoration, and community based conservation is crucial.

Alongi, D. M. (2016). Mangroves. In Encyclopedia of estuaries (pp. 393-404). Springer, Dordrecht.

Salt Marshes: Salt marshes are intertidal wetlands that are typically found in high latitude and temperate zones. They are dominated by grasses and herbaceous plants. These ecosystems store substantial amounts of carbon in their sediments and biomass below ground, and they are very productive. Regular tidal flooding encourages the deposition of sediments, whereas soggy soils slow down decomposition and decrease oxygen availability. Additionally, salt marshes improve the quality of coastal water by acting as natural filters by retaining pollutants and nutrients. They play an important part in integrated aquatic environment management strategies because of their ability to stabilise shorelines and support fisheries. By capturing pollutants, nutrients, and sediments that are carried out from the land to coastal waterways, they serve as organic biofilters. By removing excess nitrogen and phosphorus through microbial processes like denitrification and plant absorption, nearby estuarine and coastal environments experience less eutrophication and toxic algal blooms. Maintaining healthy fisheries and aquaculture operations depends heavily on this nutrient regulating role. Salt marshes also support rich bird populations, contributing to overall biodiversity conservation.

Salt marshes serve as organic barriers against erosion, wave action, and storm surges, protecting the coastline. Through they have vast root networks, the dense vegetation stabilises sediments and lowers wave energy. Salt marshes can absorb floodwaters and lessen damage to coastal infrastructure during heavy weather events. The importance of salt marshes in climate adaptation and reducing the risk of disasters is growing as a result of rising sea levels and stronger storms.

Haight, C., Larson, M., Swadek, R. K., & Hartig, E. K. (2019). Toward a salt marsh management plan for New York City: recommendations for strategic restoration and protection. In Coastal wetlands (pp. 9971022).

Seagrass meadows: Seagrasses are blooming plants that grow in shallow coastal waters while submerged. Seagrass meadows contributes disproportionately to carbon burial despite their relatively tiny global area because of their high sediment trapping efficiency. By stabilising sediments and decreasing resuspension, seagrass rhizomes and roots improve carbon storage. Invertebrates, young fish, and endangered species like sea turtles and dugongs depend on these ecosystems for vital habitat. Seagrass meadow declines brought on by eutrophication, pollution, and physical disturbance can drastically lower fisheries productivity and blue carbon storage.

Additionally, seagrasses help stabilise sediment and protect the coast. Their root systems bind sediments and thus causes lesser erosion, leaves attenuate wave energy and increase water movement. This natural coastal defence mechanism aids in shielding shorelines from harms caused by waves and storm surges. Seagrass meadows are crucial for coastal ecosystem resilience and climate adaptation in the face of rising sea levels and more frequent storms.The loss of seagrass meadows disrupts their blue carbon function by lowering biodiversity and fisheries productivity as well as releasing stored carbon back into the atmosphere.

Bennett, S., Alcoverro, T., Kletou, D., Antoniou, C., Boada, J., Buñuel, X., ... & Marbà, N. (2022). Resilience of seagrass populations to thermal stress does not reflect regional differences in ocean climate. New Phytologist, 233(4), 1657-1666.

Mechanism of Carbon Sequestration

Seagrass meadows, salt marshes, and mangroves are examples of blue carbon ecosystems that effectively sequester carbon through sedimentary and biological processes.

Photosynthesis, in which plants take up atmospheric or dissolved CO_2 and transform it into organic matter, is the first step in carbon sequestration. Roots and rhizomes, or below-ground biomass, account for a sizable amount of this carbon and are essential for long-term storage.

Sediment burial and trapping is another important method. Because dense vegetation slows water flow, fine sediments and suspended organic particles can settle and be buried. These sediments are usually anoxic and wet, which significantly slows down microbial breakdown and stores carbon for generations or even millennia. Methane generation is further suppressed by high sulphate concentrations in coastal sediments, which increases net carbon retention. While biogeochemical interactions between organic matter and minerals improve carbon stability, sediment stabilisation by roots and rhizomes stops stored carbon from oxidising and resuspending. Furthermore, some carbon is laterally transferred to nearby marine systems, where it might be buried in layers that are deeper. Blue carbon ecosystems are extremely efficient natural carbon sinks and useful instruments for managing aquatic environments and mitigating climate change because of these processes.

Role of Blue Carbon Ecosystems In Aquatic Environment Management

Blue carbon ecosystems are essential for the management of aquatic environments as they control the climate, enhance water quality, and promote ecosystem sustainability. These ecosystems mitigate climate change by acting as effective carbon sinks, storing significant amounts of carbon in biomass and sediments. They are crucial for managing water quality because they reduce eutrophication and toxic algal blooms in coastal waters by capturing sediments, nutrients, and contaminants from land-based runoff. Additionally, blue carbon ecosystems safeguard coastlines naturally by stabilising sediments, decreasing erosion, and protecting shorelines from storms, waves, and sea level rise.

Additionally, many commercially significant species use blue carbon ecosystems as nidification and feeding grounds, supporting fisheries and biodiversity. Aquatic biodiversity is preserved and fish stock sustainability is improved through their protection and restoration. Including blue carbon ecosystems in frameworks for coastal planning and management provides a practical, natural method of preserving thriving aquatic environments.

Benefits of Blue Carbon Ecosystems for Coastal Communities and Fisheries

Blue carbon habitats not only sequester carbon but also gives significant co-benefits to coastal populations and fisheries. Many commercially significant fish and shellfish species use them as nurseries and feeding grounds, which improves recruitment and creates sustainable fish stocks. This increases the productivity of fisheries. In addition to providing resources and chances for ecotourism, these ecosystems maintain traditional fishing, shellfish gathering, and small-scale aquaculture, all of which contribute to coastal livelihoods. By preventing erosion and storm damage to fishing villages, boats, and infrastructure, blue carbon environments naturally defend the coast. These habitats improve fisheries and aquaculture conditions by filtering nutrients and sediments, which improves water quality. Local involvement, resilience, and sustainable coastal management are further strengthened by community-based conservation and restoration of these ecosystems.

Threats to Blue Carbon Ecosystems

Natural and man-made hazards are putting more and more strain on blue carbon ecosystems, like seagrass meadows, salt marshes, and mangroves, which reduces their ability to store carbon and deliver ecosystem services. Coastal growth and land-use change, including port construction, urbanisation, industrial expansion, and tourism infrastructure, are among the main risks. Habitat loss and the release of previously stored carbon into the atmosphere have resulted from the clearing or reclamation of large areas of salt marshes and mangroves for aquaculture and towns. The growth of aquaculture and irresponsible fishing methods, especially in tropical areas pose significant threat to blue carbon ecosystems. Destructive fishing practices, overuse of pesticides, and the conversion of mangroves into prawn farms damage vegetation and sediments, lowering biodiversity and deteriorating habitat structure. These actions impair the function of blue carbon ecosystems in regulating the climate and interfere with carbon burial processes. Blue carbon environments are also negatively impacted by pollution and nutrient enrichment. Eutrophication, hypoxia, and decreased light penetration are caused by increased nutrient and pollutant loads in coastal waterways brought on by sewage discharge, plastic trash, industrial effluents, and agricultural runoff. Because increasing turbidity and algae development restrict photosynthesis and result in widespread die-offs, seagrass meadows are particularly vulnerable to poor water quality.

Blue carbon habitats are at the risk of pressures associated with climate change. In addition to stressing seagrasses and related creatures, rising sea levels have the potential to submerge salt marshes and mangroves more quickly than they can deposit sediments. Storms that occur more frequently and with greater intensity have the potential to physically harm vegetation and erode sediments, releasing stored carbon. Degradation of ecosystems is also a result of inadequate management and bad governance. Conservation efforts are hampered by a lack of awareness, a lack of enforcement of coastal legislation, and the alienation of local groups from decision-making. Blue carbon habitats continue to deteriorate in the absence of integrated coastal zone management and restoration projects, reducing their ecological advantages and functions.

Management and Policy Implications

The protection of current habitats and the rehabilitation of damaged regions must be given top priority in an integrated, ecosystem-based strategy for the effective management of blue carbon ecosystems. Coastal protection services, fisheries production, and carbon reserves are all maintained through the preservation of mangroves, salt marshes, and seagrass meadows. Nature-based approaches to mitigating climate change are strengthened when blue carbon habitats are incorporated into environmental and climate policies, such as national greenhouse gas inventories and climate action plans. To strike a balance between conservation and sustainable coastal development, policy frameworks like Marine Spatial Planning and

Integrated Coastal Zone Management are crucial. For successful implementation, community involvement, sound governance, and ongoing research and monitoring are essential. Blue carbon ecosystems are more resilient and sustainable over the long run when local livelihoods are supported and policies are aligned across sectors.

Conclusion

Blue carbon ecosystems have high capacity to sequester carbon and provide a variety of ecosystem services, blue carbon ecosystems like seagrass meadows, salt marshes, and mangroves are essential tools for managing aquatic environments. They are essential in reducing the effects of climate change and in promoting fisheries, biodiversity preservation, water quality enhancement, and coastal protection. However, habitat loss and carbon emissions from human activity and climate change are posing an increasing threat to these ecosystems. It is crucial to preserve and restore blue carbon ecosystems via community involvement, supportive legislation, and coordinated management. For long-term environmental and socioeconomic resilience, integrating blue carbon into aquatic and coastal management plans offers a natural, sustainable effects.

References

Donato, D. C., Kauffman, J. B., Murdiyarso, D., Kurnianto, S., Stidham, M., & Kanninen, M. (2011). Mangroves among the most carbon-rich forests in the tropics. Nature geoscience, 4(5), 293-297.

Edenhofer, O. (Ed.). (2015). Climate change 2014: mitigation of climate change (Vol. 3). Cambridge University Press.

Mcleod, E., Chmura, G. L., Bouillon, S., Salm, R., Björk, M., Duarte, C. M., ... & Silliman, B. R. (2011). A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO2. Frontiers in Ecology and the Environment, 9(10), 552-560.

Citaristi, I. (2022). United nations environment programme UNEP. In The Europa directory of international organizations 2022 (pp. 193-199). Routledge.

Deegan, L. A., Johnson, D. S., Warren, R. S., Peterson, B. J., Fleeger, J. W., Fagherazzi, S., & Wollheim, W. M. (2012). Coastal eutrophication as a driver of salt marsh loss. Nature, 490(7420), 388-392.

Mitsch, W. J., & Gosselink, J. G. (2015). Wetlands. John wiley & sons.

Orth, R. J., Carruthers, T. J., Dennison, W. C., Duarte, C. M., Fourqurean, J. W., Heck, K. L., & Williams, S. L. (2006). A global crisis for seagrass ecosystems. Bioscience, 56(12), 987-996.

Fourqurean, J. W., Duarte, C. M., Kennedy, H., Marbà, N., Holmer, M., Mateo, M. A., ... & Serrano, O. (2012). Seagrass ecosystems as a globally significant carbon stock. Nature geoscience, 5(7), 505509.

Waycott, M., Duarte, C. M., Carruthers, T. J., Orth, R. J., Dennison, W. C., Olyarnik, S., ... & Williams, S. L. (2009). Accelerating loss of seagrasses across the globe threatens coastal ecosystems. Proceedings of the national academy of sciences, 106(30), 12377-12381.

Alongi, D. M. (2014). Carbon cycling and storage in mangrove forests. Annual review of marine science, 6(1), 195-219.

www.agriallis.com

AGRIALLIS
Science for Agriculture and Allied Sector: A Monthly Magazine

Volume 8, Issue 4

Article Id
AL04512

BROWN MANURING: AN ECO-FRIENDLY APPROACH FOR SUSTAINABLE SOIL FERTILITY MANAGEMENT

Email
rajagopal2304@gmail.com

[1]Raja Gopal V* and [1]Rajaganapathy V

[1]Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore – 641 003, India

Sustainable agriculture focuses on maintaining soil fertility, reducing chemical inputs, and improving crop productivity while protecting environmental resources. One of the emerging eco-friendly techniques gaining importance in modern farming systems is brown manuring. Brown manuring is a method of incorporating partially decomposed green manure crops directly into the soil without uprooting them completely. Unlike conventional green manuring where the crop is ploughed into the soil before flowering, brown manuring involves killing the green manure crop using herbicides or mechanical methods and leaving the residues on the soil surface. This practice provides organic matter, suppresses weeds, and enhances soil fertility. In recent years, brown manuring has been widely promoted in rice-based cropping systems, particularly in regions where farmers face labor shortages and water scarcity. The technique is considered a practical alternative to traditional green manuring because it requires less labor and time while still providing many agronomic and ecological benefits.

Concept of Brown Manuring

Brown manuring is a soil fertility management practice in which a fast-growing leguminous crop is grown along with the main crop and then terminated at an early stage. The crop residues are left on the soil surface where they gradually decompose and release nutrients. The practice is commonly adopted in direct seeded rice (DSR) systems. In brown manuring, seeds of a green manure crop such as Sesbania species are broadcast in the field along with the main crop. After about 25–30 days, the green manure crop is killed using a selective herbicide such as 2,4-D. The killed plants dry and turn brown, forming a mulch layer on the soil surface, hence the name brown manuring. The decomposing biomass contributes organic matter and nutrients to the soil while also acting as a natural weed suppressant.

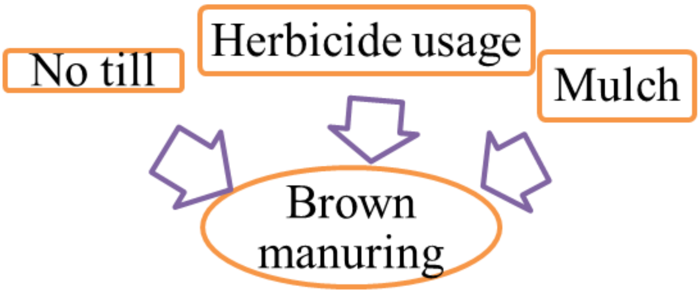

Fig. 1: Concepts of brown manuring

Crops Used for Brown Manuring

Several leguminous crops are suitable for brown manuring due to their rapid growth and nitrogen-fixing ability. Some commonly used crops include:

- *Sesbania aculeata* (Dhaincha)
- *Sesbania rostrata*
- *Crotalaria juncea* (Sunn hemp)
- Cowpea (*Vigna unguiculata*)
- Green gram (*Vigna radiata*)

Among these, Sesbania aculeata is widely preferred in rice fields because of its quick growth, high biomass production, and ability to fix atmospheric nitrogen.

Method of Brown Manuring

The process of brown manuring generally involves the following steps:

1. **Field preparation**
2. **Sowing of main crop and green manure crop**
3. **Growth stage** - during the initial stages and helps in suppressing weeds.
4. **Termination of green manure crop**
   After about 25–30 days, the green manure crop is killed by spraying a herbicide such as 2,4-D or by mechanical flattening.
5. **Residue decomposition**

Advantages of Brown Manuring

1. Improvement in Soil Fertility: Brown manuring adds organic matter to the soil through decomposing plant residues. Leguminous crops used in brown manuring fix atmospheric nitrogen, which becomes available to the main crop after decomposition.

2. Weed Suppression: The mulch formed by dried plant residues acts as a natural barrier that suppresses weed growth. This reduces the need for additional herbicide applications.

3. Reduced Fertilizer Requirement: The nitrogen fixed by leguminous crops helps in reducing the requirement for chemical nitrogen fertilizers. This can lower production costs and minimize environmental pollution.

4. Improved Soil Structure: The addition of organic matter enhances soil structure, increases water infiltration, and improves soil aeration.

5. Moisture Conservation: The mulch layer created by brown manuring reduces evaporation from the soil surface, helping conserve soil moisture during dry periods.

6. Cost-Effective and Labor Saving: Compared to traditional green manuring, brown manuring requires less labor because the green manure crop is not ploughed into the soil.

Role of Brown Manuring in Rice-Based Cropping Systems

Brown manuring is particularly beneficial in direct seeded rice systems, where weed management is a major challenge. The early growth of Sesbania suppresses weeds and improves crop establishment. Research studies have shown that brown manuring can contribute approximately 25–40 kg nitrogen per hectare through biological nitrogen fixation and biomass decomposition. It also enhances soil microbial activity and nutrient cycling. In regions with labor shortages, brown manuring provides a practical solution because it eliminates the need for additional tillage operations required in traditional green manuring.

Environmental Benefits

Brown manuring contributes significantly to sustainable agriculture and environmental protection. By increasing soil organic matter and reducing dependence on chemical fertilizers, the practice helps lower greenhouse gas emissions associated with fertilizer production. Additionally, improved soil structure and organic matter content enhance soil carbon sequestration. The practice also supports beneficial soil microorganisms that play a key role in nutrient cycling and soil health.

Challenges and Limitations

Despite its advantages, brown manuring has some limitations that may affect its adoption.

One of the main challenges is the need for proper timing of herbicide application to terminate the green manure crop. If the crop is not killed at the right stage, it may compete with the main crop for nutrients and water. In some cases, farmers may also lack awareness or access to suitable seeds for brown manuring crops. Furthermore, the effectiveness of brown manuring may vary depending on soil type, climate, and cropping system.

Future Prospects

With increasing emphasis on sustainable agriculture and resource conservation, brown manuring has strong potential to become an important component of integrated nutrient management. Advances in precision agriculture, improved seed varieties, and better weed management practices can further enhance the efficiency of brown manuring systems. Agricultural extension programs and farmer training initiatives are essential to promote awareness and adoption of this technique. Integrating brown manuring with other practices such as conservation tillage, crop rotation, and organic amendments can contribute to resilient and sustainable farming systems.

Conclusion

Brown manuring is an effective and environmentally friendly practice that improves soil fertility, suppresses weeds, and enhances crop productivity. By integrating leguminous green manure crops with main crops and allowing the biomass to decompose naturally, farmers can reduce dependence on chemical fertilizers and improve soil health. The practice is particularly suitable for direct seeded rice systems where weed management and nutrient availability are critical challenges. With proper management and increased awareness among farmers, brown manuring can play a significant role in promoting sustainable agriculture and improving long-term soil productivity.

References

Bhatt, R., Kukal, S. S., & Busari, M. A. (2016). Sustainability issues on rice–wheat cropping system. *International Soil and Water Conservation Research*, 4(1), 64–74.

Kumar, V., Ladha, J. K., & Gathala, M. K. (2018). Direct seeded rice: Recent developments and future research needs. *Advances in Agronomy*, 147, 297–413.

Prasad, R., Shivay, Y. S., & Kumar, D. (2017). Agronomic practices for improving nitrogen use efficiency in rice. *Indian Journal of Fertilisers*, 13(4), 44–52.

Yadav, R. L., Dwivedi, B. S., & Pandey, P. S. (2019). Integrated nutrient management for sustainable agriculture. *Indian Journal of Agronomy*, 64(2), 151–160.

Article Id
AL04513

GENOMICS-DRIVEN CROP IMPROVEMENT UNDER CLIMATE STRESS

Email
vswargam11@gmail.com

[1]Swargam. Vaishnavi* and [2]V. Swarnalatha

[1]Department of Genetics and Plant Breeding, PJTAU, Rajendranagar, Hyderabad (500030), Telangana, India

[2]Department of Genetics and Plant Breeding, Agricultural College, Palem, PJTAU-509215, India

Molecular breeding, also known as marker-assisted selection (MAS), is a genomics-driven approach that utilizes DNA markers tightly linked to phenotypic traits to enhance the efficiency and precision of plant breeding programs. This technique enables the indirect selection of desirable traits such as drought tolerance, heat and disease resistance at the seedling stage, thereby significantly reducing the time and resources required compared to conventional breeding methods. The success of molecular breeding largely depends on the identification and characterization of reliable genetic markers, including random amplified polymorphic DNA (RAPD), intersimple sequence repeats (ISSRs) and amplified fragment length polymorphism (AFLP). These markers serve as powerful tools for detecting genetic variation, mapping quantitative trait loci (QTLs), and tracking the inheritance of complex traits under climate stress conditions. By integrating high-throughput genotyping and genomic information, MAS facilitates the rapid development of climate-resilient crop varieties capable of withstanding multiple abiotic and biotic stresses, ultimately contributing to sustainable agricultural productivity. (Cooper *et al.*, 2014)

As the climate shifts, agricultural systems face increased vulnerability to pests, diseases and environmental stresses such as drought and heat, posing significant challenges to global food security. Traditional breeding methods, which rely heavily on phenotypic selection across multiple generations are often too slow to keep pace with these rapidly evolving threats. In contrast, DNA marker-based approaches significantly improve the speed and precision of plant improvement programs by enabling early and accurate selection of desirable traits. These modern strategies involve the use of DNA markers as substitutes for phenotypic selection to accelerate the development and release of improved germplasm. The major approaches include marker-assisted selection (MAS), marker-assisted backcrossing (MABC), marker-assisted recurrent selection (MARS) and genome-wide selection (GWS). Such methods rely on identifying DNA markers that are strongly associated with the expression of target traits, including those governed by quantitative trait loci (QTLs). The integration of these techniques into breeding pipelines has been widely adopted in both private and public sector programs. Advances such as the availability of diverse molecular markers, high-throughput genotyping platforms, reduced costs of assays and access to whole-genome sequences such as maize (Murthy *et al*., 2026) have greatly enhanced the efficiency and accessibility of these approaches. Collectively, these innovations enable the precise and efficient incorporation of important traits into crop varieties, supporting the development of climate-resilient agriculture.

In this context, molecular breeding approaches particularly genomic selection offers a powerful alternative by combining precision, speed and the ability to handle complex traits controlled by multiple genes. Genomic selection, a rapidly emerging method for crop improvement, uses genome-wide marker profile data to predict the breeding value of individuals in segregating populations, enabling the early identification and selection of superior genotypes. This approach accelerates the development of resilient crop varieties that are better adapted to changing climatic conditions and capable of withstanding multiple biotic and abiotic stresses (Wang *et al*., 2018).

The statistical methods used in MAS, when linked to dynamic system modeling, provide a realistic procedure of defining an ideotype as a combination of genetic markers (Ragi *et al.*, 2026). Molecular breeding has made spectacular progress in a wide range of applications, such as genetic transformation, genetic diversity assessment, large-scale transcriptome and proteome studies, identification of candidate genes for trait improvement and whole genome sequencing.

Understanding Disease Resistance at the Genetic Level

Molecular breeding enables researchers to identify and target genes responsible for disease resistance. These genes can be integrated into crop varieties using advanced techniques like marker-assisted selection (MAS) and genome editing. By mapping disease resistance loci in the genome, breeders can select plants with the desired traits more efficiently. For example, genes that confer resistance to diseases like blight, rust, or fusarium wilt can be rapidly identified and incorporated into commercial crop varieties.

Climate Resilience: Drought, Heat and Flood Tolerance

Climate change is expected to bring more extreme weather events, including droughts, floods and heatwaves. Molecular breeding can help develop varieties that are better adapted to these conditions. For instance, genes associated with drought tolerance (such as those that improve root growth or water use efficiency) can be identified and introduced into crops. Similarly, heat tolerance can be enhanced by incorporating genes that help plants cope with higher temperatures, such as those involved in protein stability or antioxidant defense.

Speeding Up the Development of Resilient Varieties

Traditional breeding methods require multiple generations to achieve desirable traits. Molecular breeding, on the other hand, accelerates the process by using tools like genetic markers to identify plants with specific desirable traits early in the breeding process. This means new varieties with enhanced disease resistance or better climate resilience can be developed more quickly.

Genome Editing: CRISPR and Beyond

Advanced genome editing tools like CRISPR-Cas9 enable precise modifications to the DNA of crops. With CRISPR, specific genes can be edited to enhance disease resistance or improve tolerance to stress. For example, researchers have used CRISPR to develop rice varieties that are resistant to bacterial blight or wheat varieties that are more resistant to fungal diseases. This level of precision allows breeders to make small, targeted changes rather than introducing entire new genes from other species, reducing potential risks of unintended consequences.

Broadening Genetic Diversity

Climate change and evolving pests or diseases can lead to new threats for which existing crop varieties may not be resistant. Molecular breeding can tap into a broader genetic pool, including wild relatives and landraces, to introduce new resistance traits. These varieties may possess genes that confer resistance to emerging diseases or better adaptability to changing climates. Molecular tools can help identify these genes and bring them into commercial breeding programs, ensuring a wider genetic base for resistance.

Integrated Pest Management (IPM) and Crop Rotation

Molecular breeding doesn't just focus on direct disease resistance, it can also improve crops in ways that make them more compatible with sustainable practices like integrated pest management (IPM) and crop rotation. For example, breeding for traits like enhanced natural pest resistance (through plant-produced chemicals) can help reduce reliance on chemical pesticides, while also promoting ecological balance.

Climate-Specific Traits

Molecular breeding can help tailor varieties to specific climatic regions and microclimates. For instance, crops can be bred to thrive in areas with erratic rainfall, saline soils, or high-altitude conditions. These traits can be fine-tuned by identifying specific genetic pathways that allow plants to tolerate unique environmental stressors.

Reducing Environmental Impact

By developing crops that are more resilient molecular breeding can also reduce the need for chemicals and other interventions that have negative environmental impacts. Disease-resistant crops reduce the need for pesticide use, and drought-tolerant crops reduce water consumption, both of which contribute to more sustainable farming practices.

Example of Molecular Breeding in Action

An example of molecular breeding's success in developing disease-resistant varieties is the development of banana varieties resistant to Panama disease (a fungal infection) using genetic engineering and marker-assisted breeding. In drought-prone regions, crops like maize and sorghum have been improved for water-use efficiency through molecular breeding, helping farmers adapt to climate-induced water scarcity.

Challenges and Considerations

While molecular breeding holds great potential, it also faces some challenges. There is a need for comprehensive understanding of the complex interactions between genes, environmental factors, and diseases. Moreover, the regulatory approval process for genetically modified organisms (GMOs) can be time-consuming and complex, potentially slowing down the release of new varieties.

Conclusion

Genomics-driven crop improvement and molecular breeding provide powerful tools to address climate change and emerging plant diseases. By enabling faster and more precise selection of desirable traits, these approaches overcome the limitations of conventional breeding and accelerate the development of stress-tolerant, disease-resistant crops. The integration of genomic technologies and advanced breeding strategies will play a crucial role in ensuring sustainable agriculture and global food security under changing environmental conditions.

References

Cooper, M., Messina, C.D., Podlich, D., Totir, L.R., Baumgarten, A., Hausmann, N.J., Wright, D. and Graham, G. 2014. Predicting the future of plant breeding: complementing empirical evaluation with genetic prediction. *Crop & Pasture Science*, 65(4), 311-336.

Grigorieva, E., Livenets, A. and Stelmakh, E. 2023. Adaptation of agriculture to climate change: A scoping review. *Climate*, 11(10), 202.

Murthy, B.P., Argiddi, R.V., Raj, G.B., Prasanth, M., Podile, V.R. and Suresh, M. 2026. Recent Innovations and Emerging Trends on Genetic Engineering and Biotechnology in Agronomy. *New Technologies in Agronomy for Sustainability*, 227-258.

Ragi, S., Singh, V.J., Nandakumar, S., Krishnan, S.G., Bollinedi, H., Ellur, R.K., Vinod, K.K., Harshitha, B.S., Saran, D., Samdarshi, S. and Basha, F.T. 2026. Integrating marker-assisted identification and multi-environment trait stability models to select superior rice restorer lines for hybrid breeding. *Frontiers in Plant Science*, 17, 1781490.

Wang, X., Xu, Y., Hu, Z. and Xu, C. 2018. Genomic selection methods for crop improvement: Current status and prospects. *The Crop Journal*, 6(4), 330-340.

Article Id
AL04514

INVENTORY OF AROMATIC FOLK RICE VARIETIES OF WEST BENGAL

[1]Jimi Banik, [2]Purnima Halder, [3]Rajib Das, [2]Sitesh Chatterjee*

Email

sitesh.chatt@gmail.com

[1]Department of Botany, University of Kalyani, Kalyani, Nadia-741235, West Bengal, India

[2]Rice Research Station, Government of West Bengal, Chinsurah (R.S.), Hooghly- 712102, West Bengal, India

[3]Pulses and Oilseeds Research Station, Government of West Bengal, Berhampore, Murshidabad - 742101, West Bengal, India

West Bengal is the richest reservoir of rice bio-diversity and thus named the rice bowl of India. The '*Bangalee*' association with rice lies in the many rituals and festivals, in happiness and sorrow, in birth and death. '*Nabannaya'* the famous harvest festival celebrated for the new harvest. The new born's first solid food - '*Annaprasan*', the auspicious marriage ceremony initiates with '*Ashirbad*' with rice grains & '*Durba'* leaves. Even after death, spreading of popped rice paves way for the departed soul. Rice grows in West Bengal in three different season's*viz*., *Aus* (autumn rice*)*, *Aman* (winter rice) and *Boro* (summer rice). Occupies nearly 53% of the total agricultural crop areas and contributes about the same percentage (53%) towards the total production of all agricultural crops. Topped the list of the rice producing States of the country West Bengal Ranked 2nd in case of area having a percentage share of 15.8 in the National context. But has ranked 5th with respect to productivity. In this article nine folk rice varieties, popularly grown by the farming community of West Bengal*viz*. *Badshahbhog*, *Dadsaal*, *Gobindobhog*, *Gopalbhog*, *Radhunipagol*, *Radhatilak*, *Kalonunia*, *Kataribhog* and *Kaminibhog*were studied.

The state of West Bengal is an Indian state with amazing extremes in geography, people of this land along with the plant and animal life-forms. The state has its northern most extreme in the Himalayas and traverses through the Gangetic plains to the Bay of Bengal over a course of about 483 km and can demonstrate almost all the geophysical features and its associated biodiversity that the Indian subcontinent stands for. Darjeeling as the northernmost district lies cradled in the laps of the mighty Himalayas. Beyond this the state has a huge area under submontane terais which invariably is home to an immense biodiversity. The western districts show an absolute contrast in the form of semi-arid regions with red lateritic soil and the almost dry lands of Chhotanagpur plateau, along with spread over low hills and forests of '*sal'* and '*segun'*.The eastern districts are characterised by vast riverine flood plains on both sides of the river Bhagirathi and its tributaries. The southern most part of the state is caressed by the Bay of Bengal in the deltaic regions of Sundarban mangroves and coastal regions of Midnapur (source: http://wbbb.gov.in/westbengal).Well-known Indian rice researchers, Richharia and Govindasamy (1990), in their book 'Rices of India' have provided numerous evidence to show that the country had been endowed with more than 2 lakh (2,00,000) rice varieties. This is in fact a richness of biodiversity that no other country can make claim for. Each of such rice variety is the outcome of the vision and hard work of farmers of past times who worked extensively to select rice varieties which could adapt themselves to a variety of climates, soil types, topography and agronomic practices. In the Chattisgarh region and Maharastra alone, Dr. Richharia identified more than 20,000 rice varieties. Cowel (1957), Kangle (1966), Keith (1914), Cleveland et al., (1993, 2000), Arumugasamy et al., (2006) and Sathya et al., (2007) had recorded large numbers of traditional rice varieties found in different parts of India and their adaptation to specific conditions. Deb (2005) in his famous book entitled "Seeds of Tradition, Seeds of Future" provided detailed morphological descriptions of 416 Indian folk (traditional) rice varieties, which are on the verge of extinction from farmers' fields. A World Wildlife Fund (WWF)-India survey, conducted in 1994 in six districts of southern West Bengal, recorded 137 traditional rice varieties that were found being cultivated in marginal farms (Deb, 1995). Every locality has its own set of crops, especially rice varieties which serves as the primary source of livelihood of the local farming community. Each locality's food security is also directly dependent on such crop diversity. Our climate is changing dramatically so for safeguarding our food we need to conserve crop diversity. It is quiet impossible to save crop varieties and their wild relatives only in the laboratory. Pests and diseases change their behaviour with climate, and crops can cope in the battle with pests and diseases only by means of on-farm conservation. Traditional crop landraces have evolved in response to changing local selection pressures, while still maintaining a high level of genetic variation (Soleri and Cleveland, 2004), and, therefore, are often superior to modern cultivars in marginal environmental conditions (Deb, 2009). Agroforestry and multiple cropping systems, involving species and crop genetic diversity are the most reliable methods of ensuring long term sustainability of crop production (Gliessman, 2007; Deb, 2009).

Concerns in Conservation of Rice Diversity

Concerns in the free interchange of data, information and knowledge pertaining to biodiversity conservation exercises can be broadly categorised as:

a. Behavioural and psychological concerns
b. Concerns about communicating data
c. Practical concerns
d. Insufficient strategies and resources

According to Global Biodiversity Informatics Outlook, following actions are needed to be taken to overcome these kinds of concerns (GBIF,2010).

1. An improved data, information and knowledge sharing that can facilitate further development in national and international policies related to biodiversity conservation.
2. Continuation of funding required for effective and efficient dissemination of information resources and maintenance of infrastructures.
3. New research approaches can be designed and adopted to provide access to any data and information related to biological diversity.
4. Provision of appropriate access to the respective data, information and knowledge of each funded project.
5. Promotion of long-term investment for maintenance of data and information resources.
6. Provision of increase in open access to publications and reports.
7. Promotion of access to publications on which data and information are based.
8. Maintenance and emboldenment of the publication of 'data papers' that designate available data sets that academics have worked to accumulate information to be made accessible.
9. Generation of encouragement and incentives for academics and research institutions to increase admittance to data and information.
10. Establishment of infrastructure or repositories to establish and maintain easy-to use electronic information to ensure long-term access to data, information and knowledge.

Inventory: Here we discuss some aromatic folk rice varieties grown in West Bengal

1. Aromatic rice: *Kalonunia*

Description: W.W. Hunter a British author in his book 'A Statistical Accounts of Bengal' published during 1876 by Trubner & Co, London also mentioned the *Kalonunia* variety widely cultivated in Terai area of the then Darjeeling district. In volume X he mentioned the socio-economic status of people of three districts Darjeeling, Jalpaiguri and the State of Kuchbehar. In Darjeeling district rice form the staple agricultural product of the plains or terai portion of the district. *Kalonunia* rice is black in texture and because of that when the crops are full grown, the field is looking black and the air is filled up with a special fragrance.

Etymology: Grains of *Kalonunia* are relatively small, but very much tasty; it is sold in market in higher price level than the high yielding varieties. However, it has a low yield potential. A small quantity of *Nunia* rice can fill up the belly for the whole day. A handful of *Kalonunia*paddy after decoating the paddy seed-coats could provide ample amount of cooked rice.The black variety of paddy was exclusive to them and it was very tasty indeed. It is costly and cultivated by rich people for their self consumption. It is famous for its taste and aroma. This *Kalonunia* is also known as *bhogdhan* where *bhog* means the offering of *prasada* to deity. Some people also called it *Tulsi dhan* due to its use in rituals. The boiled atap *Kalonunia* in milk will prepare a delicious food item with sugar or molasses which is popularly known as *payas*. *Payas* is prepared and presented in all religious ceremonies and pujas to the guests.

Applications: *Kalonunia* is an excellent aromatic rice of norther parts of West Bengal (Roy *et al*., 2014). It face highest price in the local market at any part of the year. It is much preferred by the local people for preparation of *Payas*(Porridge) during rituals and for any special functions. It can be enjoyed as everyday plain rice or as an alternative to basmati. It is considered the best tiny aromatic rice in this part of the state. This tiny, non-glutinous (not sticky) rice cooks in about 10 minutes producing a delicate aroma, taste and texture. It is traditionally seasoned with whole aromatic spices such as cinnamon sticks, cloves and cardamom pods.

Socio-Economic profile: *Kalonunia* is being cultivated by the farmers in traditional way.Generally, it is being cultivated in low fertile lands and some times in the fallow lands, like low laying lands near the road side and river. The *Kalonunia* cultivating farmers also do not take much care on inter-cultivation practices. As those practices are being followed since long, the genetic makeup of this cultivar may have been changed to low yield potential.

2. Aromatic rice: *Gobindobhog*

Description: *Gobindobhog* is short, plump, and delicate paddy, characteristic making it ideal for both sweet and savoury dishes. Its natural fragrance intensifies when cooked, filling the kitchen with a warm, appetising aroma that can only be described as Bengal itself. *Gobindobhog* continues to hold its exceptional place as the soul of every Bengali kitchen, whispering stories of love, devotion, and belonging. This aroma comes from the rice's genetic makeup and the unique alluvial soil of the Burdwan and Hooghly districts of West Bengal, where it is primarily cultivated. The region's fertile land, fed by the river Ganges, provides the perfect balance of minerals and moisture. When combined with traditional farming techniques, this gives *Gobindobhog* rice its distinct aroma and soft texture.

Etymology: What truly distinguishes *Gobindobhog* rice from other varieties is its signature fragrance. The aroma is subtle yet unmistakable – rich, buttery, and naturally sweet.

Applications: For Bengalis, *Gobindobhog* rice isn't just an ingredient – it's a nostalgia,it's a cultural heirloom. It has witnessed generations grow, festivals celebrated, and families come together. Its fragrance doesn't just fill the air; it fills hearts with memories.Even in today's world of global cuisines and modern diets, *Gobindobhog* continues to hold its irreplaceable place as the soul of every Bengali kitchen, whispering stories of love, devotion, and belonging.*Gobindobhog* rice cooking signifies Bengal itself, simmering in tradition and love. Over time, *Gobindobhog* became a part of Bengal's everyday life – gracing the kitchen shelves of every household and forming the base of iconic dishes like *khichuri*, *payes*, and *pulao*. It's the rice that evokes nostalgia – reminding Bengalis of festive mornings, the scent of ghee, and the warmth of family gatherings.

Cultural role: The name *Gobindobhog* comes from two words – *Gobindo* (Lord Govinda or Krishna) and *Bhog* (offering to the deity). Historically, this rice was used as a sacred offering in temples across Bengal, especially in Jagannath Puri and Nabadwip.That's how it earned the reputation of being the rice fit for the gods.

3. Aromatic rice: *Radhatilak*

Description: This variety is quiet similar to *Gobindobhog*. It is an aromatic variety and widely cultivated in Nadia district. The word has two parts: '*Radha*' and '*Tilak*', where '*Radha*', is indicated as the lover or *Gopini* of 'Lord Krishna' in Hindu mythology and '*tilak*' means sectarian mark painted by the Vaishnavas mostly on their foreheads, chests and arms (Ghosh, 2019).

Etymology: This variety is characterised with Yellow-straw coloured grain having reddish brown spot at tip, short-bold type white kernel, and pleasant aroma.

Applications: The variety has some special end-uses like *bhog* (special *khichdi*), *payas* (desert), *pistak* or *pitha*(home-made cake), etc. duringreligious festivals andsocial functions in the native areas. *Radhatilak*rice is usually adapted to rainfed mediumland in lower Gangetic alluvial region of West Bengal.

Cultural role: *Radhatilak* is an aromatic variety cherished for its role in special occasions, festivals, and traditional ceremonies, where it symbolizes prosperity and regional heritage.

4. Aromatic rice: *Radhunipagol*

Description: The *Randhunipagol* is one of the most aromatic strains of rice from West Bengal. The fairly strong aroma, can make the cook go mad – hence the name. Light on the stomach, sleek and tasty, it's a perfect as a table rice.

Etymology: *Radhunipagal* is traditionally cultivated in *Rahr* (red and laterite) and lower Gangetic plains ofWest Bengal for about 400–500 years. The earliestrecord of *Radhunipagal* rice was found in two districtgazetteers on 24 Parganas (Hunter, 1875) and Medinipur(Hunter, 1876.

Applications: This variety is very popular in Bengali societyand culture for preparation of *bhog*(rice intermixed withpulses), *payash*(dessert), *pistak*or*pitha*(home-madecake), etc. during social functions and religious festivalsfor a long period, but its cultivation has been marginalized to small pockets of a few districts (Birbhum, Burdwan,Hooghly, Bankura, etc.) during last four decades dueto large-scale adoption of high-yielding varieties in theregion. Farmers in native areas cultivate *Radhunipagal*rice following traditional practices intermixed with a few modern technologies in recent times during *kharif*(wet) season.*Randhunipagal*rice is prized for its excellent cooking and eating qualities. It yields a soft, aromatic, and fluffy texture, making it ideal for both table rice and sweet dishes. It retains a soft, creamy texture even after cooling to room temperature.

Cultural role: Traditionally, it was consumed as table rice by those who could afford it, while others reserved it for ritualistic offerings and ceremonial dishes. The rice's aroma is strongest when it is soaked or hydrated, making it an excellent choice for raw rice-based dishes like '*Nabanna*' or '*Malida*'.

5. Aromatic rice: *Gopalbhog*:

Description: *Cultivate in a small pocket in the district Birbhum.*

Quality attributes: *T*his variety is medium tall, broad erect leaf, no awn, medium bold grain, brown husk, and lodging susceptible. Gopal means *balkrishna* and this variety is specially cultivate to offer *Bhog*to"*balkrishna"*. It is also very good as table rice.

6. *Dadsal*

Description: Is a climate-resilient aromatic rice from Assam but now cultivating in both south and North 24 Parganas.

Applications: Consumed especially as table rice. This variety is available in local markets.

7. Aromatic rice: *Badshabhog*

Description: Probably one of the most popular aromatic rice varieties from Bengal.It is being cultivated in largest area under traditional aromatic rice varieties in West Bengal.

Etymology: *Badshahbhog* as the name suggests is "fit for the kings".

Quality attributes: The short, slim white rice is perfect for the special winter meals. *Badshahbhog* is traditionally used under special occasions and best suited for pulao and other savory dishes.

Applications: It is an aromatic variety and widely cultivated in Aman season.The short, slim white rice is perfect for winter meal. The variety is iconic dishes like *khichuri*,*payesh*, and *pulao*.*Badshabhog* is an aromatic variety suitable for special dishes.

8. Aromatic rice: *Kataribhog*

Description: *Kataribhog* rice is a traditional, medium-aromatic rice variety native to Malda and Dakshin Dinajpur, it is primarily cultivated in the Dinajpur district, with some cultivation reported in adjacent areas of Bangladesh.*Kataribhog* rice offers a mild to moderate fragrance with notes of sweetness and nuttiness, enhancing its appeal in various culinary preparations without overpowering other flavours.

Etymology: The name *Kataribhog* derives from Bengali linguistic roots, combining "*katari*," which translates to "sword" or "dagger" in reference to the rice's sharp, slender, and pointed grains, and "*bhog*," denoting "enjoyment" or "delicacy," underscoring its esteemed status as a flavorful aromatic variety suitable for special dishes. This nomenclature reflects traditional agricultural descriptors in the Bengal region, where grain morphology and sensory qualities often inform varietal names. Such naming conventions tie into broader Bengali traditions of classifying rice based on aesthetic and gastronomic attributes, as seen in other varieties like *Gobindabhog*.

Quality attributes: *Kataribhog* rice is renowned for its moderate aroma intensity. This fragrance arises from natural volatile compounds, providing a distinctive sensory appeal that enhances its culinaryvalue without overpowering other ingredients.Compared to hybrid rices, *Kataribhog* offers superior flavour retention due to its aromatic profile and cooking characteristics

Applications: *Kataribhog* rice serves as a key ingredient in traditional Bengali sweets and savoury dishes due to its delicate aroma and non-sticky texture, which allows it to absorb flavors effectively while maintaining firm grains. It is prominently featured in payesh, a slow-cooked rice pudding made by simmering the rice in milk with sugar, cardamom, and nuts until creamy, offering a sweet, nutty profile ideal for festive occasions. In savory preparations, it excels in khichuri, a one-pot dish combining the rice with roasted moong dal, vegetables, and mild spices, where its subtle caramel notes enhance the overall harmony without becoming mushy.*Kataribhog* rice complements fish curries and vegetable stir-fries, where its mild sweetness balances bold spices.

Cultural Role: *Kataribhog* rice holds a prominent place in Bengali culture, particularly as an aromatic variety cherished for its role in special occasions, festivals, and traditional ceremonies, where it symbolizes prosperity and regional heritage. Its distinctive fragrance and texture make it a preferred choice for celebratory feasts that evoke the essence of Bengal's culinary traditions. In Bengali literature, *Kataribhog* is referenced as asuperior aman (winter) rice variety, comparable to elite types like *Badsabhog*. Conservation efforts underscore *Kataribhog*'s importance as an heirloom variety.

9. Aromatic rice: *Kaminibhog*

Description: *Kaminibhog*is a traditional, aromatic, and bold-grained rice variety that originates from the Sundarbans region of West Bengal. It is a small-grained rice, sometimes described as glutinous, and is often categorized within the short, white, aromatic rice group'

Etymology: *Kaminibhog* is a bold, scented rice that is often parboiled or processed into flattened rice (chira). This scented rice is native to the Sundarbans and grows well in deep water.Kaminibhog are often cultivated in low-lying, saline-prone areas. Farmers receiving high economic returns despite the lower yield per hectare compared to modern varieties.

Applications: Due to its aroma and texture, it is frequently used for making rice flakes (*chira*) and for preparation in religious rituals.

Conclusion

Not much research has been done for developing strategies and protocols specifically for aromatic rice probably because the general protocols followed for rice conservation are suitable for conservation of aromatic rice as well. Aromatic rice has export-worthy bright future in West Bengal. But only grain quality and varietal screening need to be improved to change the status of aromatic rice production in West Bengal.

References

Arumugasamy, S., Subramaniyan, K., Subashini, S. andVijayalakshmi,K. (2006). Traditional RiceVarieties.Centre forIndian Knowledge Systems.Chennai.

Deb, D.(2005). Seeds of Tradition, Seeds of Future: Folk Rice Varieties from East Research Foundation for Science Technology & Ecology. New Delhi.

Deb, D. (2009). *Biodiversity and complexity of rice food webs*. The Open EcologyJournal, **2**:112-129.

Deb, D.(1995). *Scale dependence of food and structure. Tropical ponds at paradign*.Oikos.**72**: 245-262

Cleveland, D. A., Soleri D. and Smith,S. E. (2000). A biological framework for understanding farmers plant breeding. *Economic Botany*, **54**(3): 377-394.

Cleveland, D. A.,Soleri, D. and Smith, S. E. (1993). Do folk crop varieties have a role in sustainable agriculture. Bioscience, **44**: 740- 751.

Cowell, E. B. (1957). *TheJatakas or Stories of the Buddha's Former Births* (Vols. IVI)London: Pali Text Society. (reprint) Gyan Publishing House. New Delhi

Ghosh M (2019). *Aromatic Rice of West Bengal: Diversity, Production and Marketing* (in Bengali), Mehanati Publications, Hooghly, West Bengal, India.

Gliessman, S. B. (2007). *Agroecology: The ecology of sustainable food systems*. CRC Press.Boca Raton/ London Chang,

Hunter WW (1875). *Statistical account of Bengal: Districts of24 Parganas and Sundarbans*, Vol. I, Trubner& Co., London'

Hunter, W. W. (1876). *A Statistical Account of Bengal: Districts of Darjiling and Jalpaiguri, and state of Kuch Behar* (Vol. X). Trubner& Co.

Kangle, R. P. (1966). *The KautilyaArthasastra* (3 volumes).Motilal BanarasidassPublishers; Delhi.pp. 1203.

Keith, A. B. (1914). Veda of the Black YajusSchool, TaittiriyaSanhita, The HarvardUniversity Press

Roy, K. (2014). *Evaluation of agro-techniques and storage methods for aromatic rice landraces of West Bengal*, Ph. D. Thesis, Department of Agronomy, B.C.K.V., Mohanpur, Nadia, West Bengal.

Richharia, R., and Govindasamy,S. (1990). *Rices of India*. Academy of Development Science. Karjat.

Sathya, A.,Rajamanickam, V. and Ramasamy, K. (2007).Evaluation of biodiversity in traditional paddy varieties of Tamil Nadu. Ph.D. Thesis, Tamil University,Thanjavur, Tamil Nadu.

www.agriallis.com
AGRIALLIS
Science for Agriculture and Allied Sector: A Monthly Magazine
Volume 8, Issue 4

Article Id
AL04515

THE MULTI-FUNCTIONAL ROLE OF BUTYRIC ACID IN MODERN LIVESTOCK NUTRITION

[1]Niladyuti Ghosh*, [1]Ranjita Biswas and [2]Shubham Singha

Email
niladyuti@gmail.com

[1]Department of Biotechnology, Maulana Abul Kalam Azad University of Technology West Bengal, Haringhata, Nadia, West Bengal- 741249, India

[2]Buck Semen Station, Paschim Banga Go-Sampad Bikash Sanstha, Haringhata, Nadia, West Bengal- 741246, India

For decades, the livestock industry relied on antibiotic growth promoters (AGPs) to maintain animal health and maximize productivity. However, the rise of antimicrobial resistance, a global health threat, led to a paradigm shift, notably with the European Union's 2006 ban on AGPs in animal feed (Giacomini et al., 2022). This transition created an urgent need for safe, natural alternatives that could maintain gut health without the risks of drug resistance. Among the most promising candidates, butyric acid, a short-chain fatty acid (SCFA) that acts as a multi-functional bioactive compound (Gerunova et al., 2024). Often supplemented in the form of salts (like sodium butyrate) or glycerides (tributyrin), it provides a natural mechanism to protect the gastrointestinal tract and boost growth performance in poultry, swine, and cattle (Chen et al., 2025).

Why Butyric Acid is Important as an "Antibiotic" Alternative

Butyric acid does not just kill bacteria like traditional drugs; it reshapes the entire internal environment of the animal to favour health over disease. Its importance is rooted in three primary scientific mechanisms:

Direct and Indirect Antimicrobial Action

Butyric acid acts as a potent acidifier in the digestive tract. By lowering the pH of the intestinal contents, it creates a hostile environment for pH-sensitive pathogens such as *Salmonella*, *Escherichia coli*, and *Clostridium perfringens* (Makowski et al., 2022). In its undissociated form, the acid can penetrate the cell walls of harmful bacteria, disrupt their internal metabolism and lead to cell death (El-Saadony et al., 2022). Simultaneously, it encourages the growth of beneficial bacteria like *Lactobacillus*, which further suppresses pathogens through competitive exclusion (Melaku et al., 2021).

Restoration of Gut Integrity and Energy Supply

Unlike many synthetic additives, butyric acid serves as the primary energy source for colonocytes (the cells lining the large intestine) and enterocytes (Chen et al., 2025).

- **Villi Development:** It stimulates the growth of intestinal villi—tiny finger-like projections—increasing their height and surface area for better nutrient absorption (El-Saadony et al., 2022).
- **Barrier Function:** It strengthens "tight junctions" between cells, preventing "leaky gut" and stopping toxins or bacteria from entering the bloodstream (Wang et al., 2017).

Immunomodulation and Anti-Inflammatory Effects

Butyric acid is a natural immunomodulator. It reduces the production of pro-inflammatory cytokines (such as IL-6 and TNF-α) and inhibits inflammatory signalling pathways like NF-κB (Chen et al., 2025; Wang et al., 2017). This ensures that the animal's energy is directed toward growth and muscle development rather than being wasted on fighting chronic gut inflammation (Mazur-Kuśnirek et al., 2024).

Methods of Incorporating Butyric Acid in Animal Feed

Incorporating butyric acid into animal feed is a technical challenge. In its raw, liquid state, butyric acid is highly volatile, has a corrosive nature, and possesses a notoriously foul, pungent odour (like rancid butter) that is unpleasant for both farmers and animals.

To solve these issues and ensure the acid reaches the lower intestine rather than being absorbed too early in the stomach, several specialized methods have been developed:

1. Salt Formation (Butyrates)

The most common method is converting the liquid acid into a dry, stable powder by reacting it with minerals.

- Sodium Butyrate: The most widely used salt. It is stable, easy to handle, and highly soluble.

- Calcium Butyrate: Less common but used when a slower release or additional calcium supplementation is desired.
- Pros: Cost-effective and easy to mix into mash or pelleted feed.
- Cons: Can still have a lingering odour and is often absorbed very quickly in the upper GI tract (stomach/duodenum) unless protected.

2. Encapsulation (Coated Butyrates)

To ensure the butyric acid reaches the hindgut (the lower part of the intestine where most pathogens reside), the salts are often "encapsulated" in a lipid matrix.

- **Micro-encapsulation:** The butyrate crystals are coated with a layer of vegetable fat (usually palm or stearin) or ethyl cellulose.
- **Targeted Release:** The fat coating is only broken down by lipase enzymes in the small intestine. This "slow-release" mechanism ensures the active ingredient is delivered precisely where it is needed most.
- **Pros:** Odourless for the handler and highly effective for gut health.

3. Esterification (Glycerides/Tributyrin)

This is a more advanced chemical method where butyric acid is bonded to a glycerol molecule.

- **Tributyrin:** A triglyceride consisting of three butyric acid molecules. It is a stable, liquid (or powder-supported) ester.
- **Mechanism:** Tributyrin is not affected by the acidic pH of the stomach. It travels to the small intestine, where pancreatic lipase cleaves the ester bonds, releasing the butyric acid directly at the intestinal wall.
- **Pros:** High concentration of butyric acid, neutral smell, and superior "by-pass" properties compared to uncoated salts.

4. Powder Carriers (Adsorption)

Liquid butyric acid or its esters can be sprayed onto a porous "carrier" to turn it into a free-flowing powder.

- **Carriers used:** Silica, sepiolite, or cereal by-products.
- **Usage:** This makes it easier to include in a premix (a concentrated blend of vitamins, minerals, and additives) before it is added to the final bulk feed.

The Economic Benefits of Using Butyric Acid in Animal Feed

The economic benefits of using butyric acid in animal feed are often based on Return on Investment (ROI). While these additives increase the initial cost per ton of feed, the long-term gains in efficiency and animal health typically outweigh the expense.

Here is how the economics break down for a commercial farming operation:

1. Improved Feed Conversion Ratio (FCR)

The FCR is the most critical metric in livestock production, measuring how much feed is required to produce 1 kilogram of meat or a dozen eggs.

- **Mechanism:** By enhancing the height of the intestinal villi and increasing the surface area for absorption, butyric acid ensures that the animal extracts more nutrients from every gram of feed.
- **Economic Impact:** Even a small improvement in FCR (e.g., 2–3%) can save thousands of dollars in large-scale operations, especially when grain prices are high.

2. Reduced Veterinary and Medication Costs

By acting as a "natural antibiotic," butyric acid strengthens the immune system and the gut barrier.

- **Economic Impact:** Farmers see a significant drop in the need for therapeutic antibiotics and veterinary interventions. This not only saves on the cost of drugs but also avoids the "withdrawal periods" where animals cannot be sold for meat because they have medication in their systems.

3. Lower Mortality and Increased Uniformity

In poultry and swine production, "uniformity" (animals being roughly the same size at the time of slaughter) is vital for processing efficiency.

- **Economic Impact:** Butyric acid helps vulnerable young animals (chicks or weaned piglets) survive the critical early stages of life. Lower mortality rates mean more "marketable units" at the end of the cycle. Improved uniformity ensures that the farmer receives the maximum price per kg without penalties for undersized animals.

Conclusion: The Future of Food Security

As the global livestock industry moves away from traditional growth-promoting antibiotics, butyric acid stands out not just as a replacement, but as a more sophisticated tool for precision nutrition. By targeting gut health at a cellular level, it offers a dual advantage: protecting the animal from pathogens while simultaneously maximizing the efficiency of every gram of feed.

Looking ahead, the next frontier for butyric acid lies in synergistic formulations. Researchers are increasingly combining it with probiotics (live beneficial bacteria) and prebiotics (fibres that feed those bacteria) to create "synbiotics" that mimic the complex natural ecosystem of a healthy gut. For the scientist, it represents a triumph of biochemistry over resistance; for the producer, it is an essential investment in a sustainable, antibiotic-free future; and for the animals, it is a guarantee of safer diet free from synthetic additives and drugs.

References

Chen, W., Ma, Q., Li, Y., Wei, L., Zhang, Z., Khan, A., Khan, M. Z., & Wang, C. (2025). Butyrate Supplementation Improves Intestinal Health and Growth Performance in Livestock: A Review. *Biomolecules*, *15*(1), 85. https://doi.org/10.3390/biom15010085

El-Saadony, M. T., Umar, M., Hassan, F., Alagawany, M., Arif, M., Taha, A. E., Elnesr, S. S., El-Tarabily, K. A., & Abd El-Hack, M. E. (2022). Applications of butyric acid in poultry production: the dynamics of gut health, performance, nutrient utilization, egg quality, and osteoporosis. *Animal Health Research Reviews*, *23*(2), 136–146. https://doi.org/10.1017/s1466252321000220

Gerunova, L. K., Gerunov, T. V., P'yanova, L. G., Lavrenov, A. V., Sedanova, A. V., Delyagina, M. S., Fedorov, Y. N., Kornienko, N. V., Kryuchek, Y. O., & Tarasenko, A. A. (2024). Butyric acid and prospects for creation of new medicines based on its derivatives: a literature review. *Journal of Veterinary Science*, *25*(2). https://doi.org/10.4142/jvs.23230

Giacomini, P. V., Braga, F. S. C., Araujo, R. G. A. C., Cruz-Polycarpo, V. C., & Polycarpo, G. V. (2022). Meta-Analysis of Butyric Acid: a Performance-Enhancing Additive to Replace Antibiotics for Broiler Chickens. *Brazilian Journal of Poultry Science*, *24*(3). https://doi.org/10.1590/1806-9061-2021-1463

Makowski, Z., Lipiński, K., & Mazur-Kuśnirek, M. (2022). The Effects of Different Forms of Butyric Acid on the Performance of Turkeys, Carcass Quality, Incidence of Footpad Dermatitis and Economic Efficiency. *Animals*, *12*(11), 1458. https://doi.org/10.3390/ani12111458

Mazur-Kuśnirek, M., Lipiński, K., Antoszkiewicz, Z., & Matusevičius, P. (2024). Different forms of butyric acid in poultry nutrition – a review. *Journal of Animal and Feed Sciences*, *33*(3), 270–280. https://doi.org/10.22358/jafs/186022/2024

Melaku, M., Zhong, R., Han, H., Wan, F., Yi, B., & Zhang, H. (2021). Butyric and Citric Acids and Their Salts in Poultry Nutrition: Effects on Gut Health and Intestinal Microbiota. *International Journal of Molecular Sciences*, *22*(19), 10392. https://doi.org/10.3390/ijms221910392

Wang, C. C., Wu, H., Lin, F. H., Gong, R., Xie, F., Peng, Y., Feng, J., & Hu, C. H. (2017). Sodium butyrate enhances intestinal integrity, inhibits mast cell activation, inflammatory mediator production and JNK signaling pathway in weaned pigs. *Innate Immunity*, *24*(1), 40–46. https://doi.org/10.1177/1753425917741970

Article Id
AL04516

RECENT ADVANCEMENTS IN AQUACULTURE NUTRITION FOR A SUSTAINABLE FUTURE

Email

muralimurugesan2212@gmail.com

M. Muralidharan

Department of Aquaculture,
Faculty of Fisheries Science, Kerala University of Fisheries Science and Ocean Studies, Kochi, Kerala, India

Aquaculture nutrition has undergone transformative innovations to address global food security, environmental sustainability, and production efficiency. Recent advancements focus on alternative protein sources, precision feeding technologies, functional feed additives, and circular economy principles. These developments reduce reliance on finite marine resources, enhance fish health, and minimize ecological footprints while meeting rising protein demands.

Protein Hydrolysates and Functional Ingredients

Protein hydrolysates are produced by enzymatic or chemical hydrolysis of proteins, resulting in smaller peptides and free amino acids that are easily digestible by aquatic organisms. In aquaculture nutrition, fish protein hydrolysates derived from fish by-products, shrimp waste, or plant proteins are increasingly used to improve feed efficiency and growth performance. These hydrolysates contain bioactive peptides that stimulate appetite, improve protein digestibility, and enhance nutrient absorption in fish and shrimp. Studies have demonstrated that diets supplemented with protein hydrolysates can improve growth rates, feed conversion ratio (FCR), and survival rates in species such as tilapia, salmon, and shrimp.

Functional ingredients, such as nucleotides, taurine, carotenoids, and bioactive peptides, also play important roles in improving physiological functions and immune responses. These compounds enhance stress resistance, antioxidant activity, and disease resistance in cultured species. For example, dietary nucleotides promote immune cell proliferation and improve resistance to bacterial infections, while taurine supplementation enhances growth and metabolic efficiency in carnivorous fish species. The inclusion of functional ingredients in aquafeeds is therefore considered a key strategy to improve productivity and sustainability in modern aquaculture systems.

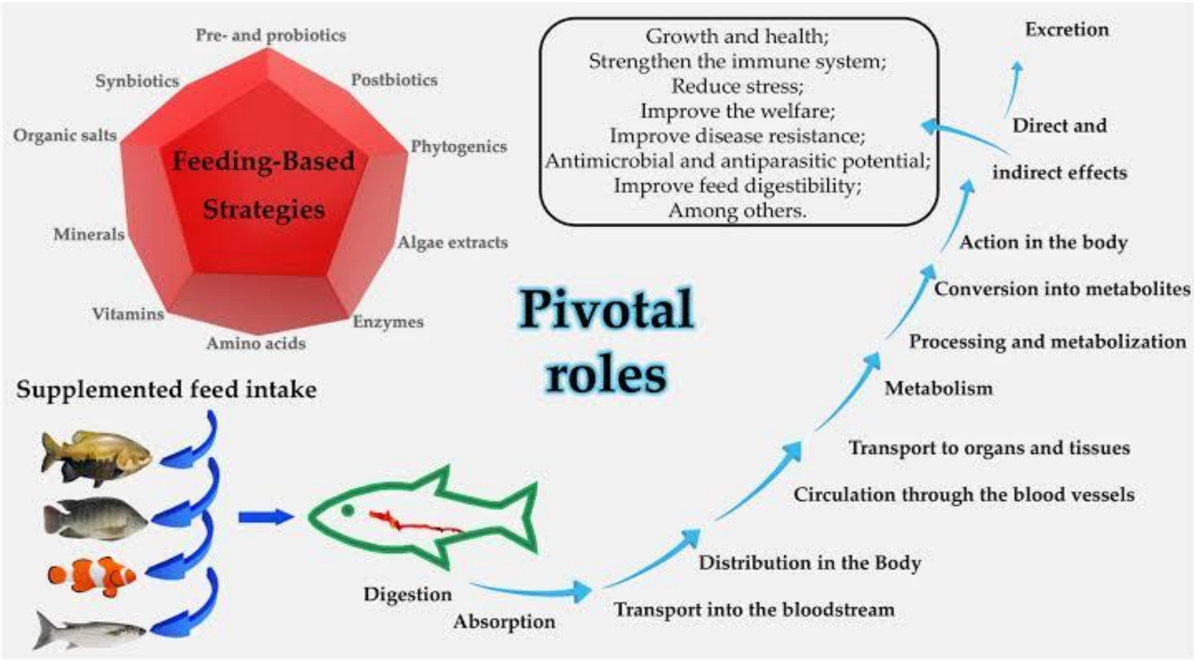

Fig. 1: Pivotal role of fish nutrition and Feeding

Smart Feeding and Precision Nutrition

Smart feeding technologies are transforming aquaculture production by improving feeding efficiency and reducing feed waste. Feed represents the largest operational cost in aquaculture, often accounting for more than 50–60% of total production expenses. Precision feeding systems use sensors, cameras, and automated feeders to monitor fish feeding behavior and deliver feed according to real-time requirements. This approach helps optimize feed utilization while minimizing environmental pollution caused by uneaten feed and nutrient discharge.Precision nutrition focuses on providing the exact nutrient requirements for aquatic organisms at different life stages. Nutrient requirements vary depending on species, size, environmental conditions, and production systems. Modern nutritional models use data analytics and computer simulations to formulate balanced diets that maximize growth while minimizing nutrient wastage. For example, dynamic feeding models can adjust feed composition and feeding frequency based on fish metabolism, water temperature, and growth rate. These advanced feeding strategies improve feed conversion efficiency, reduce production costs, and enhance the sustainability of aquaculture operations.

Alternative Protein Sources

The rapid expansion of aquaculture has significantly increased the demand for fishmeal and fish oil, which are traditionally used as primary protein and lipid sources in aquafeeds.

However, the limited availability and rising cost of these marine resources have driven the search for sustainable alternative protein sources. Plant-based proteins such as soybean meal, pea protein, corn gluten meal, and rapeseed meal are widely used as partial replacements for fishmeal in aquafeeds. These ingredients provide high protein content and are readily available, although they may contain anti-nutritional factors that can affect digestibility and nutrient utilization.

Recent research has focused on novel protein sources such as insect meals, microbial proteins, algae-based ingredients, and single-cell proteins. Insect meal derived from black soldier fly larvae has gained considerable attention due to its high protein content, balanced amino acid profile, and low environmental footprint. Similarly, microalgae and macroalgae provide essential fatty acids, vitamins, and bioactive compounds that support fish growth and health. Single-cell proteins produced from bacteria, yeast, or fungi offer promising alternatives due to their rapid production and minimal land and water requirements. The use of these alternative protein sources can significantly reduce reliance on marine resources and contribute to the sustainability of aquaculture feed production.

Insect Protein: Black Soldier Fly-derived ingredients (e.g., Palate) strengthen immune defenses in rainbow trout by activating pathogen-response genes, reducing mortality risks.

Microalgae: Autotrophic strains (e.g., *Schizochytrium* sp.) provide essential fatty acids (DHA/EPA) and amino acids, improving stress resistance and fillet quality.

By-Product Valorization: Fish processing wastes (heads, bones) are repurposed into silages or hydrolysates, enhancing gut health and reducing landfill burdens. For example, Barbados repurposes 8 tons of daily by-products into feed additives, lowering antibiotic needs.

Feed Additives and Immunonutrition

Novel additives modulate immunity and metabolism: Feed additives play an essential role in improving growth performance, health status, and disease resistance in aquaculture species. Common feed additives include probiotics, prebiotics, organic acids, enzymes, phytogenics, and immune stimulants. These additives enhance digestive efficiency, improve nutrient absorption, and strengthen the immune system of fish and shrimp. Probiotics, such as *Bacillus* and *Lactobacillus* species, improve gut microbiota balance and inhibit pathogenic microorganisms, thereby reducing disease outbreaks.Immunonutrition refers to the use of specific nutrients or bioactive compounds to modulate the immune system of aquatic organisms. Important immunostimulants used in aquaculture include beta-glucans, nucleotides, vitamins C and E, and minerals such as selenium and zinc. These compounds enhance both innate and adaptive immune responses, increasing the ability of fish and shellfish to resist infections. For example, beta-glucans stimulate macrophage activity and enhance the production of immune-related cytokines, improving resistance against bacterial and viral pathogens.

- **β-glucan**(0.4% inclusion) optimizes intestinal microbiota in tilapia, increasing survival in brackish water by downregulating inflammatory genes.

-Andrographolide(150 mg/kg) enhances antioxidant capacity in rice field eels via Toll-like signaling pathways.

- Plant extracts(e.g., *Glycyrrhiza uralensis*) upregulate immune-related genes in barramundi, improving growth rates by 15%.

The integration of immunonutrition strategies into aquafeeds reduces dependence on antibiotics and supports sustainable disease management in aquaculture.

Probiotics, Prebiotics and Gut Health

The health and productivity of aquatic animals are closely linked to the microbial communities present in their gastrointestinal tract. Probiotics are beneficial microorganisms that improve gut microbial balance and enhance digestive enzyme activity. These microorganisms colonize the intestinal tract and compete with pathogenic bacteria for nutrients and attachment sites, thereby preventing infections. Probiotics also produce antimicrobial substances that inhibit the growth of harmful microorganisms.Prebiotics are non-digestible feed components that selectively stimulate the growth of beneficial gut bacteria. Common prebiotics used in aquaculture include fructooligosaccharides (FOS), galactooligosaccharides (GOS), and mannan-oligosaccharides (MOS). These compounds promote intestinal health, improve nutrient digestion, and enhance immune responses. When probiotics and prebiotics are combined, they form synbiotics, which provide synergistic benefits for gut health and overall performance. The use of these functional additives contributes to improved growth, disease resistance, and feed efficiency in aquaculture systems.

Sustainable Formulations and Circular Economy

Camelina meal replaces 20% of fishmeal in red seabream diets, improving digestibility and stress resilience without compromising growth.

Insect- and algae-based feeds reduce aquaculture's carbon footprint by 30–40% compared to traditional options. BRF Ingredients' portfolio exemplifies circularity, using poultry by-products to create hydrolysates, thus minimizing waste.

Conclusion

In conclusion, recent advances in aquaculture nutrition and management have significantly contributed to improving productivity, efficiency, and environmental sustainability. Innovations such as protein hydrolysates, functional ingredients, and alternative protein sources have helped reduce the dependence on traditional fishmeal and fish oil while maintaining optimal growth and health of cultured species. In addition, the development of smart feeding systems and precision nutrition strategies has improved feed utilization and minimized nutrient waste in aquaculture systems.Furthermore, the use of feed additives, probiotics, and immunonutrition has strengthened disease resistance and enhanced the overall health status of fish and shellfish. The integration of modern technologies, including digital monitoring systems and precision aquaculture tools, also plays an important role in optimizing farm management and improving production efficiency.Overall, these advancements demonstrate that sustainable aquaculture can be achieved through the combination of innovative nutrition strategies, technological developments, and environmentally responsible farming practices. Continued research and collaboration among scientists, industry stakeholders, and policymakers will be essential to ensure the long-term sustainability and resilience of the global aquaculture sector.

Reference

Abdel-Tawwab, M., & Adeshina, I. (2022). Nanotechnology applications in aquaculture nutrition and fish health. *Aquaculture International*, *30*, 1–17.

Avnimelech, Y. (2015). *Biofloc technology: A practical guidebook* (3rd ed.). The World Aquaculture Society.

BRF Ingredients. (2025). *Aquaculture in 2025: New technologies, sustainability and the direction of the sector*.

Dawood, M. A. O., Koshio, S., & Esteban, M. A. (2018). Beneficial roles of feed additives as immunostimulants in aquaculture. *Reviews in Aquaculture, 10*(4), 950–974.

Føre, M., Frank, K., Norton, T., Svendsen, E., Alfredsen, J. A., Dempster, T., Berckmans, D. (2018). Precision fish farming: A new framework to improve production in aquaculture. *Biosystems Engineering, 173*, 176–193.

Glencross, B. D., Huyben, D., & Schrama, J. W. (2020). The application of nutrigenomics in aquaculture feeds. *Aquaculture Research, 51*, 1–14.

Handy, R. D., Owen, R., & Valsami-Jones, E. (2018). The ecotoxicology of nanoparticles and nanomaterials in aquatic environments. *Ecotoxicology, 17*(5), 315–325.

Houston, R. D., Bean, T. P., Macqueen, D. J., Gundappa, M. K., Jin, Y. H., Jenkins, T. L., & Martin, S. A. M. (2020). Harnessing genomics to fast-track genetic improvement in aquaculture. *Nature Reviews Genetics, 21*, 389–409.

Naylor, R. L., Hardy, R. W., Buschmann, A. H., Bush, S. R., Cao, L., Klinger, D. H., & Troell, M. (2021). A 20-year retrospective review of global aquaculture. *Nature*, *591*, 551–563.

Number Analytics. (2025). *The future of aquaculture in nutrition*.

Ringø, E., Olsen, R. E., Gifstad, T. Ø., Dalmo, R. A., Amlund, H., Hemre, G. I., & Bakke, A. M. (2016). Prebiotics in aquaculture: A review. *Aquaculture Nutrition*, *16*(2), 117–136.

Troell, M., Joyce, A., Chopin, T., Neori, A., Buschmann, A. H., & Fang, J. G. (2009). Ecological engineering in aquaculture: Potential for integrated multi-trophic aquaculture (IMTA). *Aquaculture, 297*, 1–9.