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CIRCULAR ECONOMY IN AQUACULTURE FEEDS: WASTE TO WEALTH

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Abstract

The aquaculture sector faces increasing costs and environmental concerns due to its heavy reliance on conventional fishmeal and fish oil. At the same time, large volumes of agricultural, food processing, and fishery wastes are discarded each year, contributing to pollution and resource wastage. This article explores how circular economy principles recycling and repurposing waste streams as fish feed ingredients can turn these challenges into opportunities. By utilizing local by-products such as rice bran, wheat bran, bakery and brewery residues, and fish processing waste, farmers can cut feed costs, reduce environmental impacts, and create new income streams. Success stories from India, Jamaica, Indonesia, and beyond highlight the practical benefits and scalability of these approaches. The paper also discusses processing and safety considerations critical for successful waste-to-feed conversion, and suggests actionable steps for students and farmers interested in adopting circular feed strategies. The transition from waste to wealth in aquaculture not only supports farm profitability and food security but also paves the way for a more sustainable and resilient future for the industry.

1. Introduction: Why It Matters

The aquaculture industry is at a turning point. Traditional fish feeds depend heavily on fishmeal and fish oil, which are not only expensive but also place big pressure on wild fish stocks (Cargill, 2024). Since feed costs make up 50–70% of total production expenses, farmers especially those running small-scale fish farms are feeling the weight more than ever (Aquafishcrsp, 2024). Meanwhile, millions of tons of agricultural, food processing, and fisheries waste end up in landfills each year, creating environmental problems and wasting valuable resources.

Circular economy principles offer a promising solution to both challenges. By transforming waste into wealth, these approaches can significantly reduce feed costs while creating more sustainable aquaculture systems (Skretting, 2024). For small-scale farmers in developing countries, where feed can account for up to 80% of operational costs, these innovations could mean the difference between profitable farming and abandoning aquaculture altogether (Global Seafood Org, 2018).

2. Understanding Circular Economy in Aquaculture Feeds

2.1 What Does It Really Mean?

Circular economy in aquaculture feeds represents a fundamental shift from the traditional "take-make-dispose" model to a regenerative approach where waste becomes a valuable input for another process (FAO, 2019). Instead of allowing agricultural by-products, food processing residues, or fisheries waste to burden landfills, these

materials are transformed into nutritious feed ingredients that can partially or completely replace conventional components.

This approach keeps nutrients cycling within the food system, reduces environmental pollution, and creates new economic opportunities for farmers and processors alike (Global Seafood Org, 2021). The beauty of circular feed systems lies in their ability to address multiple challenges simultaneously: waste management, feed costs, environmental impact, and resource efficiency.

2.2 The Science Behind Waste-to-Feed Conversion

The transformation of waste materials into high-quality feed ingredients requires careful processing to ensure both nutritional value and safety. Common processing methods include drying, fermentation, enzymatic treatment, and pelletizing (Manage, 2024). Fermentation, in particular, has proven especially effective for materials like rice bran and food waste, as it increases digestibility while reducing anti-nutritional factors that could harm fish health (Nithya et al., 2023).

Recent advances in solid-state fermentation have shown remarkable results. For instance, fermented brewer's spent grain can be included in fish diets at levels up to 20% without negatively affecting performance, and at 10% inclusion, it actually exceeds the performance of conventional control diets (Mispeces, 2025).

3. From Waste Streams to Feed Ingredients

3.1. Agricultural By-Products: Hidden Treasures

Rice bran represents one of the most widely used alternative feed ingredients globally. Containing approximately 12% protein in its regular form, defatted rice bran can reach 25-26% protein content, making it a valuable protein source for fish feeds (Robinette et al., 1988). Studies have shown that fish fed with feeds containing defatted rice bran perform equally well as those fed standard commercial feeds, while significantly reducing production costs.

Wheat bran, another agricultural by-product, offers similar benefits with high carbohydrate content and cost-effectiveness, particularly in regions like India and Southeast Asia where these materials are readily available (FAO, 1987). The key advantage of these materials lies not just in their nutritional value, but in their consistent availability and low cost compared to traditional feed ingredients.

3.2. Food Processing Waste: Turning Problems into Solutions

Bakery residues have emerged as particularly promising feed ingredients. Recent research on various bakery waste products including biscuits, cream cake, bread, and dry rusk demonstrated significant potential for fish nutrition (BioRxiv, 2024). When properly processed and incorporated into fish feeds, these materials can reduce feed costs substantially while maintaining fish growth performance.

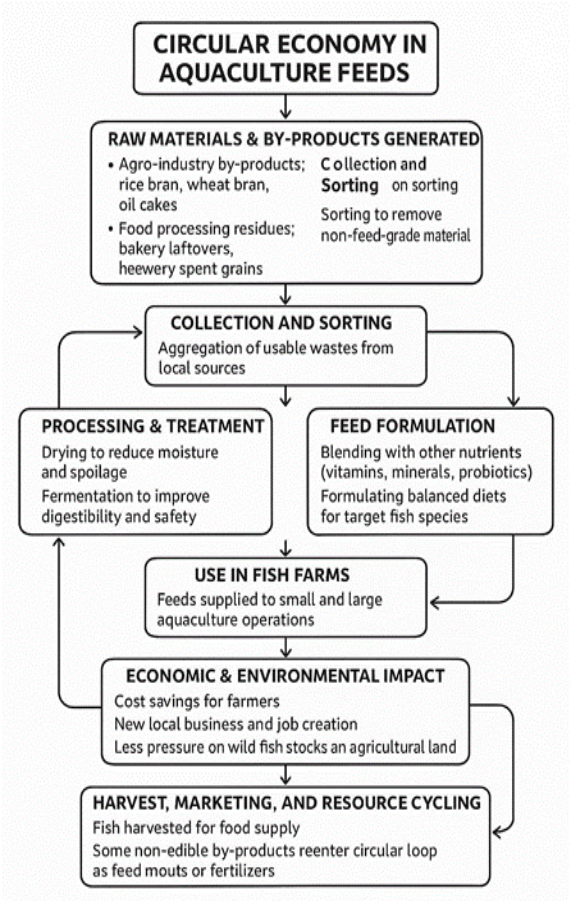

Fig 1: Flow of Circular Economy in Aquaculture Feed

The study found that fish fed rusk waste showed the best growth performance, with some formulations achieving feed conversion ratios comparable to commercial feeds at a fraction of the cost. This is particularly significant for countries like Pakistan, where imported feed ingredients create substantial financial burdens for small-scale farmers (BioRxiv, 2024).

Brewery spent grain, a major by-product of the beer industry, contains high levels of protein and is available in vast quantities globally. Each year, approximately 38 million tons of brewery spent grain are generated worldwide from beer production (PMC, 2024). Advanced processing techniques, including fermentation and enzymatic treatment, can transform this waste into a high-value aquaculture ingredient (Life Brewery, 2020).

3.3. Fish Processing Waste: Closing the Loop

The fish processing industry generates enormous amounts of waste typically 30-85% of the total fish weight depending on the species and processing methods (Agriallis, 2025). These by-products, rich in proteins, bioactive peptides, omega-3 fatty acids, and minerals, represent a significant opportunity for circular economy applications.

India's innovative "Waste to Wealth" program, implemented by the Central Institute of Brackishwater Aquaculture (CIBA), demonstrates the practical potential of fish waste conversion. Fisher communities convert fish processing waste into PlanktonPlus (liquid fertilizer for aquaculture) and HortiPlus (organic manure for horticulture), creating new income streams while solving environmental problems (Hakai Magazine, 2017).

4. Economic Benefits for Small-Scale Farmers

4.1. Cost Reduction: The Primary Driver

The economic impact of circular feed ingredients on small-scale farmers cannot be overstated. In Bangladesh, researchers developed a cost-effective tilapia feed using locally available ingredients including rice bran, wheat flour, mustard oil cake, and various organic wastes. This formulation cost just 22 cents per kilogram compared to 35 cents for commercial feed a 37% cost reduction (WorldFish Center, 2008).

The savings become even more dramatic when considering the protein component, which typically represents over 60% of feed costs. By utilizing local by-products, farmers can significantly reduce

their dependence on expensive imported protein sources while maintaining fish growth and health (Blue Life Hub, 2025).

4.2. Creating New Income Streams

Circular economy approaches don't just reduce costs they create entirely new revenue opportunities. Farmers and rural entrepreneurs can establish small-scale processing operations to convert local waste streams into valuable feed ingredients. In Indonesia, farmer Syafruddin Darmawan has been producing his own feed for 15 years using locally available materials including rice bran, fish meal, corn, tofu dregs, and palm kernel cake (The Fish Site, 2023).

His enterprise, Mutiara Feed Kampar, produces 1-3 tonnes daily at costs ranging from €0.36-0.42 per kilogram, compared to market prices of €0.66 per kilogram. This represents substantial savings while providing employment and supporting the local economy through reduced dependence on imported ingredients.

4.3. Supply Chain Resilience

Local sourcing of feed ingredients also provides crucial protection against supply chain disruptions and price volatility. During the COVID-19 pandemic and subsequent global events, many farmers experienced severe difficulties accessing imported feed ingredients or faced dramatic price increases (Manolin Aqua, 2024). Farms utilizing local waste streams maintained more stable operations and costs.

5. Environmental Impact and Sustainability

5.1. Waste Diversion and Pollution Reduction

The environmental benefits of circular feed systems extend far beyond aquaculture. By diverting organic waste from landfills, these systems prevent the generation of methane and other greenhouse gases while reducing leachate pollution (Agriallis, 2025). A single biogas unit processing fish waste can reduce LPG consumption by 25-30% while producing valuable fertilizer as a by-product (CMFRI, 2018).

Research in Hong Kong has demonstrated that food waste-based fish feeds can actually produce safer fish for human consumption. Health risk assessments based on major environmental contaminants showed that fish fed food waste-based pellets had lower levels of mercury, PAHs, and DDTs compared to those fed commercial feeds (Global Seafood Org, 2024).

5.2. Resource Conservation and Ecosystem Protection

Traditional aquaculture feeds place enormous pressure on marine ecosystems through fishmeal production. The industry currently consumes 73% of global fishmeal production and 71% of fish oil production (Life Brewery, 2020). By utilizing alternative ingredients, circular feed systems can significantly reduce this pressure while maintaining fish nutrition and growth performance.

Plant-based and waste-derived ingredients also require substantially less land, water, and energy to produce compared to conventional feed ingredients. Insect farming, for example, uses minimal land and water while converting organic waste into high-protein feed ingredients with excellent environmental credentials (Freezem, 2024).

5.3. Success Stories: Jamaica's "No Common Feed" Initiative

Jamaica provides an excellent example of circular economy principles in action. Until 2022, all aquaculture feed components for industrial feed mills were imported, creating substantial costs and supply vulnerabilities for local farmers (Blue Life Hub, 2025). The "No Common Feed" (NCF) project began testing local resources as alternatives to imported ingredients.

Local by-products including bakery residues, brewery grains, and fish processing waste were systematically evaluated as feed ingredients. The project demonstrated that these materials could successfully replace imported components while reducing costs and improving supply stability. More importantly, it created local employment and reduced environmental waste from disposal of these materials.

The success of this initiative illustrates how circular economy principles can transform entire regional aquaculture systems. By utilizing locally available waste streams, Jamaica is developing a more resilient and sustainable aquaculture sector while addressing environmental challenges related to waste disposal.

6. Processing and Safety Considerations

6.1. Ensuring Feed Safety Through Proper Treatment

The conversion of waste materials into safe, nutritious feed requires careful attention to processing methods and quality control. Heat treatment, fermentation, and proper drying are essential for eliminating pathogens and ensuring feed safety (Global Scientific Journal, 2021). Treatment protocols must be rigorously followed to prevent disease transmission while maximizing nutritional value.

The European Commission's experience with food waste regulations highlights the importance of proper processing standards. While concerns about disease transmission led to initial restrictions on food waste use in animal feeds, subsequent research has shown that appropriate processing can eliminate these risks, particularly for fish feeds where cross-species disease transmission is less likely (Global Scientific Journal, 2021).

6.2. Quality Control and Nutritional Optimization

Successful circular feed systems require consistent quality monitoring and nutritional optimization. Regular analysis of waste stream composition helps ensure that feed formulations meet fish nutritional requirements while maintaining cost advantages. The addition of enzymes, probiotics, vitamins, and minerals can further enhance the nutritional value of waste-based feeds (PubMed, 2016).

Research has shown that strategic supplementation can improve not only growth performance but also fish health and immunity. For example, adding baker's yeast to food waste-based diets significantly improved feed conversion and fish health in grass carp studies (ScienceDirect, 2016).

7. Future Prospects and Recommendations

7.1. Scaling Up Successful Models

The evidence clearly demonstrates that circular economy approaches in aquaculture feeds can deliver significant economic, environmental, and social benefits. However, scaling these successes requires coordinated efforts from governments, industry, and research institutions. Investment in processing infrastructure, technical training,

and quality control systems will be essential for widespread adoption.

Small and medium-scale processing enterprises represent particularly promising opportunities for rural development and employment generation. These operations can process local waste streams into standardized feed ingredients, creating employment while reducing costs for farmers and environmental burdens for communities.

7.2. Technology and Innovation

Continued technological advancement will play a crucial role in expanding circular feed options. Improved fermentation techniques, enzymatic processing, and novel ingredients from sources like insects and algae offer exciting possibilities for the future. Black soldier fly larvae, for example, can convert organic waste into high-protein feed ingredients with remarkable efficiency (Dialogue Earth, 2024).

The development of mobile processing units could bring waste-to-feed conversion capabilities directly to farming communities, reducing transportation costs and creating local employment opportunities. These systems could process multiple waste streams simultaneously, maximizing resource utilization and economic benefits.

8. Practical Applications for Students and Farmers

8.1. Getting Started with Circular Feeds

For students and new farmers interested in implementing circular economy principles, starting small with readily available local materials offers the best approach. Rice bran, vegetable waste, and bakery residues provide excellent entry points for experimentation and learning. Simple processing techniques like drying and basic fermentation can be mastered with minimal investment while providing valuable experience.

Understanding local waste streams and seasonal availability patterns helps in planning sustainable feed formulations. Many successful circular feed operations began as small-scale experiments that gradually expanded as farmers gained experience and confidence with alternative ingredients.

8.2. Building Knowledge and Networks

Collaboration with local research institutions, extension services, and other farmers accelerates learning and problem-solving. Many countries now have demonstration projects and training programs specifically focused on alternative feed ingredients and circular economy approaches in aquaculture.

Students can contribute to this growing field through research projects, internships with innovative farms, and participation in sustainable aquaculture initiatives. The combination of environmental benefits, economic opportunities, and technical challenges makes circular feeds an exciting area for career development and entrepreneurship.

9. Conclusion

The transformation of waste into wealth through circular economy principles represents one of the most promising developments in modern aquaculture. By converting agricultural by-products, food processing waste, and fisheries residues into valuable feed ingredients, these approaches simultaneously address multiple challenges facing the industry: rising feed costs, environmental pollution, resource scarcity, and supply chain vulnerability.

The evidence from successful implementations around the world demonstrates that circular feeds can deliver substantial economic benefits, particularly for small-scale farmers who face the greatest challenges from rising conventional feed costs. Environmental benefits include reduced waste disposal burdens, lower greenhouse gas emissions, and decreased pressure on marine ecosystems.

As the global aquaculture industry continues to grow, circular economy principles will become increasingly important for ensuring sustainable development. The success stories from Jamaica, Indonesia, India, and other countries provide valuable models for implementation, while ongoing research continues to expand the range of viable waste-to-feed conversion technologies.

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