GPH-International Journal of Agriculture and Research
(Online ISSN 3050-9602)
Volume 9 | Issue 07 | July 2026
Published by: Global Publication House
DOI: https://doi.org/10.5281/zenodo.22067002
Available online at: www.gphjournal.org
Journal homepage: https://gphjournal.org/index.php/ar/index

Minireview – Fruits Waste as Alternative Feed Ingredients in Aquaculture

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Abstract

Agricultural byproducts of fruit waste, such as banana peels, mango peels, orange peels, pomegranate peels, and pineapple peels, are sources of nutrients and bioactive compounds that have the potential to be used as raw materials for functional feed in aquaculture. This mini-review article aims to summarize various studies on the nutritional content, bioactive compounds, and the effects of fruit waste utilization on the growth, immune system, stress resistance, and health of farmed fish. Various studies have shown that fruit waste contains protein, carbohydrates, fiber, vitamins, minerals, and phenolic compounds, flavonoids, terpenes, and carotenoids that act as natural antioxidants, antimicrobials, and immunostimulants. The use of fruit waste at appropriate doses has been shown to improve feed efficiency, growth performance, survival rates, and immune responses in fish, although its effectiveness is influenced by the type of waste, fish species, and the level of addition to the feed. The use of fruit waste as a feed raw material not only supports the development of sustainable aquaculture through *the waste-to-wealth* and circular economy concepts but also has the potential to reduce environmental pollution caused by the accumulation of agricultural waste.

Keywords:

fruits waste, bioactive compound, circular economy, feed supplementation

1. Introduction

Currently, the aquaculture sector is one of the fastest-growing food sectors. Aquaculture is a key sector in meeting global demand for quality animal protein and maintaining global food security (Amjad et al., 2025; Reda et al., 2024; Mathew et al., 2026). Recent data shows that the total volume of aquaculture production has surpassed that of traditional capture fisheries, demonstrating the sector's vital role in the modern global economy (Iber et al., 2025; Lourenço et al., 2025; Tuci et al., 2025). However, rapid population growth has also increased demand for fish. Meanwhile, the main problem in the aquaculture sector stems from the excessive and unsustainable dependence on fishmeal and fish oil, the costs of which have become too high to maintain (Ho et al., 2026; Vijayan et al., 2024; Kari et al., 2023). The finding for cheaper and environmentally friendly alternative raw materials is a very urgent need because feed costs can absorb between 50% and 95% of the total operational expenses of aquaculture businesses (Doan et al., 2025; Sulaiman et al., 2025; Sharker et al., 2025).

Furthermore, efforts to maximize aquaculture systems have led to significant environmental stress, leading to frequent disease outbreaks and negatively impacting farmed fish populations (Giri et al., 2016; Mathew et al., 2026). To date, the only common solution to address these challenges has been the use of antibiotics and vaccines. However, as recent literature warns, this heavy reliance has had detrimental consequences: it has led to the spread of antimicrobial resistance (amr), polluted local aquatic environments, and left harmful drug residues in seafood destined for human consumption (Asiri et al., 2022; Oz et al., 2026; Srisaen et al., 2026; Wang et al., 2026).

At the same time, millions of tons of agricultural waste and byproducts from fruit processing, such as fruit peels, are produced annually, and poor management often turns these resources into environmental pollution (Li et al., 2026; Ramírez-carmona et al., 2022). Open-air burning of waste can produce greenhouse gases such as carbon dioxide and methane, further increasing global warming. Meanwhile, toxic leachate seeps into groundwater, completely disrupting the balance of local ecosystems (Amjad et al., 2025; Macusi et al., 2025; Rapa et al., 2024).

However, these agricultural wastes actually still contain valuable sources of nutrients such as protein, carbohydrates, healthy fiber, and essential minerals (Lourenço et al., 2025; Thakur et al., 2025). More importantly, these materials are rich in structural bioactive compounds particularly terpenes, phenolic compounds, and flavonoids that act as potent antimicrobial, antioxidant, and immune-boosting agents (Leyva-lópez et al., 2020; Oh et al., 2025; Sayed-lafi et al., 2026). Recycling these agricultural wastes into functional fish feed aligns perfectly with the “waste-to-wealth” (*waste-to-wealth*) movement and the circular economy model. This could provide a highly sustainable alternative strategy to improve fish health, accelerate growth, and increase fish production while simultaneously reducing the negative effects of agricultural waste (Barreto et al., 2024; Kari et al., 2023; Serratos et al., 2025; Sharker et al., 2025).

This mini-review article aims to summarize and analyze various studies related to the nutritional content of fruit waste such as banana peel (*Musa acuminata*), mango peel (*Mangifera indica*), orange peel (*Citrus sinensis*), pomegranate peel ((*Punica granatum*), and pineapple peel (*Ananas comosus*) and their use as raw materials for fish feed. Therefore, this article is expected to assist researchers and fish farmers in conducting further research or using the research results as a basis for fish feed formulation.

2. Review Methods

This article used a literature review methodology that included searching, screening, analysis, and synthesis. The keywords "fruits waste," "feed," and "aquaculture" were used to conduct a literature search in Google Scholar and PubMed databases. Articles were then evaluated and chosen based on their publication time of year, topic relevancy, and information accuracy. Following the analysis, the information from the selected publications was compiled and synthesized as the basis for writing this article.

3. Results and Discussion

Nutritional and Bioactive Components of Fruit Waste

Agricultural waste from fruit processing, including peels, pulps, and seeds, still has significant nutritional value, the content of which depends on the plant species, cultivar type, and physiological maturity level at harvest (Table 1) (Lourenço et al., 2025; Sayed-Lafi et al., 2026; Thakur et al., 2025). Agricultural waste from fruit processing that still contains high nutritional value and can be used as fish feed includes banana peels, mango peels, citrus peels, pomegranate peels, pineapple waste, and so on. These agricultural wastes are generally characterized by high water content, often reaching 80-90% of their fresh weight, and are structurally dominated by dietary fiber and complex non-starch polysaccharides such as pectin, hemicellulose, and cellulose (Lourenço et al., 2025; Pinheiro et al., 2026; Sukri et al., 2023). Although their basic lipid and crude protein contents are generally lower than those of conventional aquaculture feedstocks such as fish meal, these industrial by-products remain a very viable and energy-rich feed alternative for a wide range of aquatic species (Lourenço et al., 2025; Sharker et al., 2025; Thakur et al., 2025).

Various studies have shown that fruit processing waste is an excellent source of a variety of bioactive phytochemicals and secondary metabolites that have a positive impact on fish physiology (Table 1) (Leyva-López et al., 2020; Lourenço et al., 2025). The main bioactive compounds identified in these materials include phenolic compounds (particularly flavonoids and phenolic acids), terpenes contained in essential oils, and carotenoid pigments (Leyva-López et al., 2020; Lourenço et al., 2025; Sayed-Lafi et al., 2026). Bioactive compounds from these plants are known to have strong effects in stimulating the immune system, fighting microbes, and scavenging free radicals, so that these various activities collectively strengthen the body's defense mechanisms against disease in farmed teleost fish (Leyva-López et al., 2020; Lourenço et al., 2025; Oh et al., 2025; Sayed-Lafi et al., 2026; Wang et al., 2026).

Table 1. Nutritional and bioactive compounds of fruit wastes used in aquaculture.

Fruit Part	Component	Level (on Dry Matter basis unless specified)	References
1. Banana Peel	Protein	75-101 g kg^{-1}	(Cheng and Chuang, 2026)
	Carbohydrates	652-743 g kg^{-1}	
	Lipid	18-28 g kg^{-1}	
	Fiber	318-365 g kg^{-1}	
	Main Bioactives	Pectin, Tryptophan flavonols, hydroxycinnamic acids, flavan-3-ols, and catecholamines	
2. Mango Peel	Protein	4.15%	(Macusi et al., 2025)
	Carbohydrates	~50% (total sugars)	(Marchao et al., 2024)
	Lipids	1.16%	
	Fiber	9.8%	(Macusi et al., 2025)
	Main Bioactives	Mangiferin, Quercetin, Gallic acid, Carotenoids, vitamin C, Vitamen E, Tannis	(Lourenço et al., 2025; (Sharker et al., 2025); (Outama et al., 2022)

3. Citrus Peel	Protein	7.3% – 7.6%	(Zhuo et al., 2021)
	Carbohydrates	14.2% – 14.7% (including diet)	(Reda et al., 2024)
	Lipids	1.39% – 3.29%	(Zhuo et al., 2021)
	Fiber	13.55% – 19.6%	
	Main Bioactives	Hesperidin, D-limonene, Vitamin C, Farnesene	(Wang et al., 2026; Reda et al., 2024)
4. Pomegranate Peel	Protein	4% – 9%	(Sayed-Lafi et al., 2026)
	Carbohydrates	60% – 70%	
	Lipid	< 3%	
	Fiber	17% – 30%	
	Main Bioactives	Punicalagin, Ellagic acid, Tannins, Anthocyanins	(Motlagh et al., 2020; Sayed-Lafi et al., 2026)
5. Pineapple Peel	Protein	4.20%	(Mala et al., 2024)
	Carbohydrates	73.30%	
	Lipid	2.53%	
	Fiber	12.05%	
	Main Bioactives	Catechin, vanillic acid, sinapic acid, ferulic acid, rutin, caffeic acid, quercetin, gallic acid, and coumaric acid.	

Common Fruit Wastes Used in Fish Feed

Several studies have shown that fruit waste can be used as feed raw materials and has a positive impact on fish growth and/or physiology and has antimicrobial effects. Banana peel is known to contain tryptophan, which acts as a precursor to serotonin, regulating responses to stress, food, and behavior in fish (Cheng and Chuang, 2026). Research using banana peel powder at 10-50 g kg $^{-1}$ on juvenile hybrid grouper (*Epinephelus lanceolatus* ♂ vs. *E. Fuscoguttatus* ♀) for 8 weeks has shown increased survival rates and decreased cumulative cannibalism rates, increasing brain serotonin levels but negatively impacting fish growth. The decrease in growth in hybrid grouper may be due to stocking density, not the banana peel content. In the banana peel group, survival rates increased and cannibalism decreased, while in the control group, survival rates decreased and cannibalism increased, resulting in fewer fish in the column. Higher stocking densities in the banana peel group caused fish to compete for food and space in the aquarium, likely leading to slower growth. On the other hand, adding banana peel to water is known to reduce residual concentrations of mg and cu^{2+}. This suggests that banana peel can act as a pollutant absorbent (Cheng and Chuang, 2026). These results are in line with research conducted by Macusi et al. (2025), which stated that the administration of 50% banana peel for 10 weeks did not show significant differences in growth but could increase the survival rate in red tilapia fingerlings (*Oreochromis* spp.) Compared to commercial feed. Haetami et al. (2019) also studied the addition of banana peel to commercial feed with concentrations of 0%, 0.50%, 0.75%, 1.00%, and 1.25% per kilogram of feed for patin fish larvae for 21 days. The results showed that the administration of 0.75% banana peel resulted in the highest growth and survival rates compared to other treatment groups.

Administering 50% mango peel for 10 weeks has also been shown to increase survival rates but has no effect on the growth of red tilapia fingerlings (Macusi et al., 2025). The growth performance of nile tilapia given 25 g kg $^{-1}$ mango peel for 8 weeks was also higher than the control, although not significantly different; however, 50 g kg $^{-1}$ actually decreased growth. This is suspected to be due to the high content of antinutritional factors such as tannins, which increase with the concentration of mango peel used. However, overall, the use of mango peel powder at 25 g kg $^{-1}$ can significantly increase innate immunity (lysozyme and peroxide) and the expression of immunity-related genes (Il-1 and Il-8) compared to the control. This is suspected to be due to the many bioactive compounds such as carotene, quercetin, mangiferin, and vitamins C and E, which are known to increase immune system activity (Outama et al., 2022).

On the other hand, the use of orange peel has been shown to significantly increase the growth of freshwater fish (*Catla catla*) (Shabana et al., 2019) and nile tilapia (*Oreochromis niloticus*) fingerlings compared to the control (Salem and Abdel-ghany, 2018). This increase in growth is thought to be due to the bioactive compounds in mango peel that help increase digestive enzyme production, thereby improving feed efficiency, which ultimately enhances fish growth (Shabana et al., 2019).

Pomegranate peel and pineapple peel are also agricultural waste that still contain nutrients, especially bioactive compounds that have pharmacological effects and can improve the immune response in fish. The addition of fruit peel has different effects depending on the fish species and the dosage used. For example, administering 5 g kg^{-1} of pomegranate peel has no significant effects on the growth performance of common carp under normal and stressful conditions, but administering more than that dose decreases common carp growth (*Yousefi* et al., 2023). Administration of 4% pomegranate peel extract also decreases growth, while administering 2% extract modifies gut bacteria without any adverse effects on fish growth (*Motlagh* et al., 2020). However, dietary 10 g/kg pomegranate peel has increased the growth performance of rainbow trout (Yousefi et al., 2023). Meanwhile, administration of pineapple peel extract is known to improve the growth and immune system of nile tilapia, with the most optimal concentration being 10 g kg $^{-1}$, but administering higher doses can reduce survival rates. The increase in fish growth when given the right dose of pineapple is due to the presence of bromelain, which plays a role in increasing villus length and mucosal folds, thereby boosting the enzymatic activity of lipase and pepsin, thus enhancing gut tissue and intestinal absorptive cells (Doan et al., 2021). The decrease in fish growth when given pomegranate extract or pineapple peel in high doses may be attributed to the presence of high amounts of polyphenols and fiber that reduce digestion (Yousefi et al., 2023; Doan et al., 2021).

Meanwhile, administration of pineapple peel extract is known to improve the growth and immune system of nile tilapia, with the most optimal concentration being 10 g kg $^{-1}$, but administering higher doses can reduce survival rates. The increase in fish growth when given the right dose of pineapple is due to the presence of bromelain, which plays a role in increasing villus length and mucosal folds, thereby boosting the enzymatic activity of lipase and pepsin, thus enhancing gut tissue and intestinal absorptive cells (Doan et al., 2021).

Future Perspectives

The use of fruit waste as a raw material for fish feed still has very broad prospects for development through more in-depth research on the optimum dosage, processing methods, and combinations of various types of waste to increase nutritional value and reduce antinutrient content. Biotechnological approaches, such as fermentation and extraction of bioactive compounds, have the potential to increase the availability of nutrients and the biological effectiveness of fruit waste as a functional feed. In addition, research on molecular mechanisms, effects on gut microbiota, gene expression related to growth and the immune system, as well as economic evaluation and life cycle analysis, is needed to support the application of fruit waste on an industrial scale. The development of fruit waste-based feed formulations is expected to be an innovative strategy for creating a more sustainable, efficient, and environmentally friendly aquaculture system while supporting the reduction of agricultural waste and global food security.

4. Conclusion

Fruit waste is a promising alternative raw material source for aquaculture feed because it still contains nutrients and various bioactive compounds that can improve fish growth, health, immune response, and stress resistance when used at appropriate doses. Various studies have shown that the effectiveness of fruit waste is influenced by the type of waste, fish species, processing method, and level of use, making determining the optimum dosage a crucial factor in feed formulation. Overall, the utilization of fruit waste not only contributes to reducing production costs and reducing dependence on conventional raw materials but also supports the concept of a circular economy and sustainable agricultural waste management, thus potentially becoming an innovative solution for future aquaculture development.

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