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Utilizing Fruit Waste in Nile Tilapia (*Oreochromis niloticus*): A Review of Growth Performance, Feed Utilization, and Health Effects

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ABSTRACT

The growing demand for sustainable and cost-effective aquafeeds has encouraged the valorization of fruit-processing by-products as alternative feed ingredients and functional additives. This review evaluates the nutritional characteristics and effects of banana peel, orange peel, mango peel, pineapple waste, and grape seed on growth performance, feed utilization, and health in Nile tilapia (Oreochromis niloticus). Relevant literature was identified through Google Scholar and PubMed and synthesized according to its relevance and reported findings. These by-products provide carbohydrates, dietary fiber, and bioactive compounds, including phenolics, flavonoids, and antioxidants. The reviewed studies indicate that appropriately formulated fruit-waste supplements can improve weight gain, specific growth rate, feed conversion ratio, digestive function, antioxidant activity, and innate immune responses, although outcomes vary with the material, processing method, and inclusion level. Reported beneficial treatments include banana peel powder, orange peel-derived pectin, mango peel powder, pineapple waste or its extract, and grape seed proanthocyanidins. However, excessive inclusion may reduce nutrient digestibility and feed efficiency because of high fiber content and antinutritional compounds. Fermentation and other processing approaches may improve ingredient suitability. Overall, fruit waste shows promise as a feed resource for Nile tilapia and may contribute to circular-economy approaches in aquaculture. Further research is needed to standardize processing and inclusion rates, clarify physiological mechanisms, assess safety and economic feasibility, and evaluate environmental benefits under practical farming conditions.

***Keywords*:** Fruit waste, Nile tilapia, *Oreochromis niloticus*, Feed utilization, Growth performance, Immune response, Sustainable aquaculture, Circular economy

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1. INTRODUCTION

World aquaculture production has been increasing significantly since 2015, and in 2018, it reached 82.1 million tonnes of farmed seafood, with Asia leading global production. Human protein needs from animal sources can be met by the fisheries sector, both through aquaculture production and capture, with a value of approximately 17% of total animal-source protein for human consumption (Rocha et al., 2022). One of the determining factors for aquaculture success is the availability of nutritious feed. The highest production costs also come from feed use, accounting for approximately 75-95% of operating expenses in intensive farming systems (Sukri et al., 2022). This situation is due to the increasing price of fish meal and the supply shortage (Yuangsoi et al., 2018). To reduce costs, production requires searching for and developing material and cheaper feed, while still providing adequate nutrition and not giving a negative impact on fish growth and health.

Temporarily, the amount of fruit waste resulting from food processing is produced abundantly throughout the world. However, its processing and utilization are not optimal, causing an impact on the environment. The fruit waste is still rich in macronutrients like carbohydrates, proteins, and lipids, as well as various bioactive compounds that have pharmacological effects (Poddar et al., 2025).

Several studies have shown that fruit waste can still be used as a feed additive without negatively impacting growth and health. Zhuo et al. (2021) reported that the use of fermented lemon peel in Asian seabass (*Lates calcarifer*) can improve growth, immune response, and intestinal morphology. The use of grape seed as a dietary inclusion in common carp (*Cyprinus carpio*) can increase growth, immune response, and disease resistance (Mehrinakhi et al., 2021). The use of olive pomace at levels of up to 8% has been shown to replace fish oil in feed for gilthead seabream (*Sparus aurata*) and rainbow trout (*Oncorhynchus mykiss*) (Sioriki et al., 2016).

Nile tilapia (*Oreochromis niloticus*) is the most widely cultivated fish worldwide due to its numerous advantages, including adaptability to a wide range of environmental conditions, rapid growth, and low technology dependence in most cases. Tilapia cultivation is also easily accessible in various parts of the world, utilizing alternative cultivation techniques such as aquaponics. The development of feed alternatives with lower costs is needed to increase tilapia production (Sara Ramírez-Bolaños et al., 2023). The use of fruit waste can be a good alternative to address this problem while reducing the negative impact of waste on the environment. Several studies have examined the effects of using fruit waste as an alternative feed for tilapia. Therefore, the purpose of this article is to review and summarize various research results on the effects of using fruit waste as an alternative feed for tilapia.

2. RESEARCH METHODOLOGY

This article used a literature review methodology that included searching, screening, analysis, and synthesis. The keywords "fruit waste," "fish feed," "growth," "immune," and "*Oreochromis niloticus*" were used to conduct a literature search in Google Scholar and PubMed databases. Collected articles were then analyzed and selected based on relevance to the topic, year published, and data accuracy. The information obtained was then synthesized as the basis for writing this article.

3. RESULT AND DISCUSSION

3.1. Environmental Impact of Fruit Waste and Its Contributor to Pollution

The fruit processing industry generates waste rates varying between 20% and 50%, depending on the fruit type. Fruit and vegetable waste is the most commonly wasted food category, accounting for 38% of total global food waste, with an estimated 0.5 billion tons annually. This amount of waste has reached unsustainable levels and is increasing its negative impact on the environment. This waste can take the form of peels, seeds, and pomace, along with substantial volumes of wastewater (Argun et al., 2025; Lee et al., 2024). Due to its fermentable and biodegradable nature, fruit waste can produce various hazardous compounds that pose a risk to human health and cause environmental pollution (Lee et al., 2024). Landfill disposal traps fruit waste under layers of other garbage where oxygen cannot reach. Anaerobic (oxygen-free) decomposition breaks down the fruit and produces methane (CH_4), a powerful greenhouse gas. Methane traps heat in the atmosphere much more effectively than carbon dioxide, worsening global warming. Worldwide emissions from food waste account for about 7% of total greenhouse gas emissions (Poddar et al., 2025). Anaerobic decomposition of the biomass produces gases that disturb the natural balance of air. Fruit waste contains high water content and soluble sugars. Rainwater seeping through piles of rotting fruit creates a toxic, acidic liquid called leachate. Leachate drains into local groundwater and nearby waterways, carrying high concentrations of nutrients. These nutrients trigger rapid algae growth in water bodies, a process called eutrophication that suffocates fish and aquatic life (Lee et al., 2024).

3.2. Nutritional and Bioactive Components of Different Fruit Wastes

Waste processing fruit (such as peels, seeds, and pulp) is often considered a by-product that is not valuable. In fact, these parts are rich in nutrients and bioactive compounds and have potential functional traits for application as an alternative feed for fish. Here are the details of the component nutrients and bioactives from some fruit wastes:

Banana Peel

Bananas are a fruit that is widely planted and consumed in tropical and subtropical areas of the world, with an average consumption of 12 kg per capita. Global banana production has also increased steadily for 20 years. With increased production and consumption, banana peel waste is also rising. Banana peel waste is utilized by bacteria, causing a foul odor, thus impacting the environment. Meanwhile, banana peels still have considerable nutritional content, including carbohydrates (59.51-76.85% DM), protein (5.5-7.8% DM), lipids (2.24-11% DM), and fiber (47-53% DM). Banana peels are also a good source of amino acids and fatty acids because they contain nine essential amino acids and nine non-essential amino acids and are rich in polyunsaturated fatty acids, such as linoleic acid (Omega-6) and α-linolenic acid (Omega-3), which account for more than 40% of the total fatty acids. Banana peels also contain many bioactive compounds, such as flavonoids, tannins, phlobatannins, alkaloids, glycosides, anthocyanins, gallocatechin, and terpenoids, and more than 40 individual phenolic compounds have been identified in banana peels (Zaini et al., 2022).

Orange Peel

Orange is a popular fruit. It is good when consumed in both direct and juice forms because of its fresh taste and high vitamin C content. The production of oranges reaches approximately 60 million tonnes annually. However, only 50% of these oranges are utilized or consumed, with the remainder being waste, such as peels, seeds, and spent pulp. Orange peel waste is known to reach 32 million tonnes annually. One kilogram of fresh oranges can produce 0.5 kg of orange peel (Singh et al., 2025; Vasconcellos and Saavedra, 2026). To reduce waste, orange peel can be used as an alternative feed ingredient because it still contains nutrients, including carbohydrates (20.32% DM), protein (2.83% DM), lipids (7.9% DM), and fiber (4.65% DM) (Naqvi et al., 2021), and also contains phenolic compounds and flavonoids (Naqvi et al., 2021).

Mango Peel

Mango is a plant that is also grown in the world in large quantities because of its delicious taste and high nutritional value. World mango production reached 52.08 million tonnes in 2018, an increase of 150% compared to the previous decade. However, consumption of mango leaves, about 35% of the total fruit, is wasted and becomes trash. Mango peel still contains nutrition such as fiber (35.6% DW), carbohydrates (52.3% DW), protein (6.3% DW), and fats (1.6% DW), and bioactive compounds such as phenolic compounds, flavonoids, carotenoids, and vitamins C and E (Outama et al., 2022; Sánchez-Camargo et al., 2019).

Pineapple Waste

Pineapple is among the most popular fruits globally because of its taste. It is typically eaten raw, prepared as a beverage, in preserved form, and more recently as a dehydrated snack (Baidhe et al., 2021). Worldwide pineapple production was estimated at 29.4 million metric tons in 2022 and is anticipated to hit 37 million metric tons by 2030. The leading ten pineapple-producing nations are Costa Rica, the Philippines, Brazil, Indonesia, China, India, Thailand, Nigeria, Mexico, and Colombia. Nonetheless, one ton of pineapple produces more than 0.5 tons of pineapple waste (PAW) (Kamusoko and Mukumba, 2025). The crown and stem are taken off prior to peeling, and then the core is extracted for additional processing. Waste elements, namely the peel, core, stem, and crown, represent 29-40%, 9-10%, 2-5%, and 2-4% (w/w) of the fruit, respectively. As a result, with the increase in pineapple production, the amount of pineapple waste grows accordingly. Waste management presents an increasing problem, as the refuse is susceptible to microbial degradation and leads to major ecological concerns (Yuangsoi et al., 2018). Nonetheless, pineapple waste is still abundant in nutrients. Proximate analysis reveals that pineapple peel has protein (5-9%), fiber (1-6%), fat (2-3%), and carbohydrates (50-80%), whereas pineapple pomace consists of protein (6.34%), fiber (19.3%), fat (1.09%), and carbohydrates (82.75%) (Kamusoko and Mukumba, 2025).

Grape Seed

In 2020, global grape production totaled 78 million tons, with the majority (71%) utilized for wine production. The highest output in Europe surpasses 23 million tons each year. Extracting grape juice results in the production of significant amounts of valuable by-products and organic waste such as pomace, seeds, stems, yeast, and pruning, which are not recognized sufficiently as profitable waste.

Grape seeds, in terms of their composition, constitute a notably intricate waste product: they include several valuable elements, primarily phenolic compounds (such as flavonoids), along with vegetable oil, natural fibers, proteins, carbohydrates, and various micro-components (D'Eusanio et al., 2023). The proximate analysis showed that grape seeds contained fat, protein, and carbohydrates (2.86, 7.06, and 82.6 g/100 g, respectively), resulting in an energy value of 384.46 kcal/100 g (Tarek et al., 2025).

3.3. The Effect of Fruit Wastes on the Growth Performance and Health of Nile Tilapia

Several studies indicate that different fruit by-products can serve as supplements to effective feed, having a beneficial or neutral effect on fish growth. Therefore, utilizing fruit waste can address two issues simultaneously: it can lessen the adverse environmental impact of waste while also providing a cost-effective alternative fish feed in comparison to more expensive options.

Banana peel or fermented banana peel is accessible and has been evaluated for use in feeding Nile tilapia (Manullang & Hasan, 2026; Tahya et al., 2025). Incorporating 10% of Kepok bananas (*Musa paradisiaca var. Balbisiana*) peel powder to Nile tilapia fingerlings for 30 days enhanced survival rate, total weight gain, total length gain, and lowered feed conversion ratio (FCR) in comparison to controls fed exclusively commercial feed (Manullang & Hasan, 2026). Munir et al. (2026) examined the application of banana peel powder at 5-15 g/kg on Nile tilapia fingerlings over a duration of 28 days. The study indicated that administering banana peel at 15 g/kg enhanced weight gain, feed intake ratio, and specific growth rate while lowering FCR in comparison to controls. Furthermore, hematological indices and antioxidant enzymes exhibited peak activity at that concentration. Nonetheless, administering banana peel at an elevated dosage led to less desirable results because of the crude fiber content and antinutritional substances, which could decrease digestibility when applied in excessive amounts. The findings from these two studies showed that the 10% and 15% banana peel levels remain acceptable regarding crude fiber content and antinutritional compounds for fish. This dose likely provides the right balance between the nutritional contribution of Kepok banana peel meal and the fish's ability to consume and utilize the feed efficiently (Manullang & Hasan, 2026).

Fermented banana peel can also improve the growth and health of Nile tilapia. Adding 2% fermented banana peel flour with Saccharomyces cerevisiae to commercial feed at a dose of 10-20% can increase absolute weight gain, oxygen consumption, blood sugar, and the hematosomatic index compared to the commercial feed control. The high levels of oxygen consumption and blood sugar indicate that the administration of banana peel flour increases metabolism and feed digestibility, resulting in a faster conversion of carbohydrates to glucose. The higher hematosomatic index value in the fermented peel flour treatment indicates that the presence of microorganisms in the feed improves metabolism, allowing tilapia to store more energy for growth. Excess glucose will be stored as glycogen in the liver (Tahya et al., 2026).

The dietary inclusion of orange peel-derived pectin (OPDP) in tilapia, at doses of 5, 10, and 20 g kg^{-1} OPDP over 8 weeks in a biofloc system, can markedly enhance the dietary use of OPDP, boosting non-specific immune response, disease resistance, and growth performance in Nile tilapia. However, the way in which OPDP enhances the growth and health of O. niloticus deserves further exploration (Doan et al., 2018). Khalil et al. (2026) administered orange peel meal (OPM) at 2.5, 5, and 10 g/kg of feed for a duration of 100 days to Nile tilapia fingerlings.

This study finds that adding orange peel meal to the diet significantly lessens the effects of heavy metals, boosts growth rate with the greatest enhancement seen at 10 g/kg, and enhances immune status (with increases seen in IgM concentrations, lysozyme activity, phagocytic activity, and phagocytic index, all in a dose-dependent increases), increases antioxidants (SOD, CAT), lowers lipid peroxidation (MDA levels), and improves the uptake and retention of various heavy metals (iron, zinc, copper, cadmium, and lead) in the liver and gills of tilapia, indicating a dose-dependent protective effect against heavy metal toxicity in nile tilapia fingerlings.

Mango peel powder also can be given to Nile tilapia within a biofloc system. Using a dose of 25 kg-1 diet for 8 weeks yields the optimal specific growth rate, weight gain, final weight, and feed conversion ratio values, though it shows no significant difference from the other treatments of 0, 6.25, 12.5, and 50 kg-1. For immune response, doses of mango peel powder at 12.5 and 25 g kg^{-1} significantly enhance lysozyme and peroxidase activity in both mucus and serum. A dosage of 25 g kg^{-1} significantly boosts the up-regulation of IL-1 and IL-8 gene expressions. In general, the addition of mango peel powder at 25 g kg^{-1} notably improved immune response and the expression of immune-related genes (Outama et al., 2022). It's not a notable enhancement. The increase in tilapia fish growth with mango peel powder is believed to not enhance digestive enzymes in the intestine and absorption; moreover, mango peel may hinder the functions of amylase and glucosidase while decreasing adipogenesis. Mango peel has non-starch polysaccharides (NSP) that might influence the decrease in fish weight. The values for growth parameters were reportedly lowest in the 50 g kg^{-1} treatment. Due to the presence of antinutritional substances at high levels, like tannins, which can connect with iron to form complexes that impede the development of gut microbiota (Outama et al., 2022).

Pineapple waste still contains a high quantity of nutrients and has been tested on tilapia. Sukri et al. (2021) investigated the effects of pineapple waste diets on the growth, texture quality, and flesh color of Nile tilapia (Oreochromis niloticus) fingerlings over 56 days at levels of 0%, 10%, 20%, and 30% supplemented to feed containing 32% protein. The findings revealed that adding pineapple waste boosted weight gain, weight gain percentage, and specific growth rate when compared to the control group, with the highest results obtained with 30% pineapple waste added. However, pineapple waste had no effect on the textural quality of filets. The active ingredient bromelain, a cysteine protease, is assumed to be responsible for the improved growth performance in tilapia. These enzymes break down proteins in meals, producing small peptides that improve protein digestion and absorption. Pineapple waste contains bioactive compounds that can modify the gut flora, improving digestion and nutritional assimilation. Pineapple waste is also abundant in fiber, which helps to minimize digestion of other food components that alter nutritional digestibility and absorption effectiveness. In another study, introducing pineapple waste extract (PWE) at concentrations of 0, 1, 2, and 3% to tilapia for 8 weeks increased pepsin digestibility but not protein digestibility. Tilapia growth improved in the group receiving pineapple waste compared to the control group, showing the best growth at a concentration of 1%. At this level, it achieves the best protein digestibility and feed efficiency, along with the lowest feed conversion ratio. Protease enzymes are crucial for protein digestion in the digestive system, as pepsin is generated in the stomach and subsequently transported to the small intestine, where trypsin and chymotrypsin enzymes from the pancreas further digest protein. Therefore, protease enzymes assist in completely breaking down proteins (Yuangsoi et al., 2018).

Grape seed is another fruit waste that can serve as a feed additive. Incorporating grape seed proanthocyanidins (GSPs) at doses of 200, 400, 600, and 800 mg/kg over 49 days has demonstrated enhancements in growth performance. The administration of 200 mg/kg GSPs exhibited beneficial effects on the growth and body composition of tilapia fingerlings, along with enhancing serum biochemical parameters associated with health status. This is thought to be due to grape seed ability to increase intestinal digestive enzyme activity, immune ability, and antioxidant ability in animals (Zhai et al., 2014). Grape seed proanthocyanidin extract (GSPE) can also be used reducing stress response such as decreasing serum cortisol, glucose, Na^{+}, and lactate levels in Nile tilapia (Yang et al., 2023).

Table 1. Summary of Several Studies on the Effects of Fruit Waste on Tilapia (Oreochromis niloticus)

No.	Fruit waste / by-product	Dose	Main result	Reference
1	**Pineapple waste extract** (*Ananas comosus*)	0, 1, 2, and 3% in feed	Treatment **1%** give results best in protein digestibility, growth , and feed utilization. There is no difference significant effect on free ammonia and total nitrogen excretion.	Yuangsoi et al. (2018)
2	**Pineapple peel powder** (*Ananas comosus*)	0, 10, 20, 30, and 40 g/kg feed	Pineapple peel powder enhances **growth performance, feed efficiency, innate immunity, and disease resistance**. Response immune highest found at **10 g/kg** . IL-1, IL-8, and LBP gene expression also increased , and the 10 g/kg treatment resulted in the highest RPS. to *Streptococcus agalactiae* .	Doan et al. (2021)
3	**Mango peel powder** (*Mangifera indica*)	**25 g/kg** feed	Mango peel powder no give change real on **growth and FCR** , however increase **innate immunity** parameters , especially Lysozyme and peroxidase activity in mucus and serum. **IL-1 and IL-8** gene expression also increased in the 25 g/kg treatment .	Outama et al. (2022)

4	**Orange peel-derived pectin (OPDP)** (*Citrus* sp.)	0, 5, 10, and 20 g/kg feed	OPDP increases several parameters **of innate immunity** , as well as increase **specific growth rate (SGR), weight gain (WG), final weight (FW), and FCR** . In the challenge test, the RPS of each OPDP treatment was 45.45%, 81.82%, and 50%, respectively, with response highest at **10 g/kg** .	Doan et al. (2018)
5	**Grape seed proanthocyanidins (GSPs)** (*Vitis vinifera*)	0, 200, 400, 600, and 800 mg/kg feed	GSPs increase **growth performance** , decreasing FCR, increasing lysozyme and albumin, and lowering triglycerides and total cholesterol. Relative survival rate The same between treatments . Research results show **200 mg/kg** Already give effect positive to growth and body composition.	Zhai et al. (2014)
6	**Banana peel powder** (*Musa paradisiaca*)	0, 5, 10, and 15 g/kg feed	Treatment **15 g/kg** produce mark highest for weight gain, feed intake ratio, and SGR, as well as the lowest FCR . Hematological parameters (RBC, WBC, Hb, HCT, MCHC) and activity antioxidants (catalase and peroxidase) were also highest at 15 g/kg.	Munir et al. (2026)
7	**Kepok banana peel powder** (*Musa balbisiana*)	0, 10, 15, and 20% feed	Addition **10% banana peel powder** produced the highest survival rate, weight gain, length gain and lowest FCR . Treatment was 10% different real compared to treatment others ($P<0.05$).	Manullang & Hasan (2026)
8	**Fermented banana peel flour** (*Musa* sp.)	0, 10, 15, and 20% feed ; fermented with 2% *Saccharomyces cerevisiae*	Treatment **15%** show results best For **absolute weight gain, oxygen consumption rate, blood glucose, and hepatosomatic index (HSI)** . Flour fermented banana peel potential used as material standard feed For reduce use of fish meal and soybean meal.	Tahya et al. (2025)

3.4. Future Perspective

The use of banana peel, mango peel, orange peel, grape seed, and pineapple waste as ingredients for tilapia fish feed (Oreochromis niloticus) holds significant potential in promoting sustainable aquaculture. Further studies should focus on identifying the ideal integration level of each waste according to nutrient content, fiber, bioactive compounds, and antinutrients. The distinct characteristics of each waste indicate that not all materials can be utilized equally, making the standardization of material specifications and processing methods crucial for achieving consistent outcomes.

Processes such as fermentation, drying, extraction, and bioprocessing are essential for enhancing nutrient digestibility and availability while minimizing barrier factors. Additionally, future research can also examine the combination of various waste fruits to understand the potential synergistic effects on growth and the efficient use of feed. The future research must also broaden assessments from growth and usage metrics to include fish health and biological function. Research on gut microbiota, digestive enzyme activity, immune response, antioxidant levels, and associated gene expression can enhance the understanding of the mechanisms involved in the bioactive compounds derived from fruit waste. Aspect security is important to consider, especially regarding potential pesticide residues, antinutrients, and the impact of using waste fruit on the quality and safety of fish flesh.

Ultimately, the production of waste fruit as tilapia fish feed must be guided not only by biological aspects but also by economic feasibility and environmental sustainability. Assessment of production costs, material availability standards, processing efficiency, effects on water quality, and life cycle analysis is necessary to guarantee its large-scale commercial application. Integrating fruit waste into fish feed can become one of the strategies for reducing agro-industrial waste and improving market and local power sources.

4. CONCLUSION

The use of fruit waste such as banana peels, mango peels, orange peels, grape seeds, and pineapple byproducts indicates promise as an alternative and effective feed component in tilapia (*Oreochromis niloticus*) farming. The nutrients, fiber, and bioactive substances like polyphenols and antioxidants found in this waste can enhance growth, feed efficiency, and fish health when applied in suitable amounts. Nonetheless, its efficacy is significantly affected by the waste type, nutrient composition, inclusion rate, and processing technique, whereas overuse may diminish feed taste and digestibility. Hence, it is essential to standardize processing and identify optimal use levels, along with conducting additional research on health, safety, economic viability, and environmental impact factors. In summary, using fruit waste can help decrease agro-industrial waste, enhance resource efficiency, and create a more sustainable aquaculture system grounded in a circular economy.

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