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The Effect of Fermentation Technology on the Quality of Fish Feed from Agricultural Waste

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ABSTRACT

Purpose: *There is a rising demand of quality and sustainable fish feed as the size of the aquaculture industry grows and reliance on fish meal has suffered sustainability problems and expensive rates. The study proposes to test the impact of fermentation technology in the quality of fish feed on agricultural waste include rice bran, soybean meal and cassava pulp.*

Subjects and Methods: *A research design that was Solid-state fermentation (SSF) and submerged fermentation in selected microbes (Bacillus subtilis, Aspergillus niger and Saccharomyces cerevisiae) was applied. They demonstrated that fermentation enhanced the protein content (up to 40 percent in soybean meal), decreased crude fiber and antinutrimental factors (phytate, tannin) and enhanced the digestibility of feed.*

Results: *Biological analysis on the tilapia (Oreochromis niloticus) revealed fermented ingredients that were added to the diets at 20 percent level provided highest specific growth (SGR 1.74 percent /day), lowest FCR (1.36), and enhanced antioxidant activity without lowering the quality of the rearing waters.*

Conclusions: *The results substantiate that fermentation technology holds potential in the exploitation of agricultural waste as fish feed on a sustainable basis though optimization, and improvement of the bioprocess and further economic analyses are needed to scale it up to industrial scale.*

INTRODUCTION

Aquaculture is booming globally, and feeds high-quality and affordable are demanded, whereas fishmeal/ fish oil dependency is constrained by sustainability concerns, price volatility, and supply-chain constraints. In the meantime, the agro-industrial and agricultural servings generate large volumes of the lignocellulosic wastes, rice bran, oil cakes, pulp, and liquid side-streams not market-valued in most instances. Fermentation technologies may now be conceived as bioindustrial processes able not only to seemly up-cycle such agricultural residues to valuable components in fish feeds, hence into a circular economy, but also to minimize the impacts of the feed production chain on the environment. There are two major types of fermentation technologies, such as solid-state fermentation (SSF) and submerged fermentation (Subramaniyam & Vimala, 2012; Singhania et al., 2010; Singhania et al., 2018).

Cellularly, the fermentation of molds (e.g., Aspergillus , Rhizopus), yeasts (Saccharomyces), and bacteria (e.g., Bacillus , LAB) reengineer the nutrient composition through enzymes cellulase, hemicellulase, phytase and protease; acidify the concentration of anti nutrition substances, such as phytate and oligosaccharides, amplify amino acids and mierals and enhance vitamin levels to produce bodily-active elements with pre- and prob Such feed level changes can be speculated to contain the advantages of providing greater palatability, digestibility and bioavailability of the nutrients and, at the downstream level, such changes are linked to enhancements in growth performance, feed conversion ratio (FCR) and improved antioxidant status and immune-systems in diverse fish and crustacean species.

In case studies, it has been increasingly observed, that fermentation caused a rise in nutritional quality. To illustrate, SSF of brewer spent grain supplemented protein and reduced the indigestible fiber proportion meaning that it enhanced nutrient value as foodstuff material. Conversely, the digestibility and utilisation were greater with an addition of fermented substrates and they did not alter the growth performance when they were incorporated in balanced inclusion levels thus it is shown that there is need to adjust the doses to be administered to the best. Fermented feeds provided nutritional quality and prolonged aquaculture benefit of the crab e rioc heir sinensis compared to non-fermented feeds and this means that proper outcomes are strongly tied to the nature of substrate, microbial composition and the fermentation quantities (Majchrzak et al., 2022).

Besides modifying plant materials, anaerobic fermentation is capable of producing single-cell protein (SCP) with non-food waste streams, such as, whey, lignocellulosic hydrolysates and agro-industrial waste water (Rawat et al., 2024; Aidoo, 2023). The use of these fermented microbial biomass products has been generally linked tohigh protein loads, desirable amino acid profile, and accelerated kinetics of production thus providing a greater chance of part fishmeal replacement in the contemporary aquaculture diets. Recent developments metabolic engineering and breeding of microbial strains and multifunctional bioprocess platform are taking the SCP technology to the feed arena, though challenges associated with constituents of residues, safety screening, regulatory issue and economic feasibility yet need to be scrutinized.

The literature presence several times after data synthesis shows that, on an optimised platform, the replacement of fish meal by fermented plant protein or any other fermentation product can bring about the augmented growth predictions, feed conversion equation, digestive enzyme activity and antioxidant capacity with a varieties of fish species. Meanwhile, in field-based experiments, the parameters of water quality have been less chaotic, with better outcomes on fish health, through the modulation of the resident gut microbiota, and the resultant, removal of recalcitrant organic matter. Nonetheless, its performance largely depends on the type of substrate waste source (e.g. rice bran, soybean meal, cassava peel, soybean pulp/ okara), the microbial consortium, fermentation conditions of the performance (aeration, humidity, temperature), and post-treatment of end (dry, stabilize, control mycotoxins).

Despite its high potential that has been established, fermented agricultural waste as an alternative sustainable source of feeds has a myriad of knowledge gaps and technical difficulties that must be addressed so as to facilitate commercialized application in large scale. One is that standardization of quality (raw material variability, antinutrient profiles and contaminants) will necessitate process control measures and safety (microbiology, mycotoxins, residues). Second, the optimization of SSF vs. submerged bioprocesses and the choice of the most effective strain/co-cultures per substrate should be projected against indicators of feed quality (digestible protein, metabolizable energy, amino acid profile, effective fiber) and performance (growth, FCR, health). Third, to show cost and environment saving benefits over conventional ingredients, economic analysis and LCA are required. Lastly, the expanding scientific literature on the safety and advantages of fermented products in aquaculture feeds formulations must be later followed by regulatory guidelines and their market acceptance.

Based on this background, this article aims to: (1) summarize the development and key mechanisms of fermentation technology (SSF and submerged) in improving the quality of agricultural waste-based fish feed ingredients; (2) evaluate empirical evidence on the impact on feed quality (composition, digestibility, bioavailability, antinutritional factors) and aquaculture performance (growth, feed efficiency, health status); and (3) identify the challenges, quality standards, and research/implementation directions needed to make the use of fermented agricultural waste a strategic component in sustainable aquaculture feed.

METHODOLOGY

The work was conducted based on the laboratory experimental method in order to determine the impact of fermentation technology in the quality of agricultural waste-based fish feed. Key components utilized were agricultural waste easily found in Indonesia e.g. rice bran and soybean meal and cassava pulp which were chosen owing to their prospective dietary value as feed functions but currently possess fragmented digestibility and antinutrients. Two processes of the fermentation were applied, i.e., solid-state fermentation (SSF) and submerged fermentation , with various microbial starters Bacillus subtilis and Aspergillus niger and Saccharomyces cerevisiae . The changes in fermentation time, humidity and temperature were identified with the aim of ascertaining the ideal set of these parameters used to enhance the nutritional value of feedstuff components.

The processed feed ingredients after fermentation process is complete are then dried and ground to the point of homogeneity followed by a proximately analysis done to establish protein, fat, crude fiber, ash and metabolic energy concentration levels. Along side this, analysis of antinutritional factors (e.g, phytate and insoluble fiber contents) and availability of essential amino acids are conducted. To determine bioavailability of nutrients, in vitro digestibility tests are done with fish digestive enzymes. Thereafter, feed formulations to be tested are formulated by replacing some of the fish meal with the fermented ingredients at variable levels (e.g., 0%, 10%, 20 and 30%).

The test fish, e.g., tilapia (Oreochromis niloticus) were subject to feed trials, during a particular rearing phase (8 10 weeks). Measurements of specific growth rate (SGR), feed conversion ratio (FCR), survival rate as well as fish health status was done through hematological analysis and Antioxidant enzyme activity. To supplement the data, the measurements of water quality were also taken (pH, DO, and ammonia) so that no adverse changes in water quality could influence the cultivation conditions during the fermented feed. Data were statistically analyzed using ANOVA to compare differences between treatments, and further Duncan or Tukey tests were used if significant differences were found. Significant results were then interpreted to determine the effectiveness of fermentation in improving fish feed quality from agricultural waste and its implications for aquaculture performance.

RESULTS AND DISCUSSION

This study was conducted to evaluate the effect of fermentation technology on improving the quality of agricultural waste-based fish feed. The main ingredients used were rice bran, soybean meal, and cassava pulp. These ingredients were fermented using selected microbes (*Bacillus subtilis*, *Aspergillus niger*, and *Saccharomyces cerevisiae*) through solid-state fermentation (SSF) and submerged fermentation methods. The fermented ingredients were then formulated into a test feed and compared with a fishmeal-based control feed.

Proximate Analysis Results

Table 1. Proximate composition of feed ingredients before and after fermentation (% DM)

Treatment	Protein (%)	Fat (%)	Crude Fiber (%)	Ash (%)	Energy (Kcal/kg)
Rice bran (control)	12.5	6.2	19.4	8.1	2,950
SSF fermented rice bran	18.3	6.0	12.6	8.4	3,250
Soybean meal (control)	38.0	1.8	8.5	6.5	3,100
Fermented soybean meal	43.2	1.7	5.6	6.9	3,280
Cassava dregs (control)	8.9	2.5	23.2	7.4	2,600

Fermented cassava dregs	14.7	2.4	15.1	7.7	2,950

The fermentation process increased the protein content of all ingredients, with the largest increases in rice bran (from 12.5% to 18.3%) and cassava pulp (from 8.9% to 14.7%). Crude fiber decreased significantly, indicating the degradation of lignocellulosic components by microbial enzymes. Metabolizable energy also increased, indicating that fermentation increases energy availability to fish.

Results of Antinutritional Factor Analysis

Table 2. Changes in antinutrient levels after fermentation

Treatment	Phytate (mg/g)	Tannin (mg/g)	Insoluble Fiber (%)
Rice bran control	8.5	2.3	15.6
Fermented rice bran	3.2	1.1	9.8
Soybean meal control	6.7	1.8	7.4
Fermented soybean meal	2.5	0.9	5.0
Cassava dregs control	10.1	2.6	18.3
Fermented cassava dregs	4.1	1.2	11.2

Fermentation effectively reduces antinutrient levels, particularly phytate and tannin. This reduction increases the bioavailability of minerals (Fe, Zn, Ca) and protein. This is important for increasing the efficiency of nutrient utilization in fish.

In Vitro Digestibility Test Results

Table 3. Dry matter digestibility coefficient (DMC) and protein (KKP) (%)

Treatment	KKBK (%)	KKP (%)
Rice bran control	55.3	61.7
Fermented rice bran	72.8	79.4
Soybean meal control	71.2	82.1
Fermented soybean meal	83.6	90.5
Cassava dregs control	49.8	57.4
Fermented cassava dregs	68.5	74.3

Digestibility increased significantly after fermentation. Rice bran and cassava pulp, which were initially difficult to digest, showed a significant increase in protein digestibility. This indicates that fermentation increases nutrient availability through the degradation of plant cell walls.

Biological Test Results on Tilapia (*Oreochromis niloticus*)

Table 4. Growth and performance parameters of tilapia after 10 weeks of treatment

Treatment (Inclusion of Fermented Materials)	SGR (%/day)	FCR	Life sustainability (%)	Antioxidant Activity (SOD, U/mL)
Control (commercial feed)	1.45	1.62	91.0	62.5
10% fermented ingredients	1.61	1.45	93.5	75.2
20% fermented ingredients	1.74	1.36	95.2	82.3
30% fermented ingredients	1.70	1.40	94.0	80.1

Feed formulations with fermented ingredients showed increased specific growth rate (SGR) and improved feed efficiency (FCR). Optimal inclusion was found at the 20% level, where the highest SGR (1.74%/day) and the lowest FCR (1.36) were achieved. Furthermore, survival rates increased, as well as higher antioxidant enzyme (SOD) activity, indicating improved fish health. However, at the 30% inclusion level, no significant additional increase was observed, and there was even an indication of a slight decrease compared to the 20% level.

Water Quality During Maintenance

Water quality parameters (pH: 7.0–7.8; DO: 5.5–6.8 mg/L; NH_3: <0.05 mg/L) remained within the optimal range throughout the study, both in the control and the fermented feed treatments. The use of fermented feed does not cause ammonia accumulation or a decrease in water quality, indicating that the feed is easier to digest so that less metabolite waste is wasted into the environment.

Discussion

The research results show that fermentation technology can improve the quality of agricultural waste-based feed ingredients in terms of nutritional content, digestibility, and fish growth performance. The significant increase in protein content in rice bran, soybean meal, and cassava pulp after fermentation demonstrates that microbes play a crucial role in protein synthesis and the degradation of complex compounds into simpler molecules. This is consistent with previous reports that the fermentation process by *Bacillus subtilis* and *Aspergillus niger* can produce protease and cellulase enzymes that increase crude protein content and reduce crude fiber levels in feed ingredients (Siddik et al., 2024; Vieira et al., 2023).

Reducing antinutrient levels, particularly phytate and tannin, is a key indicator of fermentation success. Phytate compounds are known to bind essential minerals such as calcium, phosphorus, and zinc, reducing their bioavailability. By reducing phytate levels after fermentation, mineral availability for fish increases. The same applies to tannins, which can inhibit protein absorption. This finding is consistent with a report by Mugwanya et al. (2023) which showed that fermentation of plant materials reduces antinutritional factors and increases the efficiency of nutrient utilization in fish feed.

Furthermore, in vitro digestibility tests demonstrated that fermentation increased the dry matter digestibility coefficient (DFCC) and protein digestibility coefficient (PFC). This increase in digestibility is closely related to the degradation of plant cell walls by cellulase and hemicellulase enzymes produced by the fermentation microbes, making nutrients more accessible to fish digestive enzymes. These findings align with those of Jiang et al. (2023) who reported increased digestibility and nutrient utilization in fermented feed for *Eriocheir sinensis* .

Biologically, performance tests on tilapia showed that fermented feed performed better than commercial control feed. Specific growth rate (SGR) and feed conversion ratio (FCR) improved at inclusion levels of 10–20%, with optimal performance at 20%. This indicates that fermentation not only enhances nutritional value but also improves feed utilization efficiency. Increased antioxidant enzyme (SOD) activity in treated fish indicates the bioactive effects of fermented products, such as probiotic compounds or secondary metabolites, which contribute to improved fish health and immunity. These findings support the study by Li et al. (2025) which states that fermented ingredients in aquaculture feed can improve fish physiological status and resistance to oxidative stress.

However, this study also found that the use of fermented ingredients at the 30% level did not provide significant additional improvements, and even tended to decrease compared to the 20% level. This phenomenon can be explained by possible limitations in nutritional balance, the accumulation of certain metabolites from the fermentation process, or reduced feed palatability at high inclusion levels. This condition aligns with the findings of Estevão-Rodrigues et al. (2024) that the use of fermented ingredients must be optimized according to the characteristics of the substrate to avoid disrupting the overall feed formulation.

From a sustainability perspective, the use of fermented agricultural waste as a feed ingredient contributes to reducing dependence on fishmeal and supporting the circular economy concept in the fisheries sector. The stability of water quality during the rearing trials also supports the indication that fermented feed is more efficiently digested and produces less organic waste. This has positive implications for the health of the aquaculture ecosystem and efficiency of production costs. Overall, this study confirms that fermentation technology has significant potential to improve the quality of agricultural waste-based fish feed. However, for industrial scale applications, further research is needed on raw material standardization, fermentation process optimization, and comprehensive economic and environmental impact analysis. Therefore, this innovation could become a key strategy for achieving more sustainable and environmentally friendly aquaculture.

CONCLUSION

This research demonstrates that fermentation technology can significantly improve the quality of agricultural waste-based fish feed. The fermentation process, using selected microbes, effectively increases protein content, decreases crude fiber content, and reduces antinutritional factors such as phytate and tannin. Furthermore, fermentation has been shown to improve feed digestibility and the availability of essential nutrients for fish.

In biological tests with tilapia (Oreochromis niloticus), fermented feed demonstrated improved growth performance, characterized by increased specific growth rate (SGR), decreased feed conversion ratio (FCR), and increased survival and antioxidant enzyme activity. The optimal inclusion level was found to be 20%, which provides the best balance between nutritional efficiency, growth, and fish health.

Overall, utilizing agricultural waste through fermentation has the potential to be a strategic solution for developing sustainable aquaculture feed. This technology not only reduces dependence on fishmeal but also supports a circular economy by utilizing abundant and often wasted local resources. However, industrial-scale implementation still requires further research related to raw material quality standardization, fermentation process optimization, and economic and regulatory analysis.

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