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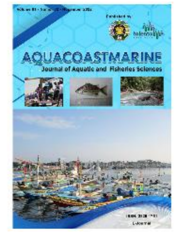

A review of the enzyme's utilization in the feed for indigenous Indonesian fish

Sebuah tinjauan terhadap pemanfaatan enzim pada pakan ikan indigenus Indonesia

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ABSTRACT

Enzymes play a vital role in improving nutrient absorption and digestion efficiency in fish feed, particularly for indigenous Indonesian fish species. This review aimed to comprehensively evaluate the current state of enzyme utilization in feed for native Indonesian fish, highlighting its benefits, challenges, and potential contributions to the advancement of sustainable aquaculture. It examined the role of protease, phytase, and Non-Starch Polysaccharides (NSP) enzymes, in enhancing feed efficiency and fish growth. The integration of these enzymes into feed formulations offers significant advantages in boosting growth performance, optimizing feed conversion efficiency, and promoting environmental sustainability. Additionally, this review discussed the potential benefits and challenges associated with enzyme application in fish feed. Looking ahead, the development of enzyme utilization in aquafeed holds great promise for enhancing the sustainability, efficiency, and productivity of the aquaculture sector. This review provides valuable insights into the potential of enzyme supplementation to maximize feed utilization for native Indonesian fish species, outlining both its advantages and challenges, while also exploring its future prospects in driving cost-effective and eco-friendly aquaculture practices.

Keyword: Catalysts, Enzymes, Feed, Sustainable Aquaculture

ABSTRAK
Enzim memainkan peran penting dalam meningkatkan penyerapan nutrisi dan efisiensi pencernaan dalam pakan ikan, terutama untuk spesies ikan asli Indonesia. Tinjauan ini bertujuan untuk mengevaluasi secara komprehensif keadaan terkini pemanfaatan enzim dalam pakan untuk ikan asli Indonesia, menyoroti manfaat, tantangan, dan kontribusi potensialnya terhadap kemajuan akuakultur berkelanjutan. Tinjauan ini meneliti peran enzim protease, fitase, dan Polisakarida Non-Pati (NSP), dalam meningkatkan efisiensi pakan dan pertumbuhan ikan. Integrasi enzim-enzim ini ke dalam formulasi pakan menawarkan keuntungan signifikan dalam meningkatkan kinerja pertumbuhan, mengoptimalkan efisiensi konversi pakan, dan mempromosikan keberlanjutan lingkungan. Selain itu, tinjauan ini membahas potensi manfaat dan tantangan yang terkait dengan aplikasi enzim dalam pakan ikan. Pengembangan pemanfaatan enzim dalam pakan akuakultur dimasa depan sangat menjanjikan untuk meningkatkan keberlanjutan, efisiensi, dan produktivitas sektor akuakultur. Tinjauan ini memberikan wawasan berharga tentang potensi suplementasi enzim untuk memaksimalkan pemanfaatan pakan bagi spesies ikan asli Indonesia, menguraikan keuntungan dan tantangannya, sekaligus mengeksplorasi prospek masa depannya dalam mendorong praktik akuakultur yang hemat biaya dan ramah lingkungan.
Keyword: Akuakultur Berkelanjutan, Enzim, Katalis, Pakan

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1. Introduction

Indonesia possesses a diverse array of indigenous fish species, which play a pivotal role in the country's aquatic ecosystems. Undoubtedly, these species constitute a significant aspect of Indonesia's cultural and economic fabric, given its maritime geography comprising numerous islands. In recent years, as the aquaculture industry endeavors to address the escalating demand for fish protein sustainably, there has been a mounting interest in refining feed formulations tailored to Indonesia's native fish. One particularly promising approach gaining traction is the incorporation of enzymes into fish feed, offering potential benefits such as enhanced nutrient utilization, improved digestibility, and the promotion of more efficient aquaculture practices (Napitupulu et al., 2022).

Enzymes, serving as biological catalysts, hold considerable importance in expediting biochemical reactions within organisms, including fish, by accelerating the breakdown of complex nutrients into simpler, easily assimilated forms. The integration of enzymes into fish feed formulations not only holds promise for augmenting feed conversion efficiency but also for mitigating environmental impacts associated with aquaculture activities. Nonetheless, effectively incorporating enzyme technology into aquatic feeds necessitates a comprehensive understanding of its effectiveness, practical implementation, and potential implications for the overall growth, health, and productivity of native fish species (Haetami et al., 2022).

This review endeavors to critically assess the current status of enzyme utilization in feed for native Indonesian fish, elucidating the advantages, obstacles, and implications for the advancement of sustainable aquaculture practices. By synthesizing research findings, this review aims to offer valuable insights into the role of enzymes in enhancing the nutritional quality of fish feed and optimizing production efficiency within Indonesia's aquaculture sector.

2. Enzyme utilization in feed of fish

In general, there are two types of enzymes: endogenous enzymes and exogenous enzymes (Figure 1). Endogenous enzymes are naturally produced by the animal’s body (stomach, pancreas, intestines), while exogenous enzymes are added to the feed externally, sourced from microorganisms, fungi, plants, or industrial fermentation. The primary function of endogenous enzymes is to facilitate the natural digestion of proteins, fats, and carbohydrates in food. These enzymes are naturally present and continuously available in the animal’s body. However, they may sometimes be insufficient for breaking down complex fibers or anti-nutritional factors. Exogenous enzymes can complement the role of endogenous enzymes by enhancing nutrient utilization, breaking down anti-nutritional compounds, and supporting more efficient digestion. This enables animals to digest feed ingredients that would otherwise be difficult to break down naturally. However, exogenous enzymes require precise dosage and formulation to be effective in feed (Liang et al., 2022).

The utilization of exogenous enzymes in the feed of indigenous Indonesian fish includes three types: protease, phytase, and Non-Starch Polysaccharides (NSP), as shown in Figure 2. The most commonly used protease enzymes are papain and bromelain. Papain is an enzyme derived from the latex of papaya (*Carica papaya*). It functions by hydrolyzing proteins into simpler forms, thereby improving protein digestibility in feed. This enzyme helps fish digest both plant- and animal-based protein sources and enhances nutrient absorption. Bromelain is an enzyme obtained from pineapple (*Ananas comosus*). It works by breaking down complex proteins into peptides and amino acids, making them easier to digest. This enzyme increases protein availability, improves feed efficiency, and supports fish growth (Choi et al., 2016).

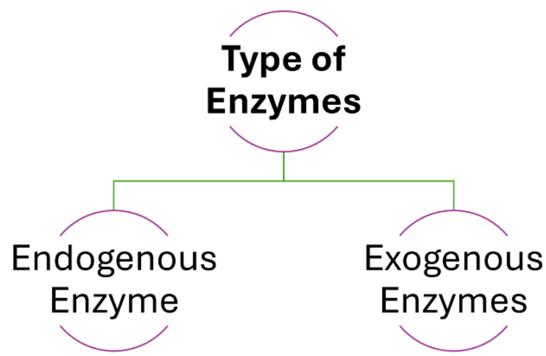

Figure 1. Type of enzymes.

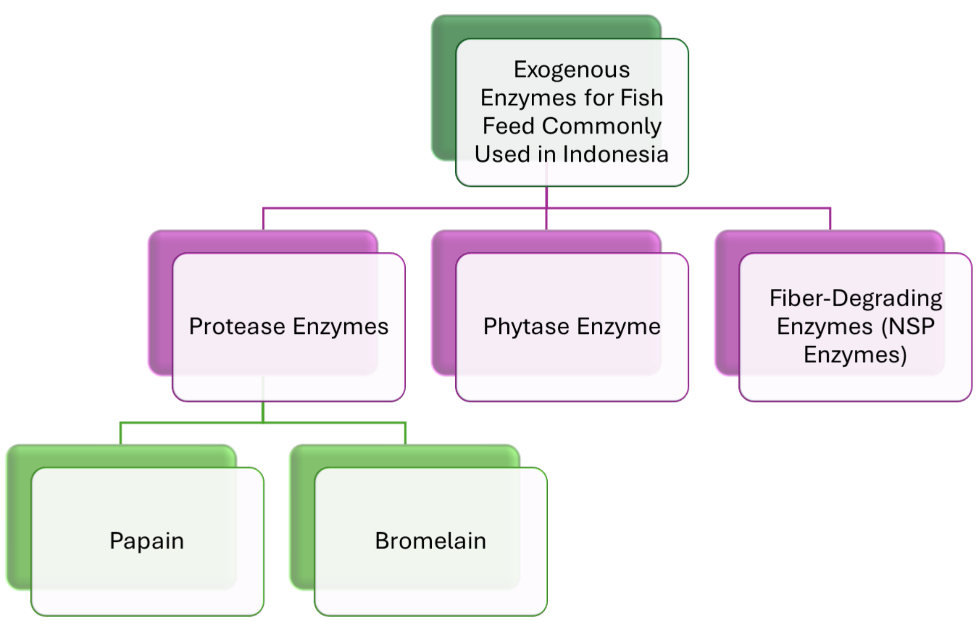

Figure 2. Exogenous enzymes commonly utilized in Indonesian fish feed.

Phytase enzyme is an exogenous enzyme that hydrolyzes phytic acid in plant-based feed, thereby releasing phosphorus, calcium, and other minerals that can be utilized by fish. It can be derived from bacteria (e.g., *Escherichia coli*, *Bacillus* sp.) and fungi (e.g., *Aspergillus niger*, *Trichoderma reesei*). Non-Starch Polysaccharide (NSP) enzymes belong to the carbohydrase enzyme group, which functions to break down non-starch polysaccharides in fish feed. NSP consists of complex fibers that are difficult for animals to digest, making NSP enzymes highly beneficial for improving nutrient utilization. Types of NSP enzymes in feed include: Xylanase – breaks down arabinoxylans (the main fiber in wheat and corn), Beta-glucanase – hydrolyzes beta-glucans (fibers in barley and wheat), Cellulase – breaks down cellulose into simple sugars, Mannanase – degrades mannans (found in palm kernel meal and soybean meal), and Pectinase – hydrolyzes pectin (a component in plant-based materials) (Liang et al., 2022).

The utilization of enzymes in indigenous Indonesian fish is summarized in Table 1. As shown in the table, treatment using protease enzymes in tilapia feed positively influenced intestinal histology, while in snakehead fish, it improved growth and survival rates compared to the control group (Farida et al., 2022; Sinaga et al., 2020). Furthermore, the use of specific protease enzymes, such as papain, in the feed for eel (*Anguilla bicolor*), Sangkuriang catfish (*Clarias gariepinus*), climbing perch (*Anabas testudineus*), goldfish (*Cyprinus carpio*), and catfish (*Pangasius hypophthalmus*), generally showed significant effects on relative growth rate (RGR), protein efficiency ratio (PER), and feed utilization efficiency (EPP) (Ananda et al., 2015; Azmi, 2024; Khodijah and Rachmavati, 2015; Sagita and Rachmawati, 2017; Sulasi et al., 2018). These studies suggest that papain can be widely applied across various indigenous Indonesian fish species. In addition to papain, another protease enzyme, bromelain, has also been used in tilapia feed and demonstrated significant improvements in EPP and growth (Andini and Widaryati, 2020). Overall, protease enzymes have been extensively studied as feed additives and have shown clear positive impacts. Besides protease, phytase enzymes have also been explored as feed additives for duck grouper (*Cromileptes altivelis*), Sangkuriang catfish, and cantang grouper (*Epinephelus* sp.), resulting in significant improvements in EPP, PER, and RGR (Chrisdiana et al., 2015; Kosim et al., 2016; Zulaeha et al., 2015). A study by Dwinanti et al. (2023) reported that the application of Non-Starch Polysaccharide (NSP) enzymes in pond fish (*Helostoma temminckii*) feed resulted in optimal growth and 100% survival. These findings demonstrate that enzyme supplementation in feed for indigenous Indonesian fish can provide substantial positive benefits.

3. Advantages and challenges

Enzymes are becoming more commonly incorporated into fish feed formulations to optimize nutrient absorption, boost feed efficiency, and support overall growth and health in aquaculture. However, as with any technological innovation, their application presents both benefits and challenges (Figure 3) that require careful evaluation (Abishag & Betsy, 2018; Chen et al., 2024; Liang et al., 2022).

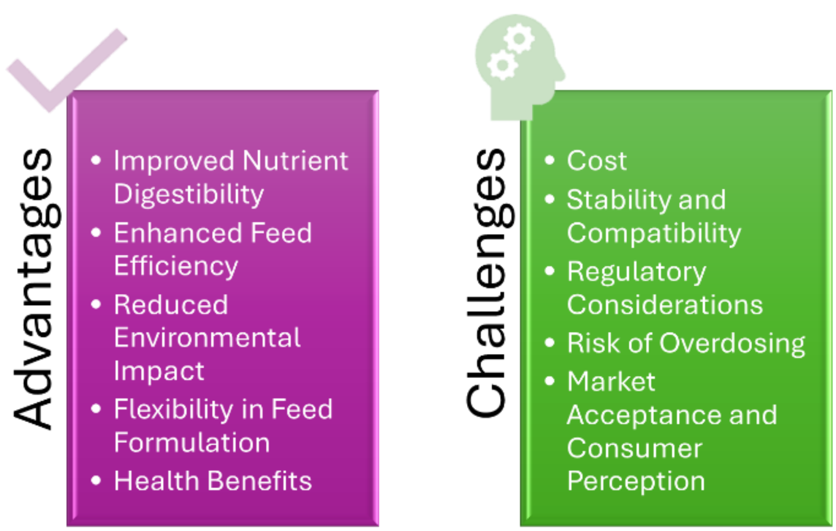

Figure 3. Advantages and challenges of enzymes in fish feed.

Table 1. Utilization of enzymes in the feed of indigenous Indonesian fish

Type of Enzymes	Type of fish	Treatments	Effect of enzyme	References
Protease Enzyme	Tilapia (*Oreochromis niloticus*)	A: 0% B: 1% C: 2%	- Enzyme treatment had an effect on the intestinal histology of tilapia - The best treatment was treatment B (1%) with an intestinal villi length of 395 μm which increased to 176 μm, at a vili width of 95 μm which increased to 31 μm.	Farida et al. (2022)
	Snakehead Fish (*Channa striata*)	A: control B: 3% C: 5%	- The highest survival rate of snakehead fish fry was found in treatment B, with an average of 93% and the lowest in treatment C with an average of 84%. - The highest absolute length and absolute weight growth was found in treatment B, with an average length of 1.66 cm and weight of 1.44 grams and the lowest in control (0%) with an average length of 1.09 cm and weight of 1.01 grams. - The highest specific growth rate of tilapia fry was found in treatment B, with an average of 1.52% and the lowest in control (0%) with an average of 0.85%. - The best feed efficiency rate was 3% protease enzyme administration which was 51.10% and the lowest in control was 47.3%. - The best feed conversion rate (FCR) was 6.1 at 3% protease enzyme.	Sinaga et al. (2020)
Protease Enzyme (Papain)	Eel (*Anguilla bicolor*)	A (0% papain enzyme/kg) B (0,85%/kg) C (1,70%/kg) D (3,40%/kg)	- Enzyme treatment had a significant effect on EPP, PER, and RGR (Sig. < 0.05). - The best treatment was D, which resulted in an EPP value of 59.12±1.74%, a PER of 1.74±0.05%, and an RGR of 1.59±0.10% per day. - The water quality in the rearing media remained within a suitable range for the test fish.	Sagita and Rachmawati (2017)
	Sangkuriang Catfish (*Clarias gariepinus*)	A: 0% B: 1.125% C: 2.25% D: 3.375%	- Enzyme treatment had a significant effect (P<0.05) on relative growth rate (RGR), protein efficiency ratio (PER), feed utilization efficiency (EPP), but did not differ significantly (P>0.05) on survival (SR). - The optimal dose of papain enzyme of 2.53% in artificial feed was able to produce a maximum relative growth rate of 5.05%/day.	Khodijah and Rachmavati (2015)
	Betok Fish (*Anabas testudineus*)	P0: 0%/kg of feed P1: 1.25%/kg of feed P2: 2.25%/kg of feed P3: 3.25%/kg of feed P4: 4.25%/kg of feed	- Enzyme treatment affected the growth performance and survival of betok fish (*Anabas testudineus*). - The best growth was the addition of papain enzyme in feed at a dose of 3.25%/kg of feed, which resulted in absolute weight growth of 4.70±0.18 g, absolute length growth of 2.0±0.20 cm, specific growth rate of 2.21±0.02%, survival of 100%, FCR of 1.26±0.03%, number of enzymes of 0.0716 IU/mL, and with an average growth of kale weight of 60.08 g.	Azmi (2024)
	Goldfish (*Cyprinus carpio*)	Papain enzyme: A1 = 0.25 g/kg feed A2 = 0.50 g/kg feed Probiotics: B1 = 10 ml/ kg of feed B2 = 15 ml/kg of feed	- Papain enzyme had a real effect (P<0.05) on EPP and PER - Probiotics had a real effect (P<0.05) on EPP and PER, and there was an interaction between the two factors in the PER variable - The quality of water in the maintenance medium was maintained at a range suitable for goldfish cultivation.	Sulasi et al. (2018)
	Catfish (*Pangasius hypopthalmus*)	A: 0% B: 0.75% C: 1.5%	- Enzyme treatment had a significant effect on the specific growth rate, protein utilization efficiency and protein efficiency ratio but had no significant effect on the survival of catfish.	Ananda et al. (2015)

Type of Enzymes	Type of fish	Treatments	Effect of enzyme	References
		D: 2.25%	- The optimal dose of adding papain to artificial feed at the specific growth rate of catfish was 1.16%.	
Protease Enzyme (Bromelin)	Tilapia (*Oreochromis niloticus*)	A: 5 g/kg B: 10 g/kg C: 15 gr/kg D: control	- Enzyme treatment had a very real effect on absolute weight growth (.001), absolute length (.000), feed utilization efficiency (EPP) (.001), but had no significant effect on feed conversion value (FCR) (.064) and survival (0.571).	Andini and Widaryati (2020)
Phytase Enzyme	Duck grouper (*Cromileptes altivelis*)	A: 0 mg/kg feed B: 500 mg/kg feed C: 1000 mg/kg feed D: 1500 mg/kg feed	- The fitase enzyme treatment had a very real effect ($P<0.01$) on EPP, PER, and RGR. - The optimum dose of phytase enzyme 986 mg/kg of feed could increase the relative growth rate of duck grouper by a maximum of 2.24%, - The optimal dose of phytase enzyme 950 mg/kg of feed could produce a maximum feed utilization efficiency of 28.5% - The water quality in the maintenance medium was still in a feasible range for duck grouper fish cultivation.	Zulaeha et al. (2015)
	Sangkuriang Catfish (*Clarias gariepinus*)	A: 0 mg/kg feed B: 250 mg/kg feed C: 500 mg/kg feed D: 750 mg/kg feed	- Enzyme treatment had a very real effect ($P<0.01$) on RGR, EPP and PER. - The optimal dose percentage of phytase enzyme of 579 mg/kg of feed in artificial feed was able to produce a maximum RGR and EPP of 4.18%/day and 86.5%. - The optimal dose of phytase enzyme of 583 mg/kg of feed was able to produce a maximum PER of 2.75% for sangkuriang catfish. - Water quality in the maintenance medium.	Kosim et al. (2016)
	Cantang Grouper (*Epinephelus* sp.)	A: 0 mg/kg feed B: 500 mg/kg feed C: 1,000 mg/kg feed D: 1,500 mg/kg feed	- Enzyme treatment had a very real effect ($P<0.01$) on EPP and PER, and a real effect ($P<0.05$) on SGR. - The optimal dose of phytase enzyme of 1,080 –1,090 mg/kg of artificial feed was able to produce an optimal SGR of 0.519%/day, 0.386%PER, and EPP of 25.3%. - The water quality in the maintenance medium was still in the appropriate range for the cultivation of cantang grouper.	Chrisdiana et al. (2015)
Non Starch Polysaccharides (NSP) Enzymes	Pond Fish (*Helostoma temminckii*)	P1: 0% of enzymes and *Lemna* sp. flour P2: 0% of enzymes and 5% *Lemna* sp. P3: 5% of enzymes and 5% *Lemna* sp. The dose of NSP enzyme used is 10 g/kg of raw materials.	- The use of *Lemna* sp flour as much as 5% with the addition of NSP enzyme (P3) gave the best results with absolute weight growth of 0.91 g, absolute length growth of 0.63 cm, specific weight growth rate of 1.35 %.day-1, specific length growth rate of 0.41 %.day-1, survival 100%, feed efficiency 28.59%.	Dwinanti et al. (2023)

Advantages:

1. Improved Nutrient Digestibility: Enzymes like phytases, proteases, and carbohydrases help break down complex nutrients in fish feed into more easily digestible forms, allowing for better absorption and utilization. This leads to improved feed conversion ratios (FCR) and enhanced growth performance (Abishag & Betsy, 2018; Azmi, 2024; Sinaga et al., 2020).
2. Enhanced Feed Efficiency: By improving nutrient digestibility, enzymes minimize feed waste and maximize the use of feed ingredients. These lowers feeding costs per unit of fish produced and promotes the sustainability of aquaculture operations (Dwinanti et al., 2023; Sinaga et al., 2020).
3. Reduced Environmental Impact: Greater feed efficiency results in reduced excretion of undigested nutrients into the water, helping to prevent pollution and eutrophication. As a result, enzymes support more eco-friendly aquaculture practices (Sagita and Rachmawati, 2017; Sulasi et al., 2018).
4. Flexibility in Feed Formulation: The addition of enzymes enables the use of alternative, cost-effective feed ingredients with higher anti-nutritional factors. This reduces dependence on expensive and environmentally unsustainable components like fishmeal (Azmi, 2024; Chrisdiana et al., 2015).
5. Health Benefits: Certain enzymes, particularly those with antimicrobial properties or gut health benefits, can aid in disease prevention and overall fish well-being. This decreases reliance on antibiotics and other medications in aquaculture (Chen et al., 2024; Farida et al., 2022; Liang et al., 2022).

Challenges:

1. Cost: Incorporating enzymes into fish feed can increase production expenses, especially if they are sourced from specialized suppliers or require specific manufacturing techniques. For small-scale fish farms, the initial investment in enzyme supplementation may outweigh potential savings on feed costs (Azmi, 2024; Chrisdiana et al., 2015).
2. Stability and Compatibility: Enzymes can degrade or lose effectiveness during feed processing, storage, or within the acidic conditions of the fish's digestive system. Maintaining enzyme stability and ensuring compatibility with feed ingredients can be complex, often requiring additional quality control measures (Dwinanti et al., 2023; Sinaga et al., 2020).
3. Regulatory Considerations: The use of enzymes in animal feed is subject to regulatory approvals in many countries. Gaining authorization for enzyme supplementation in fish feed can be a time-consuming and costly process, adding another layer of complexity to feed production (Chrisdiana et al., 2015; Kosim et al., 2016).
4. Risk of Overdosing: Excessive enzyme supplementation can negatively impact feed palatability, cause nutrient imbalances, or lead to digestive disturbances in fish. Precise formulation and dosage control are essential to prevent overdosing and minimize potential adverse effects (Abishag & Betsy, 2018; Zulaeha et al., 2015).
5. Market Acceptance and Consumer Perception: Consumer attitudes toward enzyme use in fish feed vary, with concerns about genetically modified enzymes or perceived alterations to the natural diet of farmed fish. Market acceptance and consumer perception can significantly influence demand and profitability in the aquaculture industry (Chen et al., 2024; Liang et al., 2022).

While enzyme supplementation in fish feed offers significant benefits, including improved nutrient utilization, better feed efficiency, and enhanced environmental sustainability, it also comes with challenges such as cost, stability, regulatory hurdles, and consumer acceptance. To fully leverage the advantages while addressing these challenges, careful enzyme selection, precise dosage management, optimized formulation, and rigorous quality control are crucial in aquaculture operations (Abishag & Betsy, 2018; Chen et al., 2024; Liang et al., 2022).

3. Potential future development

As aquaculture expands to meet the rising global demand for seafood, the use of enzymes in fish feed is likely to evolve through continuous innovation and refinement. Future breakthroughs in enzyme technology have the potential to further enhance nutrient absorption, boost feed efficiency, and support more sustainable aquaculture practices. Some possible directions for the future development of enzyme applications in fish feed include (Abishag & Betsy, 2018; Liang et al., 2022; Ravindran & Son, 2011; Wang et al., 2024) (Figure 4):

1. Tailored Enzyme Formulations: Future research may focus on formulating enzymes specifically tailored to the nutritional needs and digestive physiology of different fish species. By optimizing enzyme combinations for target species, nutrient absorption and growth performance can be significantly improved.
2. Novel Enzyme Sources: The discovery of new enzyme sources, including microbial, fungal, and

genetically engineered enzymes, may lead to more stable, efficient, and species-specific enzyme applications in fish feed. Advances in biotechnology could enable the production of enzymes with enhanced properties designed for aquaculture.

3. Multi-Enzyme Synergies: Investigating the interactions between various enzymes, such as carbohydrases, proteases, and phytases, may lead to the development of multi-enzyme solutions that improve nutrient digestion across a wider range of feed ingredients. Understanding these synergies could further optimize feed efficiency.
4. Encapsulation and Delivery Systems: The use of encapsulation technology may help protect enzymes from degradation during feed processing and storage, ensuring their effectiveness in the fish's digestive system. Additionally, controlled-release delivery systems could allow for targeted enzyme activation at specific points in digestion, maximizing nutrient breakdown.
5. Precision Feeding Strategies: Innovations in sensor technology, data analytics, and automated feeding systems could allow for real-time monitoring of fish feeding behavior and digestion. By integrating enzymes into precision feeding strategies, enzyme dosage and formulation could be dynamically adjusted based on individual fish needs, optimizing feed efficiency and growth.
6. Environmental Sustainability: Future enzyme innovations may prioritize environmental sustainability by enabling the effective use of plant-based feed alternatives with lower ecological impact. Enzymes could play a crucial role in reducing reliance on fishmeal and other marine-derived proteins, helping to protect wild fish populations while promoting sustainable aquaculture.
7. Regulatory Considerations and Consumer Perception: As enzyme technology advances, regulatory frameworks may need to adapt to ensure the safety and efficacy of enzyme-enhanced fish feeds. Clear communication regarding the benefits and safety of enzyme use in aquaculture will be essential for gaining consumer trust and market acceptance.

The future of enzyme utilization in fish feed presents significant opportunities for improving aquaculture's sustainability, efficiency, and productivity. Continued research and technological advancements, alongside precision feeding and environmental responsibility, will be key to unlocking these benefits and addressing challenges in the aquaculture industry (Abishag & Betsy, 2018; Liang et al., 2022; Ravindran & Son, 2011; Wang et al., 2024).

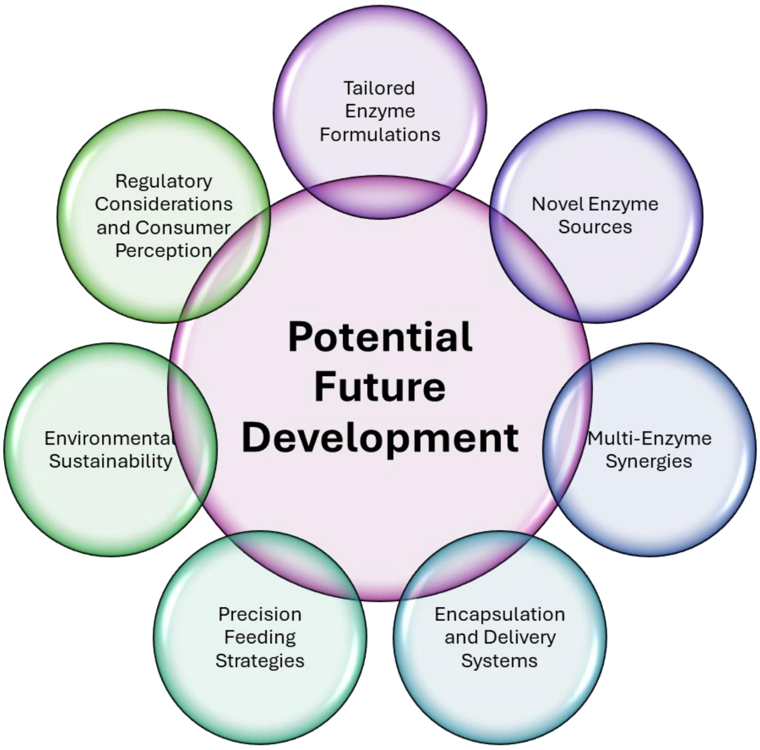

Figure 4. Potential future development of enzyme utilization in fish feed.

4. Conclusion

The utilization of enzymes in fish feed presents a promising approach to improving the digestibility, nutrient absorption, and overall efficiency of feed for indigenous Indonesian fish species. This review highlighted the critical role of endogenous and exogenous enzymes, such as protease, lipase, phytase, Non-Starch

Polysaccharides (NSP) enzymes, and multi-carbohydrase complexes, in enhancing feed conversion efficiency, fish growth, and environmental sustainability. By breaking down complex macronutrients and reducing anti-nutritional factors, enzyme supplementation optimizes the bioavailability of essential nutrients, leading to better growth performance and reduced feed waste. Despite its significant benefits, challenges such as cost, formulation accuracy, and variability in enzyme effectiveness need to be addressed for broader commercial adoption. Future research should focus on optimizing enzyme combinations, exploring new sources of enzymes, and tailoring enzyme applications to specific fish species and dietary compositions. In conclusion, enzyme supplementation in aquafeed has immense potential to support sustainable and cost-effective aquaculture practices in Indonesia. By integrating scientific advancements, technological innovations, and industry collaboration, enzyme utilization can contribute to a more efficient, eco-friendly, and productive aquaculture sector, ensuring better fish health, improved resource efficiency, and long-term sustainability.

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