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Optimizing Binder Type and Concentration to Enhance Stability and Acceptability of Pasta Feed for Swamp Eel (*Monopterus albus*)

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ABSTRACT

Feed stability is a crucial factor in aquaculture, as it affects both the physical integrity of the feed and its acceptance by aquatic species. For *Monopterus albus* (swamp eel), maintaining feed stability while ensuring palatability is vital for optimal growth and health. This study aimed to evaluate the effects of different binder types and concentrations on the stability and acceptability of pasta feed for *Monopterus albus* (swamp eel). Seven binders—gelatin, gluten, CMC, chitosan, alginate, guargum, and carrageenan—were tested at 0%, 10%, 15%, and 20% concentrations using a completely randomized design. Feed disintegration and breakdown times, along with feeding behavior, were analyzed using non-parametric tests. Gelatin, CMC, and chitosan significantly improved feed stability ($p < 0.05$), maintaining cohesion for over 40 minutes. Gelatin at 10% concentration yielded optimal results, balancing water resistance and palatability. Behavioral observations showed that gelatin-based feeds were most preferred, with increased feeding frequency and consumption. When combined with natural attractants such as worms and snails, gelatin feeds enhanced intake rates. These outcomes indicate that protein-based binders, particularly gelatin, offer superior mechanical and nutritional advantages compared to polysaccharide alternatives. Gelatin's dual role as a binder and nutritional enhancer provides a promising strategy for sustainable aquaculture feed development.

INTRODUCTION

Eel aquaculture has become an increasingly significant component of freshwater aquaculture systems across Asia, particularly due to its high market demand and nutritional value. However, the development of *Monopterus albus* (swamp eel) culture remains notably limited compared to other freshwater species. One of the major constraints is its dependence on fresh or live natural feed, which affects production efficiency and sustainability. The carnivorous feeding behavior of *M. albus* poses challenges in formulating suitable artificial feeds that replicate the nutritional profiles of its natural prey, which includes worms, snails, and small aquatic organisms (Yu *et al*., 2022; Yue *et al*., 2020). As the demand for aquaculture products grows, the reliance on natural feed resources becomes unsustainable, prompting the urgent need for nutritionally balanced and physically stable artificial feeds that support the species feeding behavior and water quality management.

The increasing scarcity and cost of traditional protein sources such as fishmeal have intensified the exploration of alternative feed ingredients and binders that enhance feed functionality. However, the technological challenge of maintaining feed stability in water while ensuring nutrient retention and palatability persists. For *M. albus*, feed form is a crucial determinant of feeding efficiency. Studies have demonstrated that the physical form of feed—pellet, powder, or paste—directly influences consumption rates, nutrient utilization, and overall growth performance (Yu *et al*., 2025). While pellets are generally favored in commercial aquaculture for their convenience and stability (Deng et al., 2021), swamp eels display a marked preference for soft-textured feeds such as paste (Sintiya *et al*., 2025). Nonetheless, the high moisture and low structural integrity of pasta feeds result in rapid disintegration and nutrient leaching when immersed in water, contributing to feed wastage and environmental deterioration (Aksoy *et al*., 2022).

The main problem in developing eel pasta feed lies in achieving sufficient water stability without compromising palatability. Low feed stability often results from inadequate binding strength among feed particles, high moisture content, and suboptimal feed formulation, which collectively lead to rapid dissolution and poor nutrient retention *(*Karim *et al*., 2024; O'Mahoney *et al*., 2011). Excessive disintegration not only reduces feed efficiency but also contributes to organic matter accumulation and eutrophication in aquaculture systems (Bohnes *et al*., 2018; Wang *et al*., 2012). Thus, identifying binders that improve feed cohesion while maintaining acceptability is critical for sustainable eel aquaculture. Feed binders—such as starches, proteins, gums, and cellulose derivatives—are added to formulations to enhance structural stability, moisture retention, and texture. Their selection depends on compatibility with feed ingredients, binding capacity, and digestibility (Genodepa *et al*., 2007). Optimizing the binder type and concentration can significantly enhance feed performance by improving water stability, reducing nutrient leaching, and increasing feed intake.

Several studies have confirmed that inappropriate binder selection can lead to serious environmental consequences. Poorly bound feeds contribute to nutrient leakage, increasing ammonia and organic matter in the water column, thereby reducing dissolved oxygen and threatening aquatic biodiversity (Li *et al*., 2024). Furthermore, decomposition of uneaten feeds releases greenhouse gases, emphasizing the link between feed stability and environmental sustainability (Bossier & Ekasari, 2017; Ng & Koh, 2016). Therefore, developing sustainable, environmentally friendly binders is essential not only for optimizing feed performance but also for mitigating the ecological footprint of aquaculture.

Numerous binder types—such as gelatin, alginate, sodium carboxymethyl cellulose (CMC), and chitosan—have been evaluated for their ability to enhance feed quality. Gelatin, a protein-based binder derived from collagen, offers excellent water resistance due to its film-forming properties, which strengthen feed structure and limit nutrient loss (Argüello-Guevara & Molina-Poveda, 2012; Ruscoe *et al*., 2005). Alginate, a polysaccharide extracted from brown seaweed, has demonstrated superior water-binding capacity and is often employed in shrimp feeds to improve both texture and nutrient retention (Rosas et al., 2008). CMC, a cellulose derivative, contributes to improved cohesion and viscosity while enhancing palatability in aquatic diets (Yusoff *et al*., 2021). Meanwhile, chitosan, derived from crustacean shells, serves as a natural biopolymer with excellent adhesive and water-resistant properties. The effectiveness of these binders varies across species and formulations, underscoring the importance of systematic evaluation tailored to eel-specific feeding behaviors.

Recent advances in binder technology have emphasized the necessity of combining multiple binders to achieve both mechanical stability and nutritional balance. For instance, integrating CMC and alginate has improved pellet durability and digestibility in crustacean feeds (Diamahesa et al., 2025). Similarly, specific concentrations of carrageenan—typically between 2–4%—have enhanced pellet stability and reduced nutrient leaching in shrimp diets (Diamahesa & Azhar, 2025). Such optimizations in binder composition not only improve feed integrity but also contribute to cost-effectiveness and reduced environmental waste. However, despite these advances, there remains limited understanding of the interactive effects of binder type and dosage on the water stability and feeding behavior of *M. albus*.

Several previous studies have underscored the importance of binder optimization in achieving feed stability, yet species-specific evaluations remain scarce. The unique feeding behavior and digestive physiology of swamp eel require customized binder solutions distinct from those used in other fish species. Studies in other aquatic organisms—such as *Litopenaeus vannamei* and *Octopus maya*—have established that binder characteristics influence feed durability, dustiness, and nutrient digestibility (Argüello-Guevara & Molina-Poveda, 2012; Rosas *et al*., 2008). Inadequate binder application can lead to excessive nutrient loss and reduced feed conversion efficiency (Lim & Cuzon, 1994). Moreover, the balance between binder concentration and feed texture plays a decisive role in ensuring both stability and acceptability. Overly high binder levels may increase feed hardness, thereby reducing intake, whereas insufficient levels lead to feed disintegration (Ungureanu *et al*., 2016). Therefore, a comprehensive understanding of binder interactions with feed structure and eel feeding responses is essential to develop a functional pasta feed for this species.

Given these knowledge gaps, this study aims to identify and evaluate different binder types and concentrations that optimize both the physical stability and acceptability of pasta feed for *Monopterus albus*. The research hypothesizes that binder type and concentration exert significant effects on feed durability and eel consumption behavior. Specifically, the study evaluates seven types of binders—gelatin, gluten, CMC, chitosan, alginate, carrageenan, and guargum—applied at varying concentrations (0%, 10%, 15%, and 20%) to determine the most effective combination. This approach provides empirical evidence for selecting binder formulations that maintain feed integrity while promoting higher consumption rates. By establishing binder optimization benchmarks, the findings are expected to contribute to improved feed technology, reduced environmental impact, and enhanced economic efficiency in aquaculture practices.

METHODS

Experimental Design

This study was conducted through three experimental stages designed to evaluate the effects of different binder types and concentrations on the stability and acceptability of pasta feed for *Monopterus albus*. The experiment was conducted from June to September 2025 at The Fish Reproduction and Production Laboratory of University of Mataram.

A Completely Randomized Design (CRD) was employed with two primary factors: (1) binder type, consisting of seven levels—gelatin, gluten, carboxymethyl cellulose (CMC), chitosan, alginate, guargum, and carrageenan—and (2) binder concentration at three levels—

10%, 15%, and 20%. Each treatment combination was replicated three times to ensure reliability and statistical robustness. The factorial design allowed the assessment of both individual and interactive effects of binder type and concentration on feed characteristics, including water stability and consumption by eels.

The experimental setup was selected to isolate and measure the effects of binders while minimizing random environmental variability. Each replication consisted of an independent experimental unit with identical conditions of temperature, water quality, and eel size distribution.

Feed Stability Test

Feed Preparation and Binder Treatments

Feed stability testing followed procedures ensuring accurate assessment of disintegration and durability in water. Commercial pellet feed was first ground into fine powder to serve as the base substrate. The mixture was supplemented with 25% crushed earthworms as a protein source and attractant to mimic the natural diet of eels (Abidin *et al*., 2025). The control feed contained 0% binder to establish a baseline for comparison.

For the binder treatments, each binder type was mixed with feed powder in the prescribed concentration levels. Alginat, CMC, guargum, carrageenan, and chitosan were blended thoroughly before the addition of worm paste to ensure uniform distribution. Hot water (100°C) was used to activate the binding process, with the amount of water varying depending on the binder's absorption capacity. Specifically, CMC required 1000% water, alginate, gelatin, gluten, and chitosan required 1500%, and guargum and carrageenan required 2000%. The control feed used only 150% water. Gelatin and gluten binders were pre-cooked until thickened, promoting greater cohesion and elasticity before being combined with the feed mixture.

The prepared pasta feeds were shaped into cylindrical strands of approximately 1.5 cm length using a precision extruder, ensuring consistency across treatments. Feed samples were allowed to cool at room temperature for 24 hours before being subjected to stability testing. This approach provided reproducible feed forms suitable for evaluating both physical integrity and palatability under aquatic conditions.

Stability Assessment Procedures

Two main parameters were measured: feed disintegration time and feed breakdown time. The first**,** feed disintegration time, referred to the duration until visible cracks or partial fragmentation appeared while the feed still retained its general shape. The second, feed breakdown time, indicated the complete loss of structural integrity, where the feed dispersed into fine particles due to water agitation. These observations followed methodologies proposed by O'Mahoney *et al*. (2011) and Nor Asma Husna *et al*. (2021) who established immersion-based tests for aquatic feed stability assessment.

Feeds were immersed in freshwater under static conditions at ambient temperature, and the physical condition of each sample was visually assessed at regular intervals. Each feed sample was tested in triplicate to ensure reproducibility. The degree of disintegration was used as an indicator of water resistance, a key determinant of feed quality (Lim & Cuzon, 1994; Ruscoe et al., 2005). High stability indicated longer nutrient retention in water, preventing nutrient leaching and waste accumulation (Aksoy *et al*., 2022).

Feed Consumption Test

Feed Acceptance

The second stage of the experiment focused on evaluating feed acceptance and consumption rate among eels when offered pasta feeds, resulting in high stability across each binder. High-stability feeds identified from the previous stage were used in this test.

Each feed type was placed 20 cm apart in a shared pond to allow equal accessibility while preventing competition. Feed consumption behavior was recorded using an infrared camera positioned above the tank to capture nocturnal feeding activity, as *M. albus* are primarily nocturnal feeders. Observations included the number of eels approaching, consuming, or rejecting each feed type. Each test lasted 45 minutes and was replicated 10 times.

Application Trials

Following the first-round trials, the gelatin-based binder was selected for further evaluation, as it showed the highest feed acceptance during initial observations. Subsequent formulations included combinations of gelatin-bound feed with different attractants to test synergistic effects on palatability. The used attractant were earthworm (*Lumbricuss* sp.) and snail (*Pomacea* sp.). Four formulations were prepared: (1) 100% pellet flour (control), (2) 50% worms + 50% pellet flour, (3) 50% snails + 50% pellet flour, and (4) 75% snails + 25% pellet flour. Each feeding session was conducted for 45 minutes under controlled pond conditions, and all treatments were replicated 10 times. Feed consumption was measured by recording the mass of feed consumed.

Data Analysis

Data obtained from both the feed stability and feed acceptance experiments were analyzed using non-parametric statistical methods due to the non-normal distribution commonly observed in aquaculture feeding behavior data (Rodríguez-Viera *et al*., 2014; Valverde *et al*., 2016). The Kruskal–Wallis test was first applied to detect overall differences among treatments. When significant effects were identified, the Mann–Whitney U test was employed for pairwise comparisons at a confidence level of $p < 0.05$. These non-parametric methods provided reliable means to assess treatment differences without assuming normality (Ahvenharju & Ruohonen, 2005).

Data were processed using standard statistical software, and results were presented as means ± standard deviations. Visual representations in figures were used to enhance interpretability. The combination of factorial design and non-parametric analysis strengthened the statistical validity of the findings by ensuring that observed differences were due to treatment effects rather than random variation.

RESULTS

Feed Stability Test Results

The stability assessment of pasta feeds revealed that both binder type and concentration had significant effects ($p<0.05$) on feed disintegration and breakdown times (Figure 1).

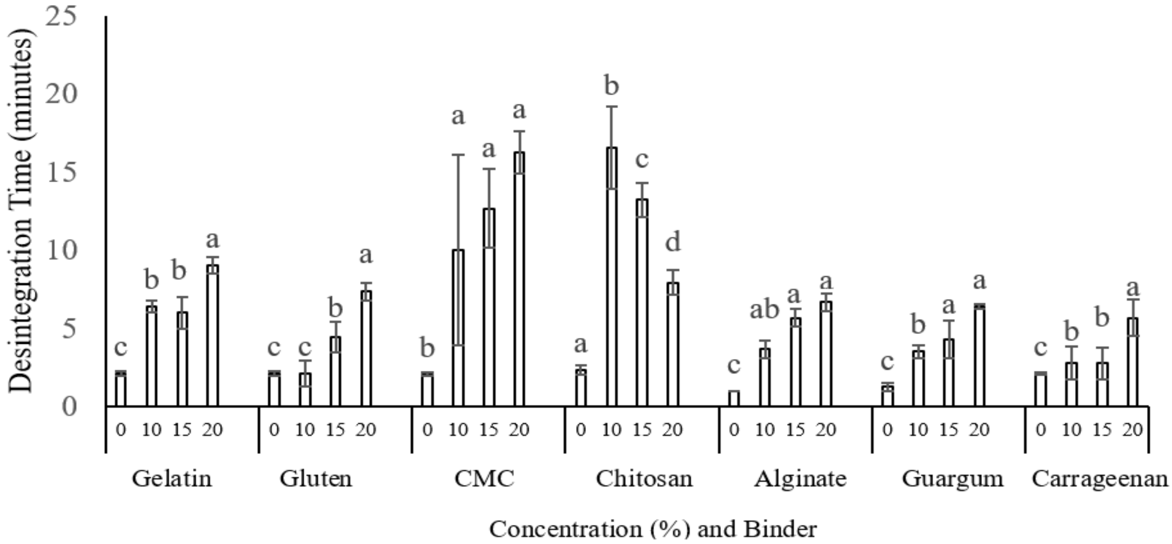

Figure 1. Disintegration Time (Minutes) of Pasta Feed at Varying Binder Types and Doses. Bars Represent Mean ± SD. Different Superscript Letters Indicate Significant Differences ($p > 0.05$).

As shown in Figure 1, disintegration time varied widely among binder types. Feeds formulated without binders (control) disintegrated within the first few minutes of immersion, indicating minimal cohesion and rapid nutrient loss. Among binder treatments, feeds containing gelatin (10%), CMC (10%), and chitosan (10%) exhibited the longest disintegration times, exceeding 20 minutes on average, while those containing alginate and gluten showed notably shorter times (<14 minutes).

The complete feed breakdown time results, shown in Figure 2, further confirmed the differences in binder performance. Gelatin, CMC, and chitosan-maintained feed integrity for more than 40 minutes, significantly longer than alginate or gluten-based feeds. Increasing binder concentrations from 10% to 20% marginally improved breakdown resistance in some treatments, but the benefit plateaued, indicating an optimal binder level of around 10–15%.

As observed in this study, gelatin and CMC both exhibited extended breakdown durations, with gelatin maintaining feed form up to 35–40 minutes and CMC sustaining structural integrity for over 45 minutes. Gluten and alginate, however, displayed shorter breakdown times (10–15 minutes), suggesting their weaker mechanical cohesion under water stress.

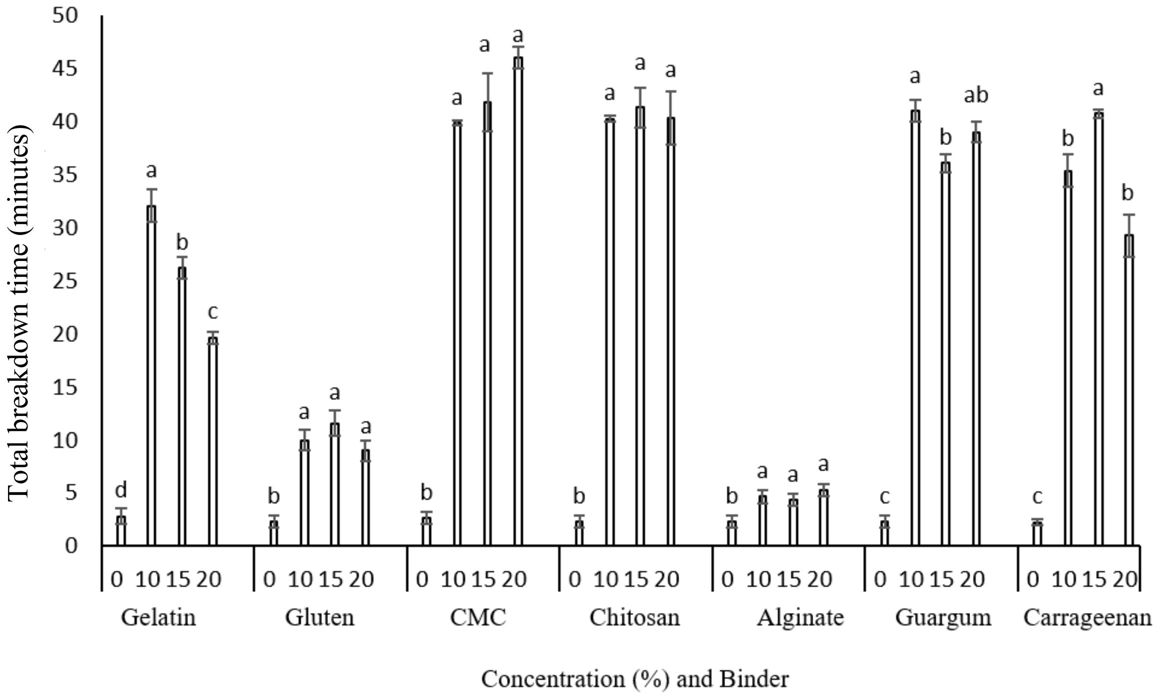

Figure 2. Total Breakdown Time (Minutes) For Pasta Feed with Varying Binders and Doses. Bars Represent Mean ± SD. Different Superscript Letters Indicate Significant Differences (p > 0.05).

Eel Feed Response

Behavioral responses of *Monopterus albus* to pasta feeds demonstrated that binder type significantly affected feed attractiveness and consumption. Figure 3 shows that gelatin-bound feeds were approached and consumed more frequently ($p < 0.05$) compared to other binder types. Gelatin formulations recorded an average of 18 feeding attempts within 45 minutes, whereas control and alginate feeds elicited fewer responses.

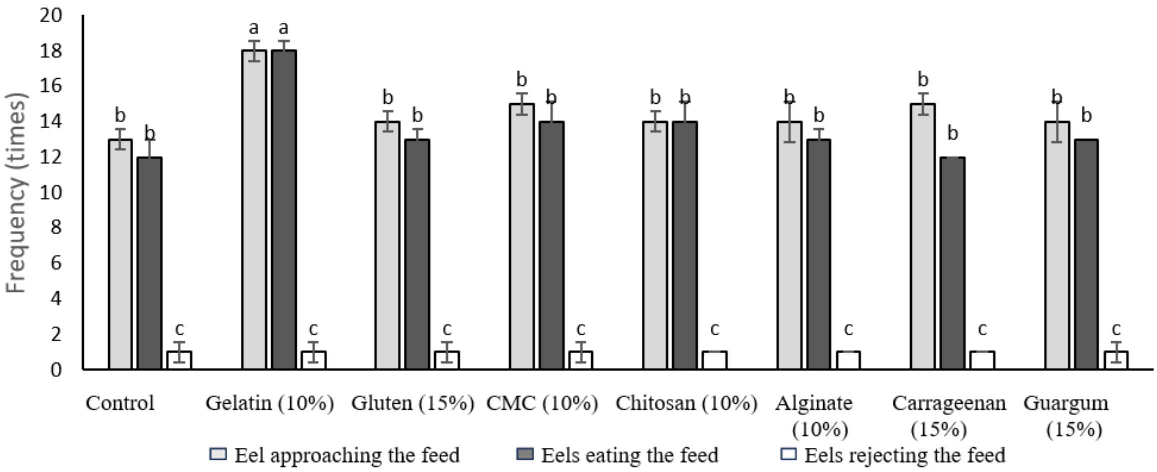

Figure 3. Eel Feeding Frequency Responses to Pasta Feeds with Different Binders. Bars Represent Mean ± SD. Different Superscripts Indicate Significant Differences ($p < 0.05$).

The second-stage trials using gelatin-based feeds combined with natural attractants—earthworms and snails—revealed substantial improvements in feed consumption. As illustrated in Figure 4, feeds containing 50% worm or snail flour exhibited significantly higher consumption levels ($p < 0.05$) compared to control feeds composed solely of pellet flour. The average consumption rates for gelatin + worm and gelatin + snail combinations reached 6–7 g per trial, while the control averaged only 3 g.

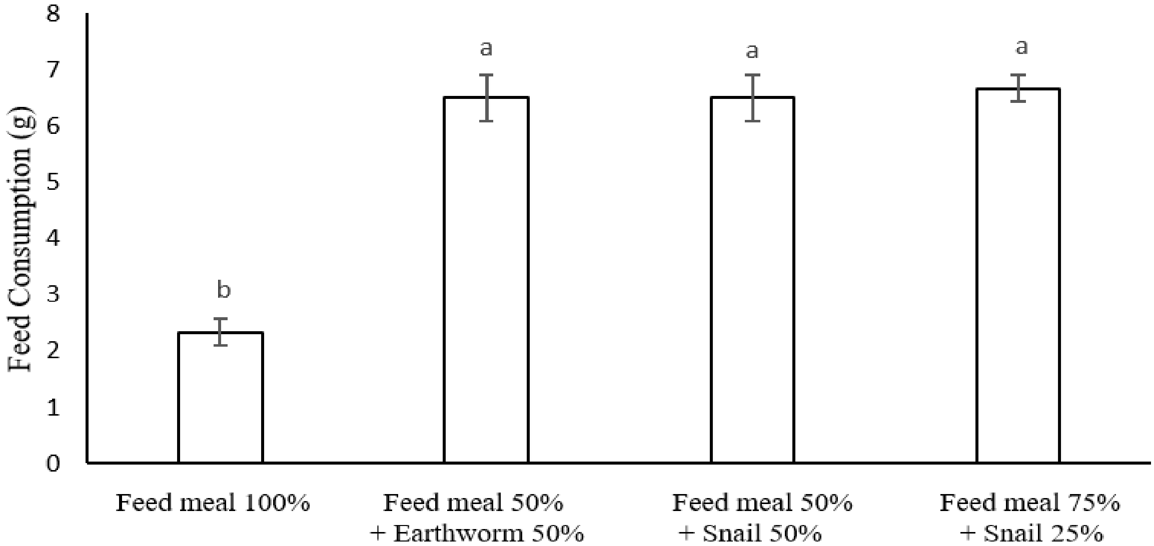

Figure 4. Average Feed Consumption (g) of *Monopterus albus* with Gelatin-Based Pasta Feed Formulations Containing Natural Attractants. Bars Represent Mean ± SD. Different Superscripts Indicate Significant Differences ($p < 0.05$).

DISCUSSION

The findings of this study confirmed that binder type and concentration significantly influenced the physical stability of pasta feed for *Monopterus albus*. This outcome supports previous research indicating that feed stability is largely governed by the binder's molecular structure and concentration, both of which determine the feed's resistance to disintegration and water penetration (Ruscoe *et al*., 2005). The present results demonstrated that moderate binder levels, particularly 10% gelatin, 10% CMC, and 10% chitosan, yielded optimal disintegration and breakdown times exceeding 40 minutes, whereas alginate and gluten-based feeds showed markedly weaker durability (<14 minutes). This pattern aligns with the principle that increasing binder concentration enhances cohesion up to a certain threshold, after which excessive water absorption compromises structural integrity (Ungureanu *et al*., 2016).

The physical performance of these binders reflects the distinct mechanisms by which protein- and polysaccharide-based compounds interact with feed components. Gelatin, as a protein-based binder, forms strong hydrophobic and hydrogen bonds, resulting in superior elasticity and cohesion. Conversely, polysaccharides such as CMC and alginate contribute to gel formation and viscosity, improving water stability but potentially reducing digestibility if applied excessively (Liu *et al*., 2022). The superior performance of gelatin observed in this study corroborates findings from Lim & Cuzon (1994), who reported that binders capable of forming elastic gels prolong nutrient retention and delay particle dispersion. The data also support the assertion that binder efficiency is influenced by mechanical and physicochemical interactions between feed particles, as identified by Rosas *et al*. (2008). Thus, while both protein and carbohydrate binders improved feed stability, protein-based gelatin demonstrated superior performance due to its dual structural and nutritional functions.

The extended breakdown times observed in gelatin- and CMC-based feeds also reflect an optimal balance between cohesion and flexibility. A disintegration time exceeding 20 minutes and a breakdown time above 40 minutes are within the ideal stability thresholds for freshwater aquaculture feeds, ensuring nutrient retention and minimal water contamination (Yusoff *et al*., 2021). However, beyond 15% concentration, binder efficacy plateaued, suggesting that further increases in binder dosage contribute more to water retention than to mechanical strength. This nonlinear effect was similarly reported by Ruscoe *et al*. (2005), who found that binder oversaturation leads to weakened particle bonding and reduced durability. Overall, the current findings reinforce that binder optimization is critical for developing durable, eco-efficient feed systems that maintain integrity without compromising palatability.

The mechanisms underlying binder function in aquatic feeds involve both adhesive and cohesive interactions that integrate feed particles into a stable matrix. Gelatin and CMC demonstrated the strongest adhesive capacity, contributing to longer immersion times and lower nutrient leaching rates. This is consistent with Lim & Cuzon (1994), who explained that molecular interactions between binder polymers and feed ingredients reduce nutrient leaching during immersion. In the current study, feeds formulated with gelatin displayed superior gel network formation, which limited particle separation and maintained shape integrity during mechanical agitation. CMC, although effective in binding, formed more viscous matrices that could inhibit enzymatic accessibility, thereby impacting digestibility (Liu *et al*., 2022).

The effectiveness of gelatin as a binder can be attributed to its ability to form thermo-reversible gels that retain structural elasticity while enhancing nutrient encapsulation. Similar effects have been observed in other aquaculture species, where gelatin inclusion led to improved intestinal microvilli structure and nutrient absorption (Gao *et al*., 2020). Furthermore, the enhanced cohesion observed with gelatin supports the conclusion that protein-derived binders outperform purely polysaccharide-based binders in terms of feed stability and nutrient delivery. Aksoy *et al*. (2022) also reported that durable feeds minimize environmental waste by reducing organic deposition, thereby improving water quality and promoting sustainable culture systems. Therefore, the integration of gelatin not only improves feed performance but also supports ecological management goals in aquaculture.

The behavioral response of *M. albus* to various binder treatments revealed that gelatin-based feeds elicited the highest feeding frequency and consumption rates. These results correspond with the sensory and biochemical attributes of gelatin, which improve texture, flavor release, and nutrient availability—factors known to stimulate olfactory and gustatory responses in eels (Shi *et al*., 2020). Unlike other binders, gelatin's amino acid composition closely resembles the natural proteins found in prey organisms, which enhances its attractiveness to carnivorous species. The elevated feeding frequency observed for gelatin-bound feeds illustrates the influence of protein-derived binders on palatability and feeding motivation.

In contrast, CMC, guargum, and carrageenan treatments produced moderate feeding responses, suggesting acceptable but less stimulating sensory characteristics. The high viscosity associated with CMC may have contributed to reduced palatability, as excessive viscosity can impede enzyme secretion and digestion, as previously noted by Liu *et al*. (2022). The preference for gelatin is also consistent with findings by Rosas *et al*. (2008), who reported that protein-based binders enhance feed acceptability and digestion efficiency in carnivorous fish species. Moreover, the integration of gelatin in the feed matrix likely enhanced the release of amino acid-based attractants upon hydration, further explaining its higher acceptance rate.

The strong correlation between feed stability and feed acceptance observed in this study indicates that eels preferentially consume feeds that maintain their form in water for longer durations. This suggests that physical integrity indirectly influences feeding motivation by ensuring consistent sensory cues during feeding events. Such observations are supported by Lim & Cuzon (1994), who linked feed durability with nutrient retention and prolonged attractiveness to aquatic species. The behavioral evidence from this study confirms that binder functionality extends beyond physical cohesion to encompass sensory and biochemical impacts on feeding behavior.

The application of gelatin-based feeds combined with natural attractants—specifically earthworms and snails—resulted in significant increases in feed consumption. This finding aligns with previous studies indicating that animal-derived attractants enhance feed intake through olfactory stimulation and nutrient enrichment (Shi *et al*., 2020; Wang *et al*., 2020). Worms and snails contain bioactive compounds and essential amino acids that act as feeding stimulants, encouraging more frequent feeding and longer feeding durations. Hu *et al*. (2021) also demonstrated that the incorporation of natural attractants triggers innate predatory behavior in *M. albus*, improving feeding efficiency and growth performance.

The synergistic effect of combining gelatin with natural attractants underscores the importance of binder–protein interactions in enhancing both physical and sensory feed properties. Gelatin not only stabilized the feed matrix but also improved nutrient retention, ensuring that the attractants' volatile compounds were gradually released during immersion. Such controlled release likely amplified the sensory cues available to the eels, maintaining feed attractiveness throughout the feeding trial. Rosas *et al*. (2008) highlighted similar synergistic effects, where gelatin-based formulations improved nutrient assimilation by enhancing matrix stability and minimizing leaching. Additionally, animal-based attractants provide functional proteins and lipids that complement gelatin's structural properties, contributing to more efficient feed utilization and energy absorption (Diamahesa & Azhar, 2025).

These results also reveal broader implications for aquaculture sustainability. The inclusion of locally available natural attractants such as worms and snails reduces dependence on industrial fishmeal, which is both costly and environmentally taxing. Xiang *et al*. (2019) and Yue *et al*. (2025) emphasized that combining animal-derived proteins with suitable binders enhances feed digestibility, promoting sustainable intensification in aquaculture production. The success of the gelatin–attractant combination in this study thus demonstrates a feasible strategy for reducing feed waste and improving growth outcomes while maintaining ecological balance.

CONCLUSION

This study demonstrated that binder type and concentration critically influence the physical stability and feeding acceptability of pasta feed for *Monopterus albus*. Among the seven binders evaluated, gelatin at a 10% concentration provided the most balanced performance, offering superior water stability, nutrient retention, and palatability. CMC and chitosan also exhibited high stability but lower feeding responses. Conversely, alginate and gluten-based feeds were less effective in maintaining cohesion and durability. The synergistic combination of gelatin with natural attractants, such as worms and snails, further enhanced feed intake, reflecting improved olfactory stimulation and feeding motivation. These findings establish gelatin as a functional dual-purpose ingredient that strengthens feed integrity while enhancing consumption efficiency. The study contributes to aquaculture nutrition by providing empirical data on binder optimization, addressing sustainability concerns through reduced nutrient leaching and environmental waste. Future research should investigate long-term growth performance, gut health, and cost efficiency using gelatin-based formulations under commercial aquaculture conditions.

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