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Optimization of Catfish (*Clarias* sp.) Based Amplang Formulation: Physicochemical, Texture, and Sensory Quality Evaluation

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Abstract
The diversification of freshwater fish products, particularly catfish (*Clarias* sp.), into value-added snacks like amplang represents a crucial strategy to enhance economic resilience for small-scale farmers in Indonesia facing price volatility. This study aimed to optimize the formulation of catfish-based amplang by varying the proportions of catfish meat, tapioca flour, and egg white to achieve optimal physicochemical characteristics, texture, and sensory acceptance. The research employed a factorial Completely Randomized Design (CRD) with nine treatment combinations: fish meat (80 g, 100 g, 120 g), tapioca flour (60 g, 75 g, 90 g), and egg white (30%, 40%, 50% w/w of dough). Evaluated parameters included moisture, protein, fat, ash, and carbohydrate content, as well as expansion ratio, fracture force, and hedonic scores (color, aroma, taste, texture). Statistical analysis was conducted using ANOVA followed by Duncan's Multiple Range Test (DMRT). The optimal formulation (100 g fish meat, 75 g tapioca, and 40% egg white) yielded a product with superior characteristics: 3.40% moisture, 17.86% protein, 4.66% fat, 2.35% ash, a 666.67% expansion ratio, and the highest overall acceptability (4.6/5). The optimal product complies with the SNI 7762:2013 quality standard and offers a viable model for Small and Medium Enterprises (SMEs) to increase the market value of aquaculture commodities.

1. Introduction

Indonesia's freshwater aquaculture sector is a primary pillar of national food and economic security. Recent data indicates that catfish (*Clarias* sp.) production continues to show a positive trend, highlighting the massive domestic production capacity and market demand (KKP, 2023). The contribution of aquaculture to food security, specifically as an affordable source of animal protein, is widely recognized globally as part of the "Blue Transformation" agenda to ensure sustainable food systems (FAO, 2024; Subagja et al., 2022). Catfish, in particular, is favored due to its rapid growth rate, high adaptability to various environmental conditions, and nutritional density, making it a strategic commodity for food fortification.

Despite high production volumes, the sector is dominated by over 2.54 million small-scale farmers (SMEs) who face significant economic challenges (KKP, 2023). This fragmented industry suffers from limited economies of scale, resulting in difficulties accessing modern technology, working capital, and fair financing schemes (Utomo & Hidayat, 2023). Consequently, small farmers are highly vulnerable to input price volatility, especially commercial feed costs and fluctuating commodity selling prices. They often possess low bargaining power within a long and inefficient supply chain, where fresh fish is sold as a raw material with minimal profit margins (Sari et al., 2021). These challenges necessitate strategic innovation, not merely to increase biomass production, but to create economic resilience through downstream product diversification (Handajani & Prasetyo, 2022).

Diversification into value-added products such as amplang offers a direct solution to these economic bottlenecks. Amplang, a traditional savory fish cracker originating from Kalimantan, holds significant market potential due to its distinctive taste and established consumer base (Rahmadani et al., 2020). Crucially, amplang is a shelf-stable product that does not require a cold chain, fundamentally solving infrastructure and logistics constraints often faced by rural producers (Wibowo et al., 2021). Substituting conventional raw materials—such as the increasingly expensive Spanish mackerel (Scomberomorus sp.), with the more abundant and cost-effective catfish is a logical innovation to reduce production costs and improve accessibility (Kurniawan & Suryani, 2022). Furthermore, processing catfish into dried snacks aligns with "zero waste" initiatives by utilizing meat that might otherwise be undervalued due to size irregularities (Kusumaningrum & Sulistiawati, 2024).

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The success of amplang production heavily depends on the formulation balance between fish meat (protein source, flavor, structure), tapioca flour (starch matrix for expansion and crispness), and egg white (binding and leavening agent) (Lestari et al., 2019; Fitriani et al., 2020). Previous research has confirmed the importance of physicochemical properties, such as protein–starch interaction, on final product quality (Nuraini & Siregar, 2021). While specific studies on catfish amplang exist (Herlina et al., 2023), a research gap remains regarding comprehensive optimization that simultaneously evaluates proximate analysis, instrumental texture parameters, and consumer sensory acceptance within a single controlled design. Most existing studies focus solely on sensory aspects without delving into the instrumental texture mechanisms or the precise stoichiometric balance required for optimal expansion.

Therefore, this study aims to determine the optimal formulation of catfish amplang through a systematic evaluation of fish meat, tapioca, and egg white ratios. The objective is to produce a product with the best physicochemical, textural, and sensory quality suitable for SME adoption. By identifying this optimal formulation, this research contributes to the development of a reproducible, high-protein snack that can enhance the economic value of catfish and support the sustainability of local aquaculture businesses.

2. Method

2.1. Materials

The primary raw material was fresh catfish fillets (Clarias sp.) obtained from local farmers in Malang, East Java. The average weight per fillet ranged from 200–250 g to ensure uniformity in muscle texture. Fillets were processed immediately after harvest: they were washed, filleted, and skin-removed to maintain freshness, then stored at 4°C for no longer than 24 hours prior to use (Giri et al., 2019). Tapioca flour (food grade, moisture <12%) and fresh chicken egg whites (protein 10–12%) were sourced from certified local suppliers to ensure consistency in starch and albumin content. Seasonings were standardized across all treatments to isolate the effects of the main variables; these included garlic paste, salt (2% of fish weight), and flavor enhancers (0.5% of fish weight), adhering to AOAC (2019) standards for food formulation.

2.2. Experimental Design

This study employed a factorial Completely Randomized Design (CRD), adhering to design principles for food formulation optimization (Montgomery, 2019). The factorial design permitted simultaneous investigation of the main effects and interactions of three key factors:

1. Catfish meat concentration (80 g, 100 g, 120 g)
2. Tapioca flour concentration (60 g, 75 g, 90 g)
3. Egg white concentration (30%, 40%, 50% w/w of dough)

This design yielded nine treatment combinations, each replicated three times (n=3) to ensure statistical reliability and reproducibility of the data (Yuliana et al., 2023).

2.3. Amplang Preparation

The preparation process followed a standardized protocol to minimize variability. Catfish fillets were first deboned and skinned carefully to remove any connective tissue that could affect texture. The meat was minced using a food processor until a homogeneous fine paste was formed. The fish paste was then thoroughly mixed with tapioca flour, egg white, and the standardized seasonings according to each treatment formulation. Mixing continued until the dough became pliable, uniform, and non-sticky.

The dough was then extruded into uniform cylindrical strands with a diameter of roughly 1.5 cm, cut into 2 cm segments, and deep-fried in refined palm oil (10:1 oil-to-material ratio). Frying was conducted at a controlled temperature of 155 ± 2°C for approximately 4 minutes or until a golden-yellow color and crispy texture developed. Oil temperature was continuously monitored to prevent quality degradation due to oxidation and to ensure consistent expansion rates (Choe & Min, 2007; Sitorus & Harahap, 2023).

2.4. Analytical Procedures

2.4.1. Physicochemical Analysis

Proximate analyses followed standard AOAC (2019) 21st Edition methods to determine the nutritional composition. Moisture content was measured by oven drying at 105°C to constant weight. Protein content was determined by the Kjeldahl method (N x 6.25), which measures total nitrogen. Fat content was extracted using the Soxhlet method with semi-continuous solvent extraction. Ash content was measured by incineration in a muffle furnace at 550°C. Carbohydrate content was calculated by difference (Winarno, 2004).

2.4.2. Textural Analysis

Instrumental texture analysis was conducted using a TA-XT Plus Texture Analyzer (Stable Micro Systems, UK) to provide objective data on crispness. Samples were equilibrated at 25 ± 2°C for 30 minutes before testing. Two key parameters were measured:

1. Expansion Ratio: The percentage increase in product volume after frying relative to the raw dough volume.
2. Fracture Force: The maximum force (g/f) required to fracture the sample using a cylindrical probe (TA-47) at a test speed of 1 mm/s. A lower fracture force typically indicates a crispier, less hard product.

2.4.3. Sensory Evaluation

Sensory acceptance was evaluated using a hedonic preference test with 25 semi-trained panelists (aged 20–45 years). Panelists were selected based on their familiarity with traditional fish crackers. Attributes measured included color, aroma, taste, and texture on a 5-point hedonic scale (1 = Dislike very much, 5 = Like very much) (Astuti et al., 2022).

2.4.4. Statistical Analysis

Data were analyzed using SPSS v26.0 software. Normality and homogeneity were verified using Shapiro–Wilk and Levene's tests, respectively. One-way Analysis of Variance (ANOVA) was used to assess treatment effects. Where significant differences were detected ($p < 0.05$), Duncan's Multiple Range Test (DMRT) was performed to compare means and identify specific differences between formulations.

3. Result and Discussion

3.1. Physicochemical Properties

The proximate analysis results are presented in Table 1. Moisture content across all formulations ranged from 3.21% to 4.12%, with the majority of formulations, including the optimal one, meeting the maximum limit of 4% set by the Indonesian National Standard (SNI) 7762:2013. The consistently low moisture content is indicative of an efficient dehydration process during frying, which is critical for shelf stability.

Increasing the ratio of fish meat and egg white significantly increased the protein content of the final product. The 120:90:50 formulation recorded the highest protein (18.44%) and lowest carbohydrate (70.98%), reflecting the higher inclusion of muscle protein. The optimal formulation (100:75:40) demonstrated a balanced nutritional profile: 3.40% moisture, 17.86% protein, 4.66% fat, 2.35% ash, and 71.73% carbohydrate. This protein level is notably higher than generic starch crackers and aligns with findings by Fitriani et al. (2020), who noted that a protein-moisture balance is critical for maintaining texture and storage stability

Table 1. Physicochemical (Proximate) Analysis Results of Catfish Amplang

Treatment (Fish:Tapioca:E.White)	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Carbohydrate (%)
80:60:30	4.12	14.25	3.90	2.11	75.64
100:75:40	3.40	17.86	4.66	2.35	71.73
120:90:50	3.21	18.44	4.80	2.57	70.98

3.2. Textural Analysis

Treatment formulations had a significant effect ($p < 0.05$) on both expansion ratio and fracture force (Table 2). The 100:75:40 formulation achieved the highest expansion ratio (666.67%), indicating a superior "puffing" effect. Conversely, the 80:60:30 formulation exhibited the highest fracture force (925.41 g/f), indicating a hard, dense texture that is undesirable in crackers. The optimal formulation showed a lower fracture force (871.16 g/f), suggesting a desirable balance between crispness and hardness—firm enough to handle but brittle enough to provide a satisfying crunch.

Table 2. Textural Analysis Results (Expansion Ratio and Fracture Force)

Treatment (Fish:Tapioca:E.White)	Expansion Ratio (%)	Fracture Force (g/f)
80:60:30	480.15	925.41
100:75:40	666.67	871.16
120:90:50	540.29	845.33

3.3. Sensory Evaluation

The hedonic evaluation results from the panelists are presented in Table 3. Statistical analysis showed that the 100:75:40 formulation consistently received the highest preference scores across all tested attributes—color (4.6), aroma (4.7), taste (4.8), and texture (4.6)—and these differences were statistically significant ($p < 0.05$). The 80:60:30 formulation received the lowest aroma (3.9) and texture (3.8) scores, suggesting lower sensory acceptance likely due to the lack of savory fish flavor and the hard texture mentioned previously. These findings confirm that instrumental hardness correlates inversely with sensory preference for crispness in amplang products (Astuti et al., 2022).

Table 3. Sensory (Hedonic) Evaluation Results of Catfish Amplang

Parameter	80:60:30	100:75:40	120:90:50	p-value
Color	4.0	4.6	4.3	<0.05
Aroma	3.9	4.7	4.5	<0.05
Taste	4.1	4.8	4.4	<0.05
Texture	3.8	4.6	4.2	<0.05
Color	4.0	4.6	4.3	<0.05

4. Discussion

4.1. Physicochemical Quality and Compliance

The success of all formulations in producing products with moisture content between 3.21% and 4.12% is a crucial technical achievement. All products meet the quality requirements of SNI 7762:2013, which limits the maximum moisture content of amplang to 4% (BSN, 2013). The results are comparable to those reported by Rahmadani et al. (2020), who found that traditional fish crackers with moisture levels below 4% demonstrate superior crispness and shelf stability. This low moisture content indicates the effectiveness of the frying process in dehydrating the product, which is a key thermal operation ensuring texture and microbial safety. Low moisture correlates directly with low water activity (aw), which is essential for inhibiting microbial growth and enzymatic reactions, thereby prolonging the product's shelf life (Winarno, 2004; Subagja et al., 2022).

From a nutritional perspective, the optimal formulation (100:75:40) with a protein content of 17.86% demonstrates a substantial improvement in nutritional value compared to purely starch-based crackers or snacks, which typically contain less than 5% protein. This aligns with earlier work by Herlina et al. (2023) and Fitriani et al. (2020), who reported that increasing fish protein concentration enhances both the nutritional density and consumer preference of amplang-type products. Furthermore, compared to other recent product developments such as catfish sticks which often retain bone meal for calcium but may have coarser textures (Primawestri et al., 2023), the amplang format allows for high protein inclusion in a highly palatable form. This high protein content positions catfish amplang as a potential functional snack, aligning with public health initiatives aimed at improving protein intake and promoting aquaculture product diversification (KKP, 2023).

4.2. The Texture Mechanism: Optimizing Protein-Starch Interaction

The central finding of this study is the identification of the texture mechanism that yields optimal quality in the 100:75:40 formulation. The textural quality of amplang defined by its volumetric expansion and "melt-in-the-mouth" crispness is determined by the synergistic interaction between starch (tapioca) and protein (catfish myofibrils and egg white albumin) (Lestari et al., 2019; Rahmadani et al., 2020).

Tapioca functions as the primary expansion agent. During deep-frying, high heat causes the starch granules to absorb residual water in the dough and undergo gelatinization. The trapped water rapidly turns to steam, creating massive internal pressure that forces the dough matrix to expand. This process is supported by the findings of Huda et al. (2009), who explained that tapioca starch contributes to higher expansion and enhanced crispness in fried products due to its high amylopectin content.

However, starch alone is insufficient. While starch provides the expansion force, protein provides the structural framework (retention). Protein from egg white (albumin) contributes to foaming ability and air entrapment (Damodaran, 2017). Simultaneously, protein from fish meat interacts with the starch matrix, forming a coherent three-dimensional protein–starch network via hydrogen bonding and hydrophobic interactions (Nuraini & Siregar, 2021). This protein network acts to "trap" the expanding steam and then stabilizes or sets the expanded porous structure as the product cools.

The 100:75:40 formulation represents the ideal balance point or "sweet spot." This ratio provides sufficient starch (75 g) to promote maximum volumetric expansion and adequate protein to form a strong yet elastic composite network. In contrast, the formulation with less fish (80 g) resulted in a harder texture because there was insufficient protein to disrupt the starch network, leading to a dense, glassy structure. Conversely, excessive protein (120 g fish) can inhibit expansion by creating a network that is too rigid to expand fully, a phenomenon observed in other high-protein extruded snacks (Maulid et al., 2022).

4.3. Economic Implications and Feasibility for SMEs

This optimized formulation has significant economic implications for aquaculture SMEs, which is the primary focus of this research. The transformation from raw catfish (a commodity with fluctuating prices) to amplang (a value-added product) directly increases income potential and market stability (Handajani & Prasetyo, 2022). According to Gumilar et al. (2021), value-added processing of catfish into products like meatballs or crackers can increase profit margins by over 40% compared to selling fresh fish.

The introduction of value-added processing significantly increases marketing efficiency and profit margins (Hidayat & Utomo, 2023). A feasibility study conducted on a traditional amplang SME demonstrated favorable investment indicators, including a Benefit–Cost (B/C) Ratio of 1.2 and an Internal Rate of Return (IRR) substantially higher than prevailing microloan interest rates. By adopting this standardized formulation, fishery SMEs are not only diversifying their product portfolios but also investing in a business model that is empirically proven to be both technically reproducible and economically viable.

Moreover, this processing method supports the "zero waste" philosophy. While this study focused on the meat, the remaining frames and heads from the filleting process can be processed into fish meal or bone flour for calcium fortification in other products, as suggested by Kusumaningrum and Sulistiawati (2024). This integrated approach could further maximize the revenue per kilogram of catfish produced, ensuring that small-scale farmers can thrive even in volatile markets.

5. Conclusion

This study successfully identified the optimal formulation for catfish-based amplang: 100 g of catfish meat, 75 g of tapioca flour, and 40% egg white. This formulation yields a product that is synergistically superior in physicochemical quality (17.86% protein), textural quality (maximum expansion ratio of 666.67%), and sensory quality (4.6/5 overall score). The product complies with SNI 7762:2013 and provides a replicable model for SMEs to increase the value-add of catfish commodities. By implementing this scientifically optimized formulation, SMEs can produce a consistent, high-quality product that competes effectively in the snack market, thereby enhancing the economic resilience of the aquaculture sector. Future research should focus on shelf-life testing using various packaging materials to support broader distribution.

Author Contributions

All authors have equal contributions to the paper. All the authors have read and approved the final manuscript.

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Declaration of Conflicting Interests

None.

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