

Research Article

Application of chia seeds (*Salvia hispanica* L.) as hydrocolloid in batter coatings: Effects on the physicochemical and sensory properties of breaded fish fillets

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Abstract - Chia seed (*Salvia hispanica* L.) has potential as a functional ingredient to enhance the quality of food products when incorporated into batter coatings, though its concentration can affect final product characteristics. This study investigated the effects of different chia seed levels (0%, 3%, 6%, and 9%) on the quality of deep-fat-fried tilapia fillets coated with batter. Key parameters, including coating adhesion, batter viscosity, cooking yield, frying loss, moisture and fat content, color, texture profile, and sensory attributes, were evaluated. Adding chia seeds tended to increase batter viscosity, coating adhesion, and cooking yield, and to reduce frying loss, though not all changes were statistically significant; fillet crispness improved at some levels. Fillets with 9% chia seed tended to have higher oil uptake and slightly lower lightness (L*) compared to other treatments, though these differences were not statistically significant. Sensory evaluation showed that, overall, panelists favored fillets containing chia seeds over the control. Based on improvements in batter viscosity, coating adhesion, cooking yield, and fillet crispness without a tendency for higher oil uptake, 6% chia seed was selected as the optimal inclusion level without compromising sensory acceptability.

Keywords: Batter, breaded products, chia seed, fish fillet, hydrocolloids

1. Introduction

Battering and breading are widely recognized processing techniques used to increase the marketability and sensory appeal of value-added food products. Coated items represent a significant segment of the convenience and ready-to-eat food industry (Das & Nagalakshmi, 2014; Rozzamri et al., 2020). Typically, food materials are dipped in a liquid batter, covered with breadcrumbs, and subsequently subjected to deep-fat frying. This sequence enhances organoleptic characteristics and contributes to strong consumer preference (Mah & Brannan, 2009; Zeng et al., 2016). Among coated products, fried items are widely appreciated for their crispy outer crust, juicy interior, and characteristic fried flavor (Park & Kim, 2022). These attributes are similarly desirable in coated seafood products such as fish nuggets. Their appealing texture and widespread availability have supported increasing global demand (Chen et al., 2020; Ye et al., 2022).

In addition to improving taste and texture, coating systems influence structural integrity, surface color, flavor retention, and storage stability in both fried and oven-processed products (Tamsen et al., 2018). Such applications extend to various products including fish fillets, nuggets, strips, and poultry-based items (Bhuiyan & Ngadi, 2024; Salehi-Koopae et al., 2024). Given the high consumption of battered and breaded foods, ongoing optimization of ingredient composition and formulation design remains essential to stimulate product development and enhance nutritional value. In standard preparation, substrates such as fish, shrimp, meat, or vegetables are immersed in a batter mixture composed primarily of starches, proteins, and functional additives, followed by

breeding and frying (Archana et al., 2016; Chen et al., 2020). The formulation of the batter is a critical determinant of the final physicochemical and sensory properties of the coated product.

Conventional batters used in fried foods are often associated with high levels of oil uptake and moisture loss during frying, which can reduce product quality and compromise nutritional value (Bhuiyan & Ngadi, 2024). These shortcomings have been linked to porous coating structures and limited barrier effectiveness in traditional formulations (Varela & Fiszman, 2011). Research on batter modification has shown that incorporating polysaccharide-based hydrocolloids can alter rheological properties, strengthen the coating matrix, and reduce the extent of oil penetration by limiting pathways for oil to enter the food surface (Li et al., 2025). Chia seed mucilage, in particular, contains long-chain polysaccharides that impart high water-holding capacity and increased viscosity, and these characteristics have been explored for improving texture and stability in food systems (Brütsch et al., 2019; Garcia e Silva et al., 2022). Although most studies on chia mucilage focus on its gel and emulsion behavior, the functional properties of this ingredient indicate potential benefits for improving batter performance, such as enhanced coating adhesion and better control of moisture and fat exchange during frying.

The incorporation of hydrocolloids and film-forming agents into batter systems has gained increasing attention in recent years (Bhuiyan & Ngadi, 2024). Hydrocolloids are high-molecular-weight biopolymers capable of holding water and modifying viscosity, gelation, and stabilization, which can help improve the texture and consistency of food products (Pirsa & Hafezi, 2023). Most are naturally

derived polysaccharides or proteins with hydrophilic functional groups, allowing their use as edible coatings or stabilizers in various formulations (Jiang et al., 2021). In fried foods, hydrocolloids have been applied to limit oil absorption during cooking while maintaining moisture and uniform ingredient dispersion (Al-Asmar et al., 2018; Abdul-Zubir et al., 2022). Examples such as xanthan gum, sodium carboxymethyl cellulose, and chitosan have demonstrated the potential to enhance coating performance and overall quality in fried fish products (Solinho et al., 2025; Cui et al., 2023; Jiang et al., 2021). Chia seed (*Salvia hispanica* L.), a member of the Lamiaceae family, is commonly consumed in beverages and fresh preparations. Beyond its nutritional value, chia seed provides functional properties such as water absorption, emulsification, and gel formation (Pintado et al., 2016). When hydrated, the seed releases a mucilaginous polysaccharide layer that exhibits hydrocolloid-like behavior, increasing viscosity and acting as a stabilizer and binder in solutions (Campos et al., 2016; Salgado-Cruz et al., 2013). The hydrocolloid-like properties of chia mucilage make it particularly suitable for incorporation into batter formulations, where it can enhance viscosity, improve coating adhesion, retain moisture during frying, and support structural stability, ultimately contributing to better quality of fried fish products (Capitani et al., 2016). Despite extensive evaluation of commercial hydrocolloids in batter formulations, research specifically addressing the use of chia seed within batter-coated fish systems remains limited. The level of chia incorporation may substantially influence batter rheology, coating adhesion, and the quality of the fried end product. Accordingly, this study examined the effects of incorporating graded levels of

chia seeds (0%, 3%, 6%, and 9%) into batter formulations for tilapia fillets, aiming to identify the optimal inclusion level of chia seed to enhance coating performance and overall product quality.

2. Materials and methods

2.1 Preparation of the tilapia fish fillets

Tilapia (*Oreochromis niloticus*) weighing 350–400 g were obtained from the local wholesale market (Pasar Borong Seri Kembangan, Selangor, Malaysia). The fish were cleaned, gutted, skinned, headed, and manually filleted. Each fillet was then cut into pieces measuring approximately 3–4 cm². The fillet pieces were rinsed under running tap water, allowed to drain for 10 minutes, and subsequently frozen at –18 °C until further use prior to the battering process.

2.2 Coating process

Chia seeds, corn flour, wheat flour, salt, black pepper, Japanese breadcrumbs, and palm oil were obtained from a local supermarket in Serdang, Selangor, Malaysia. The chia seeds were ground into a fine powder using a blender (Panasonic MX-801S, Japan). Frozen fillets were thawed overnight at 4 °C, and the surface moisture was removed using paper towels. The fillets were then lightly pre-dusted with wheat flour to improve batter adhesion.

The batter formulations were adapted from Moradi et al. (2010), with minor modifications. The dry mixture consisted of wheat flour, corn flour, salt, and black pepper, to which chia seed powder was added at 3%, 6%, or 9% (Table 1), while a formulation without chia seed served as the control. Dry ingredients and water were combined at a ratio of 1:1.4 (w/w). Each fillet was dipped into its respective batter and held above the batter container for approximately 30 seconds to allow

excess coating to drain off. The battered fillets were then coated with Japanese breadcrumbs and deep-fried in palm oil using a 3.5 L deep fryer (FDF 1038, Faber) at 180 °C for 3 minutes. After frying, the

fillets were removed from the oil, drained on paper towels to remove excess surface oil, and allowed to cool to room temperature before subsequent analyses.

Table 1. Formulation of batter with different percentages of chia seeds for coating of tilapia fish fillet.

Batter	Wheat flour (%)	Corn flour (%)	Chia seed (%)	Salt (%)	Pepper (%)
Control	82	15	-	2	1
3%	79	15	3	2	1
6%	76	15	6	2	1
9%	73	15	9	2	1

Note: *The dry ingredients were later mixed with water at the ratio of 1:1.4 dry ingredients to the water.

2.3 Moisture content

The moisture content of fried breaded tilapia fillets was determined using the oven-drying method as described by [AOAC \(2005\)](#). Samples weighing 3–5 g

were dried at 105 ± 1 °C until constant weight was obtained. All measurements were performed in triplicate. Moisture content was calculated using the following formula:

$$\frac{\text{original sample weight} - \text{dried sample weight}}{\text{original sample weight}} \times 100\%$$

2.4 Fat content

The fat content of fried breaded tilapia fillets was determined using the Soxhlet extraction method according to [AOAC \(2005\)](#). A 5 g sample was placed in a thimble and inserted into the Soxhlet apparatus. A pre-weighed round-bottom flask was filled with 200 mL of petroleum

ether and connected to the apparatus. The extraction was performed continuously under reflux for approximately 8 hours. After completion, the petroleum ether was removed from the flask using a rotary evaporator, and the fat content was calculated using the following formula:

$$\frac{(\text{weight of flask} + \text{oil}) - (\text{weight of flask})}{\text{weight of sample used}} \times 100\%$$

2.5 Viscosity of batter

The viscosity of batters containing varying concentrations of chia seeds was evaluated using a rheometer (RheolabQC, Anton Paar, USA), with shear rates

ranging from 0.1 to 100 s⁻¹ at 25 °C. Measurements were conducted in triplicate for each sample ([Chen et al., 2009](#)).

2.6 Coating material performance

Yield parameters were assessed by measuring the weight of the raw fish fillet (x), the weight of the fillet after coating but before frying (y), and the weight of

the fillet after frying (z) ([Abdul-Zubir et al., 2022](#)). The corresponding parameters were calculated using the following formulas:

Coating adhesion

$$\text{Adhesion degree} = \frac{y - x}{y} \times 100\%$$

Cooking yield

$$\text{Cooking yield} = \frac{z}{x} \times 100\%$$

Frying loss

$$\text{Frying loss} = \frac{y - z}{y} \times 100\%$$

2.7 Color analysis

The color of the samples was evaluated using a Minolta Chroma Meter (CR-300, Minolta, Japan) and expressed in the CIE L*A*B* color space. In this system, L* denotes lightness (white to dark), a* represents the red–green axis, and b* corresponds to the yellow–blue axis. For each treatment, fried breaded tilapia fillets were analyzed, with color measurements taken at three different points on both sides of each fillet, following the method of [Moradi et al. \(2010\)](#). All measurements were performed in triplicate.

2.8 Texture profile analysis

Texture profile analysis (TPA) was conducted to assess the textural characteristics of fried breaded tilapia fillets using a texture analyzer (TA.XT2i, Stable Micro Systems, United Kingdom). A compression probe (P/75) was used with a 5 kg weight to calibrate the 30 kg load cell before analysis. The settings were fixed at a pretest speed of 1.0 mm.s⁻¹, test speed of 5.0 mm.s⁻¹, and post-test speed of 5.0 mm.s⁻¹. For probe height calibration, a 30 mm distance, a 10 mm.s⁻¹ return speed, and a 5 g contact force were set.

The samples were placed in the centre of the platform, and the analysis was performed with 50 % strain.

2.9 Sensory analysis

Sensory evaluation of the fried breaded tilapia fillets was carried out with 40 untrained panelists, who assessed color, appearance, taste, crispness, juiciness, oiliness, fishy odor, and overall acceptability. Before evaluation, all panelists were briefed on the procedures and sample information, and informed consent was obtained. A 7-point hedonic scale was used to rate each attribute, where 1 corresponded to “dislike extremely” and 7 to “like extremely.” This scale was selected as it provides adequate discrimination of sensory attributes while reducing complexity for untrained panelists compared with a 9-point scale.

2.10 Statistical analysis

Statistical analysis was performed using one-way analysis of variance (ANOVA) in MINITAB. When significant differences ($p < 0.05$) were detected, mean comparisons were conducted using Tukey's test.

3. Results and discussion

3.1 Moisture and fat content

A statistically significant increase ($p < 0.05$) in moisture content was recorded in all fillets coated with chia seed-enriched batters compared with the control treatment (Table 2). However, no significant differences ($p > 0.05$) were observed among samples containing 3%, 6%, and 9% chia seed, although the 9% treatment showed a slightly higher moisture content. This enhancement may be attributed to the mucilaginous polysaccharides present in chia seeds, which possess strong water-binding properties and promote moisture retention within the product matrix (Muñoz et al., 2012). Upon hydration, chia mucilage forms a gel-like network that acts as a protective surface layer, minimizes structural porosity and limits moisture migration during frying. This barrier effect contributes to reduced water loss and improved moisture retention. In addition, chia seeds exhibit emulsifying functionality alongside their notable water-holding capacity (Yüncü et al., 2021). The elevated fiber content of chia seed mucilage (CSM) may further support moisture preservation by enhancing the ability of the coating system to entrap water (Mensah et al., 2024). Comparable

trends have been reported in emulsion-based systems, in which chia mucilage contributed to improved water retention and stability (Fernandes & Mellado, 2018).

A significant reduction ($p < 0.05$) in fat content was also observed following chia seed incorporation (Table 2). Nevertheless, samples coated with 9% chia seed exhibited slightly higher fat content compared with those containing 3% and 6%. A related pattern was reported by Karimi and Kenari (2016) in their investigation of salep and basil seed gum coatings applied to fried potato strips, in which lower hydrocolloid concentrations were more effective in limiting oil uptake than higher levels. This outcome may be associated with changes in coating microstructure at elevated viscosities. Increasing batter viscosity can lead to the formation of thicker yet less uniform films, potentially producing a rougher surface morphology that favors oil adherence and penetration (Bango et al., 2025). Furthermore, coatings with excessive viscosity may contain greater internal free volume, facilitating moisture evaporation and subsequent oil infiltration during frying (Abdul-Zubir et al., 2022). These structural modifications could explain the slight increase in fat content at the highest chia seed concentration.

Table 2. Effect of different percentages of chia seeds on the moisture and fat contents of fried breaded tilapia fillets.

Analysis	Percentage of chia seeds in batter formulation			
	Control (0%)	3%	6%	9%
Moisture (%)	48.96 ± 1.57 ^b	56.07 ± 1.01 ^a	56.17 ± 0.97 ^a	59.45 ± 1.64 ^a
Fat (%)	13.62 ± 0.51 ^a	11.46 ± 0.13 ^b	11.73 ± 0.48 ^b	13.05 ± 1.05 ^{ab}

Note: Different superscript letters in a row show significant differences ($p < 0.05$) between the control and different percentages of chia seeds.

3.2 Viscosity of batter

The incorporation of chia seeds significantly increased batter viscosity compared with the control formulation.

Viscosity increased significantly ($p < 0.05$) with increasing chia seed concentration, with the 9% formulation showing substantially higher viscosity than the 3%

treatment (an approximately 170% increase). A comparable trend was described by [Sung et al. \(2020\)](#), who reported enhanced viscosity in cake batters supplemented with chia seeds. This rheological modification can largely be explained by the substantial water-binding capacity of chia-derived dietary fiber, which promotes swelling and network formation within the aqueous phase ([García-Salcedo et al., 2018](#); [Struck et al., 2016](#)). The development of this hydrated fibre matrix contributes to resistance against flow, thereby increasing the apparent viscosity of the batter system.

From a technological standpoint, viscosity plays an essential role in maintaining batter structure by stabilizing entrapped air cells. Batters with insufficient viscosity may lack the structural strength necessary to retain air bubbles during processing, potentially compromising product expansion and textural development in the finished product ([Shaabani et al., 2018](#)).

In deep-fat frying applications, batter viscosity is a critical determinant of coating performance. It directly influences batter pickup, adhesion strength to the substrate, and overall product uniformity ([Xue & Ngadi, 2006](#)). According to [Fizman and Salvador \(2003\)](#), viscosity governs not only the quantity of batter retained on the surface but also the distribution consistency, handling characteristics, and the final appearance and textural attributes of the coated product. Similarly, [Karimi and Kenari \(2016\)](#) emphasized that the rheological properties of hydrocolloid suspensions are closely linked to coating efficiency, affecting processing yield as well as sensory qualities such as crispness and surface structure. A batter with higher viscosity is generally associated with the formation of a thicker and more continuous coating layer, which can

improve breadcrumb adhesion and contribute positively to product quality. In addition, a more structured coating may act as a partial barrier to moisture loss and oil penetration during frying. However, the present findings suggest that this effect is not strictly proportional to viscosity, as the sample containing 9% chia seed did not exhibit a further reduction in oil absorption compared with the control. This may indicate that excessive viscosity could negatively affect coating structure or uniformity, thereby limiting its effectiveness as a barrier under these conditions.

3.3 Coating adhesion

Coating adhesion, frequently referred to as coating pickup, represents a key physical parameter influencing the performance and quality of fried products ([Abdul-Zubir et al., 2022](#); [Nanda et al., 2020](#)). This parameter indicates the proportion of batter retained on the food surface after coating, thereby affecting processing yield and contributing to the structural and sensory characteristics of the final product ([Albert et al., 2009](#)).

In the present study, the incorporation of chia seeds significantly enhanced coating adhesion to fish fillets (Table 3). Fillets coated with 6% and 9% chia seed-enriched batters exhibited significantly higher ($p < 0.05$) adhesion compared with the control and 3% treatments, while no significant difference ($p > 0.05$) were observed between 0% and 3% or between 6% and 9% formulations. This improvement may be associated with the increased viscosity of the batter at higher chia seed levels. As viscosity rises, the batter exhibits greater resistance to flow and drainage, allowing a thicker layer to remain attached to the fillet surface. Although the 9% formulation showed the numerically highest adhesion, it was not significantly different from the 6% formulation.

Previous research has established a positive relationship between batter viscosity and coating pickup, whereby more viscous systems promote stronger adherence and higher retained coating mass (Fizman & Salvador, 2003). The findings of this study align with that relationship, suggesting that the rheological modifications induced by chia seed addition contributed to enhanced coating performance.

3.4 Cooking yield

An upward trend in cooking yield was observed with increasing chia seed concentration in the batter. Fillets coated with 6% and 9% chia seed formulations exhibited significantly higher ($p < 0.05$) yields compared with the control, while the 3% treatment did not differ significantly from the control. This improvement at higher chia seed levels is likely due to the water-binding and gel-forming properties of chia mucilage, which help retain moisture and reduce liquid loss during frying. The improvement in yield at higher inclusion levels may also be linked to improved coating adhesion. By forming a hydrated network within the coating matrix, the hydrocolloid component increases batter viscosity and limits coating detachment during frying, thereby contributing to greater mass retention in the finished product (Pirsa & Hafezi, 2023; Karimi & Kenari, 2016). Reduced water loss due to the moisture-binding characteristics of chia mucilage further

enhances yield. These findings are consistent with the work of Yüncü et al. (2021), who documented enhanced cooking yield in meat patties formulated with chia seed, attributing the effect to its strong water-holding and structural stabilizing properties.

3.5 Frying loss

The addition of chia seeds to the batter formulation resulted in a significant decrease ($p < 0.05$) in the frying loss of the coated fish fillets (Table 3). A progressive decline in mass loss was observed with increasing levels of chia seed incorporation. This improvement may be associated with enhanced structural integrity of the coating layer. Greater batter adhesion at higher chia seed concentrations likely produced a more compact and continuous surface film, which acted as a protective barrier during frying. Such a cohesive coating can limit moisture evaporation and reduce the detachment of surface fragments under high-temperature conditions (Kilincceker & Hepsag, 2011). The present findings are in line with Yusnita et al. (2007), who demonstrated that batters with elevated viscosity improved coating retention, enhanced product yield, and minimized frying-related losses in battered foods. Collectively, these results suggest that the rheological modification induced by chia seed addition may have contributed to improved coating stability and reduced processing losses.

Table 3. Effect of different percentages of chia seeds on viscosity, coating adhesion, cooking yield and frying loss of fried breaded tilapia fillets.

Parameter	Percentage of chia seeds in batter formulation			
	Control (0%)	3%	6%	9%
Viscosity (mPa·s)	844.0 ± 92.5 ^d	1410.9 ± 34.5 ^c	2682.0 ± 132.1 ^b	3811.3 ± 169.4 ^a
Coating adhesion (%)	48.58 ± 0.31 ^b	48.95 ± 0.92 ^b	52.31 ± 0.56 ^a	53.14 ± 0.82 ^a
Cooking yield (%)	180.72 ± 0.69 ^b	188.20 ± 1.52 ^b	203.99 ± 1.16 ^a	208.23 ± 1.53 ^a
Frying loss (%)	7.02 ± 0.25 ^a	5.96 ± 0.19 ^b	4.17 ± 0.67 ^c	3.02 ± 0.06 ^d

Note: Different letters in a row show significant differences ($p < 0.05$) between the control and different percentages of chia seeds.

3.6 Color and texture

Significant differences ($p < 0.05$) were observed in the instrumental color parameters (L^* , a^* , and b^*) of tilapia fillets coated with batters containing different concentrations of chia seeds (Table 4). Increasing chia seed levels resulted in higher a^* values, indicating enhanced red tones, while L^* values declined following frying, reflecting reduced lightness. Although b^* values appeared slightly higher in the chia seed treatments, they did not differ significantly from the control ($p > 0.05$). Both the 6% and 9% formulations showed a slight darkening of fillets compared with the lower inclusion levels, likely due to the inherent pigmentation of chia seeds and their influence on surface coloration during thermal processing.

From a sensory perspective, the coated fillets displayed a characteristic golden-brown crust, crisp surface texture, and typical fried aroma, contributing positively to consumer acceptance. Instrumental

measurements supported the visual observations, demonstrating an intensification of reddish hues alongside diminished lightness, consistent with previously reported patterns in fried meat and fish products (Barbut, 2013).

Color formation during deep-fat frying is governed by several physicochemical changes. The Maillard reaction and caramelization are primarily responsible for the formation of desirable brown pigments, whereas surface dehydration facilitates crust development and contributes to a crisp texture. In addition to these reactions, product composition—including the formulation of the coating and the characteristics of the raw material—plays a key role in determining the final appearance (Zhang & Chen, 2014). Processing conditions, such as frying temperature, duration, oil characteristics, and pretreatment methods, further modulate color intensity and overall product quality (Reda, 2004; Santis et al., 2007).

Table 4. Effect of different percentages of chia seeds on color and texture profile analysis of fried breaded tilapia fillets.

Parameter	Percentage of chia seeds in batter formulation				
		Control (0%)	3%	6%	9%
Color	L*	45.98 ± 1.98 ^a	45.45 ± 1.10 ^a	44.39 ± 0.73 ^b	41.03 ± 0.08 ^b
	a*	8.23 ± 0.65 ^b	7.0 ± 0.23 ^b	14.47 ± 0.48 ^a	14.84 ± 0.25 ^a
	b*	24.83 ± 1.83 ^a	20.53 ± 1.42 ^b	24.50 ± 0.27 ^a	25.86 ± 0.42 ^a
Texture	Hardness (N)	952.30 ± 71.00 ^c	1186.90 ± 118.10 ^{bc}	1455.90 ± 219.20 ^{ab}	1643.00 ± 119.30 ^a
	Fracturability (N)	963.30 ± 54.20 ^a	1034.30 ± 63.60 ^{bc}	1311.60 ± 207.00 ^{ab}	1516.60 ± 122.90 ^a
	Cohesiveness	0.33 ± 0.01 ^a	0.33 ± 0.01 ^a	0.33 ± 0.01 ^a	0.32 ± 0.01 ^a
	Springiness	0.81 ± 0.01 ^a	0.85 ± 0.03 ^a	0.82 ± 0.01 ^a	0.84 ± 0.01 ^a
	Chewiness (N)	254.97 ± 16.7 ^b	340.84 ± 38.0 ^{ab}	416.11 ± 116.9 ^{ab}	434.74 ± 22.4 ^a

Note: Different superscript letters in a row show significant differences ($p < 0.05$) between the control and different percentages of chia seeds.

Textural properties play a key role in shaping consumer perception and acceptance of fried products. Both formulation composition and processing parameters have been reported to exert a substantial influence on the mechanical characteristics of food systems (Pandey et al., 2014). In fried foods, crispness is widely regarded as the most desirable quality attribute, while instrumental parameters such as hardness and fracturability are commonly used to quantify this sensory perception.

In the present study, the incorporation of chia seeds into the batter significantly ($p < 0.05$) increased the hardness of the coated fish fillets compared with the control. However, the fracturability of the 6% and 9% samples did not differ significantly ($p > 0.05$) from the control, while chewiness showed a significant increase only at the 9% inclusion level. Springiness and cohesiveness were not significantly affected ($p > 0.05$). The increase in hardness suggests the formation of a firmer crust, which may contribute to improved crispness, although the limited changes in fracturability and chewiness indicate that this effect may depend on chia concentration.

Previous research supports the influence of hydrocolloids on crispness and structural integrity in fried systems. Varela and Fiszman (2011) noted that hydrocolloids can modify crust characteristics by altering moisture distribution and oil migration. For example, hydroxypropyl methylcellulose (HPMC) with varying substitution patterns has been shown to affect both oil uptake and mechanical properties. Primo-Martín et al. (2010) reported that batters prepared with HPMC containing lower methyl and higher hydroxypropyl substitution produced crispier coatings, as demonstrated by acoustic responses during mechanical bending tests. Similarly, Salvador et al. (2005) observed increased hardness in hydrocolloid-treated banana fritters, attributing this effect to the viscosity-enhancing properties of the added gums.

The improvement in crispness observed in this study may be linked to the barrier-forming capacity of chia mucilage. By reducing oil penetration and regulating moisture evaporation, hydrocolloids help promote crust formation while maintaining structural rigidity during frying (Liberty et al., 2024). Such modifications in mass transfer phenomena are likely responsible for the enhanced mechanical strength and crisp texture detected in the chia-enriched treatments.

3.7 Sensory analysis

The sensory evaluation results, encompassing color, appearance, taste, crispness, juiciness, oiliness, fishy odor, and overall acceptability, are summarized in Table 5. No significant differences ($p > 0.05$) were observed between fillets coated with chia seed batters and the control for attributes such as color, appearance, taste, and fishy odor. However, the chia-enriched coatings received higher scores for crispness, juiciness, and oiliness, which may be associated with improved moisture retention and reduced oil uptake during frying. The barrier properties of chia mucilage likely limited water

migration into the crust, thereby preserving structural integrity and enhancing textural perception (Chen et al., 2008).

In terms of overall acceptability, panelists tended to favor fillets coated with higher chia seed concentrations compared with lower concentrations or the control. This preference appears to result from the more efficient coating performance at elevated seed levels, which improved both textural and palatability attributes. These observations align with the findings of Santana et al. (2013), who reported that hydrocolloid incorporation enhanced the sensory and textural quality of fish sausage products formulated with surimi powder.

Table 5. Effect of different percentages of chia seeds on sensory attributes of fried breaded tilapia fillets.

Coating	Color	Appearance	Taste	Crispness	Juiciness	Oiliness	Fishy odor	Overall
Control	5.27 ± 0.98 ^a	5.70 ± 0.86 ^a	4.90 ± 0.56 ^a	4.02 ± 0.55 ^b	4.97 ± 0.70 ^{bc}	5.00 ± 0.91 ^{bc}	5.07 ± 0.77 ^a	5.15 ± 0.67 ^{cd}
CS 3%	5.22 ± 0.80 ^a	5.62 ± 0.89 ^a	4.90 ± 0.65 ^a	5.57 ± 0.77 ^a	5.35 ± 0.82 ^{abc}	5.57 ± 0.90 ^{ab}	5.35 ± 0.84 ^a	5.50 ± 0.86 ^{bc}
CS 6%	5.65 ± 0.78 ^a	5.80 ± 0.99 ^a	5.37 ± 0.75 ^a	5.92 ± 0.91 ^a	6.02 ± 0.72 ^a	5.55 ± 0.87 ^{ab}	5.40 ± 0.91 ^a	5.77 ± 0.74 ^{abc}
CS 9%	5.27 ± 0.75 ^a	5.52 ± 0.74 ^a	5.40 ± 0.55 ^a	5.70 ± 0.73 ^a	5.70 ± 0.58 ^{ab}	6.17 ± 0.74 ^a	5.37 ± 0.66 ^a	6.17 ± 0.77 ^{ab}

Note: Different superscript letters in a column show significant differences ($p < 0.05$) between the control and different percentages of chia seeds.

4. Conclusions

In conclusion, the inclusion of chia seeds in the batter influenced the quality characteristics of tilapia fillets, with the extent of these effects depending on the level of addition. Based on the statistical analysis ($p < 0.05$), improvements were evident in coating adhesion, cooking yield, and frying loss, which may be associated with the increased viscosity of chia-containing batters. Textural attributes such as hardness, chewiness, and fracturability were also enhanced in the treated samples compared with the control. Sensory results indicated a general preference for chia-incorporated samples, particularly in terms of crispness and juiciness, although only attributes

with significant differences were considered in the interpretation. No marked differences were detected in appearance, despite a slight shift toward darker and redder tones in the treated fillets. Among the formulations evaluated, the 6% chia seed level provided the most balanced outcome, showing consistent improvements across key physicochemical and selected sensory parameters without introducing undesirable effects. Increasing the concentration to 9% did not provide further improvement over the 6% treatment ($p > 0.05$), with no significant differences observed in oil uptake or sensory responses between the two levels. Overall, the incorporation of chia seeds at 6% can be considered the most appropriate

level within the studied range for enhancing the quality of battered tilapia fillets.

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