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Article

Nutritional and consumer sensory reactions of catfish-fortified puffed corn snacks

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Abstract: The development of nutritionally enhanced snacks is a strategy to address protein-energy malnutrition, particularly in developing regions. This study investigated proximate and sensory characteristics of extruded puffed corn snacks fortified with varying levels (0%, 5%, 10%, 15%, and 20%) of catfish (*Clarias gariepinus*) paste. Proximate analysis was performed based on the methods of the Association of Official Analytical Chemistry (AOAC). 30 untrained panelists assessed appearance, aroma, taste, texture, and overall acceptability using a nine-point hedonic scale. Incorporation of catfish significantly enhanced the snacks' nutritional profile. Moisture and protein content increased from 6.04% (control) to 8.62% at 15% inclusion and from 11.43% (control) to 17.19% at 20%, respectively. Ash rose from 1.90% (control) to 2.47% at 20%, while crude fiber decreased from 5.33% (control) to 3.01%–3.36% at all inclusion levels. While carbohydrates declined from 73.73% to 66.41% at 20%, fat content increased from 1.57% (control) to 2.58% at 10%, before slightly decreasing at 20% to 2.27%. There was a progressive increase in acceptability, with the highest mean score of 5.77 at 15% catfish inclusion, followed by a slight decline at 20% (5.63). The standard deviation decreased as catfish inclusion increased, indicating more consistent consumer preferences. The skewness and kurtosis values of the 15% showed strong consumer preference. Sensory evaluation showing a 9-point hedonic scale showed an increase in acceptability with the highest mean score of 5.77 at 15% catfish inclusion. Sensory score declined at 20% inclusion, likely due to an intensified fishy aroma. The extrusion process preserved desirable textural properties and contributed to enhanced flavor, supporting the potential of catfish as a valuable ingredient in nutritionally enriched puffed corn snacks. The study demonstrates the potential of African catfish as a fortifying ingredient in snacks with a balance between nutritional enhancement and sensory appeal. Due to under-exploration of the fish species in corn snack production, this study offers a promising approach to improving the nutritional quality of snacks without compromising consumer acceptability.

Keywords: catfish protein; consumer preference; fish-based snacks; protein-energy malnutrition; sensory evaluation

1. Introduction

Globally, snack foods are widely consumed for their convenience and taste, thereby forming an integral part of the diet in most cultures [1,2]. Nevertheless, many snack products, especially starch-based ones, are often lacking in essential nutrients, which could lead to obesity, growth retardation, reduced work capacity, and poor mental and social development [3]. There is a need to significantly increase protein quantity and overall quality of snack diets to decrease protein malnutrition in developing countries. The high energy density and low nutrient density of some snacks can contribute to overconsumption and weight gain, increasing the risk of metabolic diseases like diabetes and cardiovascular disease [4].

"Snack" refers to a light meal or food eaten between meals [3]. Snack foods are designed to be less perishable, more durable, and more appealing than natural foods. People eat snacks for pleasure and taste rather than for nutritional considerations. Extruded snacks are crispy in texture and easy to consume, thereby making them popular among many cultures. Ready-to-eat extruded snacks are accepted by many consumers due to their convenience, no preparation time, appeal, packaging, and distribution convenience [5,6]. Since snacks are appreciated by people of all ages, mainly children and teenagers, there is an appeal for the nutritional improvement of this product [7,8]. Achieving a balance between nutritional profile enhancement and maintaining sensory attributes of snack products is still a major challenge.

Extruded snacks are mainly composed of cereals like corn, rice, wheat, and oats. They are used as bases for a wide variety of snacks due to their highly versatile nature and can be processed into different forms (flours, puffed grains, flakes, and granules). These ingredients have structural and textural roles and also impart mouthfeel to the final products [9]. However, these products based on cereals and grains are low in nutrient density, high in calories and fat content, and lack some essential amino acids like threonine, tryptophan, and lysine [10,11]. While extruded snacks can be enjoyed in moderation, in large quantities they can displace healthier foods, which is why they are often considered junk food by health experts. Consumers are, however, now becoming more conscious about nutritional choices and are leaning towards more nutritious snacks [12]. Recently, the addition of fish proteins in snack products has gained significant attention due to its high nutritional value. Incorporation of fish materials in snacks adds essential amino acids, omega-3 fatty acids, and micronutrients like calcium, phosphorous, and iron to the product [13]. In this direction, low-cost fish species like tilapia and catfish provide good alternatives to affordable nutritious snack production. In a recent study, incorporation of Nile tilapia in corn snacks significantly improved protein content without undermining the microbiological and physicochemical stability of the product [14]. In another study, incorporation of whole fish powder in snacks decreased snack expansion and color while improving hardness, which was attributed to the higher mineral content of fish [1]. Manipulation of starch bases and different fish products to enhance snack texture and appeal seems to be the main focus in recent studies. Talib et al. [15] reported that incorporation of fish in different starch sources showed improved texture and physical properties in the extruded product. The study added that tapioca-based snacks improved more in the expansion ratio and sensory attributes. It is, therefore, evident that, while fish protein can improve the nutritional value of snacks, the type of fish, starch base, and processing method can significantly impact the final product and must be optimized to maintain the desired sensory appeal.

African catfish is a rich source of high-quality protein, omega-3 fatty acids, and essential vitamins and minerals, making it an ideal candidate for fortifying cereal-based snacks [7,16]. So far, many studies have been conducted on other fish species such as tilapia [14], scad fish [15], sand smelt fish (*Atherina boyeri*) [12], shrimp [17], and dried herbs (*Laurus nobilis*, *Curcuma longa*, *Zingiber officinale* Roscoe) [18]. However, there is limited research focusing on African catfish and its application in fortifying extruded corn snacks. This knowledge gap presents an opportunity to explore the potential of using this species to improve the nutritional value of snacks while maintaining their sensory integrity.

Food evaluation involves assessing products for their sensory attributes, nutritional value, and safety. A key part of this assessment is determining the proximate composition, which includes moisture, ash, fat, protein, and carbohydrate levels [19]. These components are essential in the food industry for purposes such as product formulation, quality assurance, and meeting regulatory standards. Processing techniques like extrusion can influence these parameters, particularly due to variations in temperature. The extrusion process alters the structure of food matrices by breaking covalent and noncovalent bonds, thereby changing the functional characteristics of the final product [20]. While extrusion is widely used in producing ready-to-eat cereals, snacks, and confectioneries, growing attention is being given to its impact on nutritional and functional properties. Studies have reported that extrusion can lead to both beneficial and adverse effects on food quality [19].

Sensory evaluation is an essential aspect of the development and quality assessment of snack products [15]. It encompasses a systematic approach to assessing how consumers perceive and respond to food products using their five senses: sight, smell, taste, touch, and hearing [16,21,22]. This process provides valuable insights into consumer preferences and behaviors, which are critical for creating successful snack foods that resonate with the target market. In the snack food industry, where many products are consumed primarily for pleasure rather than for their nutritional value, sensory attributes play a significant role in determining market success [23]. Attributes such as flavor, aroma, texture, and visual appeal directly impact consumer acceptance and preference [18]. Various sensory assessment methods, including descriptive analysis, consumer acceptance testing, and preference mapping, provide valuable insights into product attributes and consumer perception [24]. The hedonic scale, quality scoring, and quantitative descriptive analysis (QDA) are commonly employed techniques in sensory evaluation of extruded snacks [25]. Hence, developing a snack that not only meets nutritional standards but also delights the senses is crucial for appealing to consumers and achieving competitive advantage.

Therefore, this study aims to evaluate the nutritional properties and consumer preferences of catfish-fortified puff corn snacks. It assessed the effect of varying inclusion levels of the fish paste on the protein and lipid content, sensory properties, and overall acceptability of the snacks. The combination of proximate analysis with sensory evaluation by untrained consumers provides valuable insights into the potential of African catfish as a fortifying ingredient in extruded snack foods. The paper is divided into four sections. Section one is the introduction, while section two describes the materials and methodology, where preparation of raw ingredients, the extrusion process, and the sensory evaluation methods are explained. Section three presents the results of the proximate analysis and sensory evaluation, followed by a discussion of findings. Lastly, section four concludes with a summary of the implication of the study and recommendations for future research.

2. Materials and methods

The section explains the materials used and the various methodologies applied in the study. It is divided into study area, raw materials collection, preparation of popcorn kernel flour, preparation of catfish pastes, extrusion process, proximate composition of extruded snacks, sensory evaluation, and statistical analysis.

2.1. Study area

The study was conducted in Ibadan North Local Government Area, located in the southwestern part of Nigeria, specifically in Oyo State. Ibadan North is one of the 33 local government areas in Oyo State, with Ibadan, the state capital, serving as its headquarters. The local government area covers a landmass of approximately 486 square kilometers and is home to a diverse population. The study was carried out in the northern part of Ibadan, utilizing panelists from within this local government area. The panelists included staff, students, and business owners from the University of Ibadan, ensuring a diverse representation in terms of age, sex, occupation, and educational levels.

2.2. Raw materials

The primary raw material used in this study was maize (*Zea mays*) popcorn kernels, which were sourced from Bodija Market in Ibadan, Oyo State, Nigeria. Additional additives, including sugar, butter, flavoring, salt, and coloring, were also purchased from the same market. Fresh African catfish (*Clarias gariepinus*) was obtained from a reliable local fish supplier, with a total of 20 kg of fresh catfish procured for the study. The equipment used included a laboratory-scale single-screw extruder (CLEXTRAL BC21, Clextral, France), a hammer mill (Fritsch Pulverisette 19, Fritsch GmbH, Germany), a digital weighing scale (Mettler Toledo XS105, Mettler Toledo, Switzerland) (± 0.01 g precision), a moisture analyzer (OHAUS MB120, OHAUS Corporation, USA), packaging materials, serving plates, evaluation forms, and palate cleansers (water and unsalted crackers).

2.3. Preparation of popcorn kernel flour

The popcorn kernels used in this study were sourced from a reliable supplier and selected to ensure consistency in quality and size. The popcorn kernels were processed into fine powder using an industrial hammer mill. This mill is specifically designed for the efficient breakdown of hard kernels into smaller particles. The milling process was carefully controlled to achieve a consistent particle size, ensuring uniformity in the flour. The resulting corn flour was sieved to remove impurities and corn kernel chunks, which could affect the quality and consistency of the final product. Following the sieving process, the flour was stored in a clean, airtight container to prevent contamination and moisture absorption. The container was then placed in a refrigerator at 4 °C to maintain the quality and prevent microbial growth. The flour was stored until it was required for further use in snack preparation and analysis.

2.4. Preparation of catfish paste

Fresh catfish, with a minimum weight of 300 g per fish, was cleaned and cut into pieces. The fish pieces were steamed at a temperature of 110 °C for 10 min to facilitate deboning and skin removal [25]. The steamed fish was processed in a sanitary environment, where bones and skin were removed, and the fish was then run through an engine mill to form a smooth paste. The catfish paste was stored in an airtight container and refrigerated at 5 °C until needed for snack preparation.

2.5. Extrusion

The puffed corn snack was prepared with varying levels of catfish inclusion (0%, 5%, 10%, 15%, and 20%), with the 0% inclusion serving as the control. All other ingredients, including sugar, salt, butter, yeast, flavoring, and coloring, were kept constant across all formulations. The raw materials were mixed according to the predetermined formulation ratios and processed using a single-screw extruder. The extrusion process was carried out at a temperature of 150 °C, with a die size of 4 mm, a screw speed of 350–400 rpm, and a moisture content of 16% [26]. A total of 15 runs were conducted, comprising 5 treatments (0%, 5%, 10%, 15%, and 20% catfish inclusion) with 3 replicates each. Each run contained 8 kg of raw material. The extruder produced a puffed, string-like product, which was then dried in a laboratory oven at 60 °C for 5–6 h. After drying, the product was cooled, sorted, and packed in sealed polyethylene bags for storage until sensory evaluation.

2.6. Proximate composition

The proximate analysis of the snacks was carried out according to the methods outlined by the Association of Official Analytical Chemists (AOAC) [27]. This comprehensive analysis included the determination of key nutritional components that are essential for evaluating the overall quality and nutritional value of the snacks. Moisture content was measured using the oven-drying method to determine the amount of water present in the snack, which affects shelf life and texture. Determination of ash content was achieved by incinerating the sample at a high temperature, which helps to quantify the mineral content. Lipid was extracted using the Soxhlet extraction method to determine the fat content, which contributes to the energy content and mouthfeel of the snacks. Determination of crude fiber followed the acid-detergent fiber method, which helps in understanding the fiber content, which is important for digestive health. In addition, crude protein was measured using the Kjeldahl method, which quantifies the nitrogen content and provides an estimate of protein levels in the snack [10].

2.7. Sensory evaluation

A 9-point hedonic scale was used to assess the sensory attributes of the snacks. Flavor was evaluated for the overall taste, including the balance of sweetness, saltiness, bitterness, and any other flavor notes perceived by the panel. Aroma assessed the scent or fragrance of the snack, which plays a key role in the overall appeal of the product. Furthermore, the scale also evaluated the appearance by judging the visual appeal of the snack, including aspects such as color, shape, and uniformity. Texture evaluated the physical characteristics of the snack when it is eaten, including crunchiness, hardness, or smoothness, while mouthfeel assessed the tactile sensations within the mouth, such as creaminess, dryness, or oiliness. In overall acceptability, the rating that reflects the general likability of the snack based on the combined sensory attributes was conducted. Thirty semi-trained panelists evaluated the snacks over six weeks, with each sample coded and served in uniform portions. Panelists were provided with water and unsalted crackers as palate cleansers between samples.

2.8. Statistical analysis

The sensory evaluation data were subjected to statistical analysis using one-way Analysis of Variance (ANOVA), which was performed using SPSS version 21.0 software (IBM Corp., USA). ANOVA was chosen to assess whether there were significant differences between the mean scores of the various sensory attributes (flavor, aroma, appearance, texture, mouthfeel, and overall acceptability) across the six-week evaluation period. Significance was set at $p < 0.05$, meaning that any differences in sensory scores with a p-value below 0.05 were considered statistically significant. In addition to the ANOVA, mean scores and standard deviations for each sensory attribute were calculated to provide a clear understanding of the overall sensory profile of the snacks. This allowed for an interpretation of both the average response from all panelists and the variability in their perceptions.

3. Results and discussion

The proximate composition of extruded puffed corn snacks with varying levels of catfish inclusion is summarized in **Table 1**. Catfish incorporation significantly influenced all measured parameters. Moisture content increased from 6.04% (0% inclusion) to 8.62% (15%), then slightly decreased to 8.31% at 20%, indicating enhanced water retention likely due to the hygroscopic nature of fish proteins [28]. Crude protein increased progressively, reaching 17.19% at 20% inclusion compared to 11.43% in the control, demonstrating the effectiveness of fish protein in enhancing the nutritional value of snacks [29]. Ash content remained stable (1.80%–1.90%) up to 15% but rose to 2.47% at 20%, suggesting improved mineral content with higher fish levels. Crude fiber decreased from 5.33% to 3.01%–3.36% due to the lower fiber content of fish relative to corn, a common effect observed in protein fortification of cereals [19]. Carbohydrates declined from 73.73% to 66.41% as fish replaced a portion of the starchy base, aligning with typical nutrient trade-offs in protein enrichment [30]. Fat content increased to 2.58% at 10% inclusion before slightly dropping to 2.27% at 20%, possibly due to lipid redistribution or thermal degradation during extrusion [19]. It has been reported that fish inclusion in snacks may render them susceptible to fat oxidation and microbial growth [14]. The variation in the fat content of snack products as fish protein levels increased agrees with these findings and further suggests careful optimization to balance the fat content with fish protein. The process conditions optimization in extrusion has been highlighted as crucial in obtaining snack products with desirable properties [10]. Szymandera-Buszka et al. [31] optimized temperature and humidity in the extrusion of iron-fortified snacks. Sensory profiling showed significant correlations between extrusion temperature and snack texture, including stickiness, crispiness, and hardness. It also revealed that temperature influenced metallic, powdery, and bitter tastes.

Table 1. Proximate composition of extruded puffed corn snack with catfish inclusion.

Incl. level	Moisture	Protein	Ash	Fiber	Carbs	Fat
0%	6.04	11.43	1.90	5.33	73.73	1.57
5%	7.78	7.78	1.80	3.01	71.42	2.53
10%	7.29	14.78	1.89	3.36	70.10	2.58
15%	8.62	12.15	1.89	3.12	72.52	1.70
20%	8.31	17.19	2.47	3.35	66.41	2.27

The incorporation of *C. gariepinus* into extruded puffed corn snacks has shown a clear influence on sensory properties and consumer acceptance, consistent with findings from related literature on fish-based snack fortification [7,16]. In the present study, sensory evaluation over a six-week period using a 9-point hedonic scale demonstrated a progressive increase in mean acceptability scores from the control (0%) to 15% catfish inclusion, after which a slight decline was noted at 20%. This indicates that moderate inclusion levels (particularly 10%–15%) are most effective in enhancing the sensory appeal of fish-fortified extruded snacks. Interestingly, the increase in mean sensory scores across samples B to D was accompanied by a decrease in standard deviation, particularly in Sample D (SD = 0.87), indicating greater consistency among panelists in evaluating these products (**Table 2**). The skewness and kurtosis values provide additional insights: for Sample D, a skewness of −1.34 and kurtosis of 1.94 indicate a left-skewed distribution with a peak around higher scores, reflecting strong consumer preference. In contrast, the control sample (A) exhibited a near-symmetric distribution (skewness = 0.07) but with low scores and a platykurtic shape (kurtosis = −1.47), suggesting widespread disagreement or indifference among panelists.

Table 2. Mean statistical distribution of sample over 6 weeks.

Inclusion (%)	Mean	Std. Deviation	Kurtosis	Skewness
A (0)	2.47	1.967	−1.128	0.313
B (5)	3.61	2.331	−1.382	−0.484
C (10)	5.58	0.754	16.049	−3.016
D (15)	5.77	0.675	33.204	−4.970
E (20)	5.63	1.025	12.514	−3.450

These findings align closely with those of Surasani [32], who observed optimal sensory outcomes at 15% fish inclusion in puffed corn-fish snacks, beyond which intensified fish odor and unfavorable texture reduced product acceptability. However, Shaviklo et al. [8,33] noted that a 7% fish protein inclusion struck the best balance between nutritional improvement and sensory acceptance, particularly in populations less accustomed to strong fish flavors. The consistency across studies suggests a threshold beyond which the benefits of protein enrichment may be offset by sensory drawbacks, such as a strong fishy aroma or aftertaste, as seen in the 20% inclusion group in the current study. In addition, the present study also disagrees with those of Goes et al. [34], who reported that adding 9% residue meal from tilapia, salmon, and tuna effectively improved the nutritional value of the snacks, with tilapia and salmon snacks achieving greater sensory acceptance compared to tuna and sardine snacks. This implies that the acceptable percentage inclusion of fish in snacks may be dependent on the species used and not only the inclusion levels. Furthermore, incorporation of tilapia in snacks at different inclusion levels of 20%, 30%, and 45% over a period of 45 days at room temperature showed an enhanced nutritional profile [14]. However, less favorable results were recorded in sensory characteristics such as flavor, color, and texture as inclusion levels increased. This finding agrees with the results of this study, further highlighting the disadvantages of higher inclusion levels of fish in snacks. The increasing popularity of snack food, especially among children, has led to another opportunity for food processors to make profit. In a recent study in India, catla fish (*Labeo catla*) fish paste was mixed with corn flour at a ratio of 60:40 and fried at 180 °C–200 °C for 30 s [21]. Results showed that the crispy, golden brown, and nutritious crackers were rated high by the panelists. Although the product received high acceptability, the study could not account for a nutrient balance with the taste, as is the case in the present study.

The final texture and expansion level of processed products are influenced by the methods and conditions applied in producing them. In this direction, the extrusion process, which involves forcing material through a shaped opening while regulating temperature and pressure to form a product, is often considered most appropriate. The textural properties of the extruded snacks remained favorable across all inclusion levels, with samples C (10%) and D (15%) (**Figures 1** and **2**) particularly appreciated for their crispness and mouthfeel. These observations are consistent with Nurilmala et al. [5], who observed that fish inclusion in extruded snacks improved nutritional value without compromising physical properties like expansion ratio and texture. The browning effect noted in their study was also observed in the present samples, especially from 10% inclusion onwards, giving the snacks a golden-brown hue that panelists found visually appealing. This suggests that fish-based protein may participate in Maillard reactions during extrusion, enhancing both color and flavor development.

In a related study, response surface methodology (RSM) was used to optimize snack food production using catfish flesh, corn flour, and defatted soy flour (DSF) through extrusion cooking [7]. The study found that the extrusion process could potentially eliminate strong fish flavors, likely due to the high temperatures and pressures involved, which cause chemical changes and flavor dilution. The extrudates had low fat content and were more nutritious compared to typical cereal-based snacks, suggesting that this method could be a new way to utilize catfish in snack foods [7]. The use of spider radar charts (**Figures 1** and **2**) further enriches the interpretation of these outcomes. As indicated in **Figure 1**, the control sample (0%) had the lowest ratings across all attributes, indicating that the base formulation lacks desirable flavor and mouthfeel. In addition, **Figure 2** revealed substantial improvements with increased inclusion, peaking at 15%, which performed best in flavor, aroma, and overall acceptability, consistent with consumer preference trends observed by Canti et al. [16] in their study on catfish head crackers. Their formulation with a 70:30 CHF:TF ratio not only maximized nutritional benefits but also achieved superior sensory scores, reaffirming that fish-based ingredients can enhance both nutrition and palatability when incorporated at optimal levels.

Incorporation of fish proteins into snacks has also awakened concerns over their expansion and texture, which can be influenced by many factors, including the nature of the starch base and extrusion conditions. Talib et al. [15] studies the impact of various starch bases on the physical properties of extruded snacks incorporated with scad fish powder. Findings showed that tapioca demonstrated better improved expansion, protein content, and texture at the 75% inclusion level and was more desirable to consumers. Similar trends were observed in the present study, where protein was also improved with inclusion levels amidst impacts on expansion and texture. There has been a noticeable shift towards healthier choices in the snack food market, with preferences placed on snacks that are low in calories, sodium, and fat while maintaining higher protein and fiber [3]. This has led to a greater demand for low-carbohydrate, high-protein diets like Atkins, paleo, and ketogenic since they provide lean sources of protein with various health benefits [2]. Given these preferences, there is a need for nutritious and protein-rich snacks that are healthy and convenient for modern consumers. In response to this shift towards healthier snack options, Mostafa [12] and Chakraborty et al. [13] demonstrated that fortifying snack protein with Bombay duck fish and smell sand meat significantly improved protein content while maintaining acceptable sensory appeal. Nevertheless, these studies also highlighted the challenge of balancing sensory properties with nutritional enhancement, especially the fishy flavor and texture changes accompanying higher fish protein inclusions. This challenge was also eminent in the present study, therefore, aligning with previous studies.

In terms of nutritional enrichment, the positive trajectory observed with increasing catfish content echoes the findings of Nurilmala et al. [5] and Umiyati et al. [35], who highlighted significant increases in protein, fat, and mineral content in extruded snacks and biscuits fortified with fish grit and catfish flour, respectively. However, they also noted changes in physical attributes, such as reduced brightness due to Maillard reactions and potential browning, which could influence consumer perception. Although the current study did not focus on nutritional composition, the positive sensory responses at 10%–15% inclusion imply that nutritional enrichment can be achieved without compromising sensory quality—provided that processing conditions and ingredient ratios are carefully controlled. Incorporating protein-rich compounds from low-value fish can significantly improve the nutritional profile of the snacks. Using a conventional twin-screw extruder machine, Pradeep et al. [36] optimized the process conditions (expansion ratio, texture, color, density, and weight) for producing fish-added extruded snacks. It was revealed that the optimal combination of screw speed, heater temperature, and corn concentration produced snacks with the most favorable properties. Isleroglu [37] explained that hot extrusion is a thermo-mechanical process used in the food industry for shaping materials, especially those with starch and proteins, under high temperature and pressure. It is a method in agro-food processing that provides multiple benefits such as mixing, forming, texturing, and cooking in a single step, thereby reducing the amount of labor needed for a production session [25].

The nutritional profile of fish snacks has also been manipulated to incorporate antioxidant properties using cornmeal, gelatin powder, dry-salted brown cannonball jellyfish umbrellas (UM), and oral arms production [38]. The addition of jellyfish flour increased the protein content of the cornmeal snacks, improving antioxidant activity. Adding 20% oral arms flour did not negatively affect the sensory characteristics of the snacks. Gelatin obtained from UM had lower crude protein levels, and no β-component was observed. In contrast, oral arms gelatin had higher hydroxyproline content and exhibited improved viscosity, foam, and antioxidant properties. The nature and nutritional profile of snack food may be influenced by the nature of the fish species it is fortified with. A study showed that the addition of chitin and crayfish shell with wheat flour and glutinous rice flour affected physicochemical and starch digestion differently in puffed biscuits [39]. The study revealed that increasing inclusion levels could lead to reduced moisture content, expansion ratio, and increased biscuit density. Similarly, interaction between protein and carbohydrates in snacks from squid mantle, potato, and corn was investigated [6]. It was revealed that expanded snacks had 40%–80% protein and a biological value greater than 93%. The melting temperature was 145 to 225 °C, which was proportional to the squid content. In addition, extrusion reduced the amino groups I and II involved in protein-protein interaction and increased O-glucosidic bonds. The precision in the optimization of process conditions in snack food production using the extrusion process is what informed its choice in the present study. Idrishi et al. [40] also agreed that, though traditional processing techniques such as flaking, puffing, and popping have been in use for the preparation of ready-to-eat snacks, advances in technologies have led to extrusion machines with better outputs and less labor.

Notably, fish inclusion can also impact shelf stability and odor retention. As observed by Shaviklo et al. [8,33] and supported by the current study's slight decline in acceptability at 20%, higher fish levels may introduce challenges related to off-odors over time. This underscores the need for appropriate packaging and possibly the inclusion of natural flavoring or masking agents to preserve product appeal during storage. In addition, optimization of extrusion-cooking conditions for fish-cereal-based snacks using RSM to improve their physical properties also demonstrated the importance of moderate inclusion of fish in snacks. Sensory evaluations indicated that the extrudates with moderate levels of fish flour and moisture content had better acceptability in terms of flavor and crispness, which are important quality attributes for consumer satisfaction [24]. In a recent study, the effect of replacing wheat flour with varying amounts (0%, 10%, and 20%) of *Hypophthalmichthys molitrix* was determined through chemical, microbiological, and sensory evaluations [41]. The frozen dumpling dough was stored at −18 °C for three months, with tests conducted every 30 days. Significant differences were observed in moisture, crude protein, crude fiber, and peroxide content. However, the pH, total ash, acid-insoluble ash, and salt percentage did not change. Chemical and sensory characteristics of the snack product remained stable for 60 days post-production. The study recommended 10% silver carp paste inclusion for better properties, which is lower than the 15% recorded in the present study. In a similar inclusion levels to the present study, soybean and quinoa were included at 0%–12% to produce protein-rich extruded ready-to-eat snacks [11]. The addition of ingredients significantly increased the protein, fiber content, and antioxidant activity, with the best combination at 4% each. The increased protein and fiber agree with the present findings and suggest potential for production of extrudates that can help combat malnutrition [26].

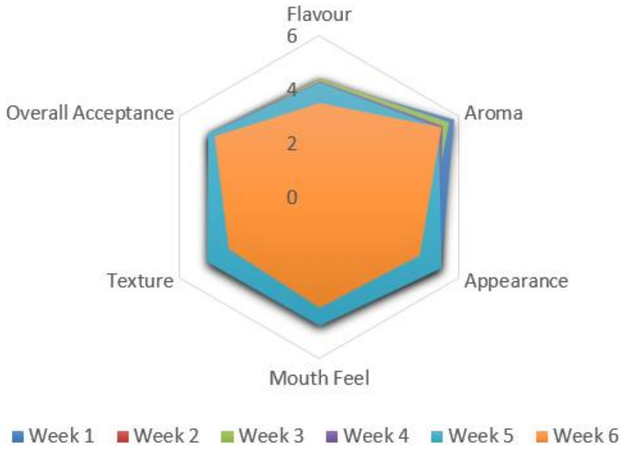

Figure 1. Spider radar for inclusion A (0%).

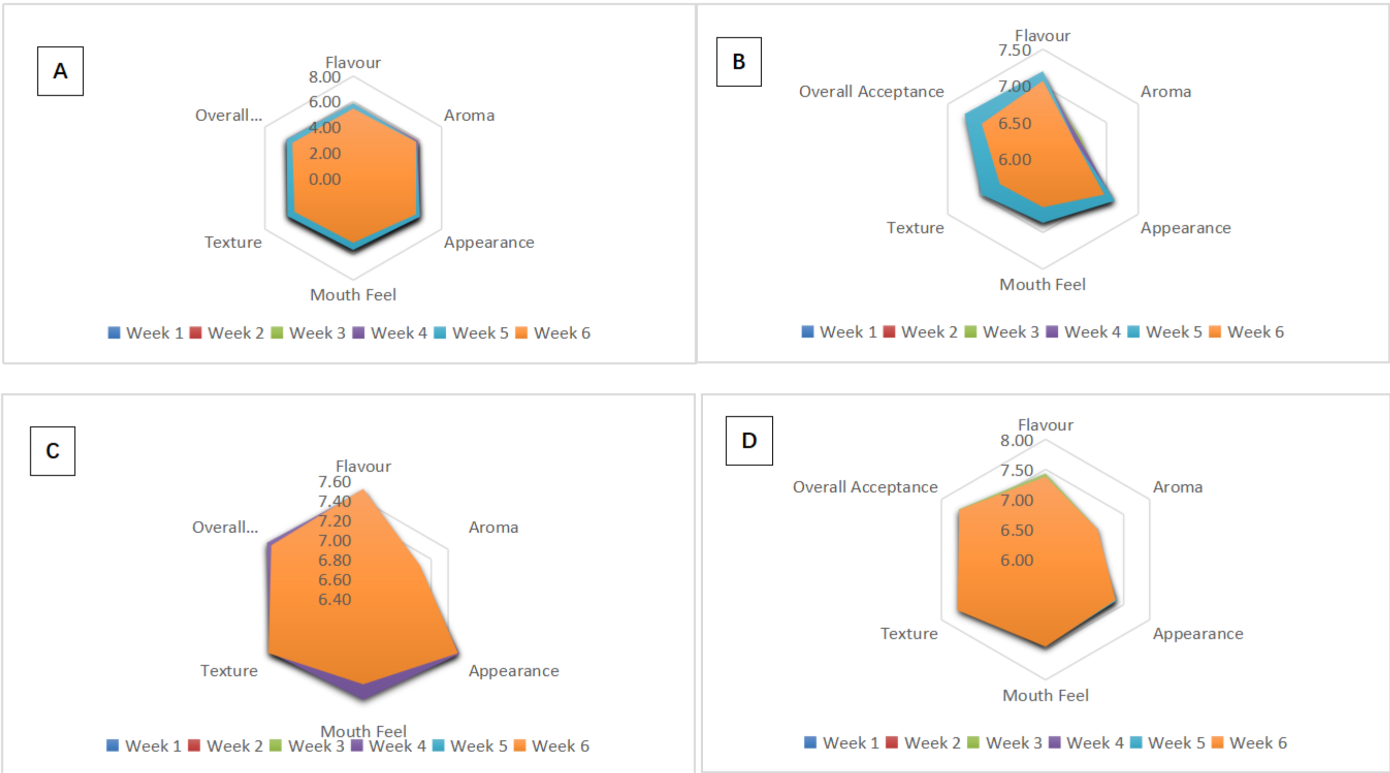

Figure 2. Spider radar for inclusion at **(A)** 5%; **(B)** 10%; **(C)** 15%; **(D)** 20%.

4. Conclusion

This study demonstrated that the incorporation of catfish into extruded puffed corn snacks significantly enhanced their nutritional profile and consumer acceptance, with notable changes observed in the proximate composition across different inclusion levels. The moisture content increased from 6.04% (control) to 8.62% at 15% catfish inclusion before slightly decreasing to 8.31% at 20%, indicating enhanced water retention due to the hygroscopic nature of fish proteins. The crude protein content increased progressively with catfish inclusion, reaching 17.19% at 20%, compared to 11.43% in the control. This shows the contribution of fish protein to improving the nutritional value of the snacks. Ash content remained stable (1.80%–1.90%) up to 15%, but rose to 2.47% at 20%, suggesting an improvement in mineral content with higher fish levels. In addition, crude fiber decreased from 5.33% in the control to 3.01%–3.36% at all inclusion levels, as expected due to the lower fiber content of fish compared to corn. Carbohydrates declined from 73.73% to 66.41% as fish replaced a portion of the starchy base, aligning with typical nutrient trade-offs in protein fortification. Fat content increased to 2.58% at 10% inclusion before slightly dropping to 2.27% at 20%, possibly due to lipid redistribution or thermal degradation during extrusion.

Sensory evaluations indicated a progressive increase in consumer acceptance scores from the control (2.47) to 15% catfish inclusion (5.77). The highest mean score was observed at 15% inclusion (5.77), with a slight decline at 20% (5.63), which was consistent with previous studies suggesting that higher levels of fish inclusion may lead to unfavorable sensory attributes like a stronger fishy aroma. The standard deviation also decreased as the catfish inclusion level increased, indicating greater consistency in consumer preferences. The skewness and kurtosis values further supported the trend, with the 15% sample exhibiting a left-skewed distribution, reflecting a strong preference from the majority of panelists. These findings suggest that moderate inclusion (10%–15%) of catfish provides a balance between nutritional enrichment and sensory appeal, while higher inclusion levels (20%) may negatively affect consumer acceptance due to the intensification of fish-related sensory characteristics. The extrusion process preserved desirable textural properties, with samples at 10%–15% inclusion being particularly appreciated for their crispness and mouthfeel. Therefore, catfish incorporation at moderate levels (10%–15%) can enhance both the nutritional value and sensory quality of puffed corn snacks, making it a feasible strategy for developing nutritionally enriched and consumer-acceptable snack products. This study was limited by a small sample size of 30 panelists in the sensory evaluation. While promising, the approach requires further investigation into consumer acceptability across broader demographics, nutrient retention during storage, and scalability in food processing to validate findings. In addition, exploring other fish species and their effects on sensory properties would further enhance our understanding of protein fortification in snacks.

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Institutional review board statement: This study was conducted in strict adherence to ethical guidelines and regulations governing research involving animals. The experimental protocols were reviewed and approved by the Institutional Animal Care and Use Committee (IACUC) of the University of Ibadan, Nigeria, under approval number UI-ACUREC/REC/066-0424/24, granted on 18/07/2024. All procedures were performed in compliance with the Nigeria laws and institutional policies concerning animal welfare and research ethics. No human participants were involved in this study. Therefore, informed consent was not applicable. Additionally, there were no conflicts of interest to disclose, and no funding was received for this research.

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