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Valorization of Crab Shell Waste into Onion Sticks: Physicochemical Characteristics and Sensory Acceptance of Soft-Shell Crab and Blue Swimming Crab Shell Flours

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Keywords:
crab shell waste, soft-shell crab, blue swimming crab, shell flour, onion sticks, sensory acceptance, waste valorization

Kata Kunci:
limbah cangkang kepiting, kepiting soka, rajungan, tepung cangkang, stik bawang, penerimaan sensoris, pemanfaatan limbah.

Abstract. *Crab shell waste is an abundant fisheries by-product that remains underutilized despite its potential as a source of minerals and other valuable components. This study aimed to evaluate the physicochemical characteristics and sensory acceptance of onion sticks formulated with different types of crab shell flour. A Completely Randomized Design was applied using four treatments: control, soft-shell crab (Scylla serrata) shell flour, blue swimming crab (Portunus pelagicus) shell flour, and a mixture of both shell flours, with three replications. Analyses included moisture content, ash content, instrumental color (L*, a*, and b*), descriptive sensory evaluation by eight trained panelists, and hedonic testing by 50 untrained panelists. Data were analyzed using ANOVA followed by Duncan's Multiple Range Test at a 5% significance level. Crab shell flour increased the ash content and modified the color characteristics of the onion sticks while enhancing crab-related aroma and flavor. Although shell flour increased the perception of sandy texture, crispness remained relatively stable across treatments. The hedonic evaluation showed that the soft-shell crab treatment achieved overall acceptance comparable to the control and exhibited a more favorable sensory profile than the blue swimming crab treatment. These findings indicate that soft-shell crab shell flour has potential as a value-added ingredient for onion stick production and as an alternative approach for utilizing crab shell waste.*

Abstrak. *Limbah cangkang kepiting merupakan hasil samping perikanan yang melimpah dan masih belum dimanfaatkan secara optimal, meskipun berpotensi sebagai sumber mineral dan komponen bernilai lainnya. Penelitian ini bertujuan mengevaluasi karakteristik fisikokimia dan penerimaan sensoris stik bawang dengan penambahan berbagai jenis tepung cangkang kepiting. Penelitian menggunakan Rancangan Acak Lengkap dengan empat perlakuan, yaitu kontrol, tepung cangkang kepiting soka (Scylla serrata), tepung cangkang rajungan (Portunus pelagicus), dan campuran kedua jenis tepung cangkang, dengan tiga kali ulangan. Analisis meliputi kadar air, kadar abu, warna instrumental (L*, a*, dan b*), uji deskriptif oleh delapan panelis terlatih, serta uji hedonik oleh 50 panelis tidak terlatih. Data dianalisis menggunakan ANOVA yang dilanjutkan dengan Duncan's Multiple Range Test pada taraf signifikansi 5%. Penambahan tepung cangkang kepiting meningkatkan kadar abu dan memengaruhi karakteristik warna stik bawang serta meningkatkan intensitas aroma dan flavor kepiting. Meskipun penambahan tepung cangkang meningkatkan persepsi tekstur berpasir, kerenyahan relatif tetap terjaga. Hasil uji hedonik menunjukkan bahwa perlakuan tepung cangkang kepiting soka memiliki tingkat penerimaan keseluruhan yang sebanding dengan kontrol dan menunjukkan profil sensoris yang lebih baik dibandingkan perlakuan tepung cangkang rajungan. Hasil penelitian menunjukkan bahwa tepung cangkang kepiting soka berpotensi dimanfaatkan sebagai bahan pangan bernilai tambah dalam pembuatan stik bawang sekaligus mendukung pemanfaatan limbah cangkang kepiting.*

Introduction

Indonesia is an archipelagic country with extensive marine resources that contribute substantially to national food production and economic activities. Among the marine commodities with considerable commercial value are crabs and other crustaceans. Crab products are widely

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consumed because of their distinctive taste, nutritional value, and market demand (Tavakoli et al., 2025). However, the processing and consumption of crabs also generate substantial amounts of shell waste. The accumulation of this waste represents an environmental concern because poorly managed crab shells can produce unpleasant odors, attract microorganisms and pests, and contribute to environmental pollution (Acquavia, 2023). Therefore, the development of value-added applications for crab shell waste is important not only from an environmental perspective but also as an approach to improving resource efficiency in the fisheries sector.

Soft-shell crab is a commercially valuable crab product characterized by a soft and edible exoskeleton. The soft condition occurs because the crab has recently undergone molting, a natural biological process in which the old exoskeleton is shed and replaced (Arshadi et al., 2016). Unlike hard-shell crabs, the entire soft-shell crab, including its exoskeleton, can be consumed. This characteristic provides an advantage in terms of edible yield and product utilization. Soft-shell crab is also generally marketed at a higher price than conventional hard-shell crab because of its distinctive characteristics and convenience of consumption (Panda et al., 2024). Nevertheless, processing activities involving soft-shell crab and other crab products can still generate shell residues that require appropriate utilization.

Another important marine crustacean commodity in Indonesia is the blue swimming crab (*Portunus pelagicus*). Blue swimming crab is widely distributed in Indonesian waters and has significant economic value, including as an export commodity to international markets such as Japan, Europe, and the United States (Sathiadhas et al., 2003). Its commercial processing, however, generates considerable amounts of shell by-products. The relatively low edible proportion of crab compared with the total biomass means that a substantial fraction of the raw material may become waste. Cristofoli et al (2023) reported that crab processing can generate waste of up to 80%, while only approximately 20% is consumed. Consequently, the accumulation of crab shell waste represents both an environmental challenge and an opportunity for the development of sustainable food ingredients.

Crab shells should not be regarded solely as waste because they contain potentially valuable nutritional and functional components. Previous studies have reported that crab shells contain protein, calcium carbonate, chitin, and ash in appreciable amounts (Lizundia et al., 2022). Scaffaro et al (2025) also identified crab shell as a potentially valuable waste material that remains insufficiently utilized. The presence of mineral and organic components suggests that crab shells can be processed into a finer ingredient, such as crab shell flour, which may subsequently be incorporated into food products. Such an approach can contribute to waste reduction while simultaneously creating opportunities for food diversification and value addition.

The conversion of crab shells into flour represents one potential strategy for improving their utilization. Drying, size reduction, grinding, and sieving can transform shell residues into a more manageable material that can be incorporated into food formulations. The resulting flour may contribute not only to mineral content but also to distinctive sensory characteristics. However, the incorporation of shell-derived ingredients into food products must be carefully evaluated because excessive or inappropriate incorporation may influence color, aroma, flavor, and mouthfeel (Balakrishnan et al., 2025). Therefore, product selection and formulation are important factors in determining whether crab shell flour can be successfully accepted by consumers.

One product that may provide a suitable application for crab shell flour is onion sticks. Onion sticks are popular snack products characterized by a savory taste, distinctive onion aroma, and crispy texture. They are commonly consumed as snacks and are widely available in Indonesia, particularly during festive occasions (Sapna et al., 2025). Their relatively simple formulation and processing characteristics make onion sticks a potential food matrix for incorporating alternative ingredients (Arena et al., 2024). The addition of crab shell flour may provide an opportunity to develop a value-added snack with enhanced mineral content while simultaneously utilizing an underexploited fisheries by-product.

Previous studies have investigated the utilization of crab shell-derived materials in food applications; however, comparative evaluation of different crab shell sources in an onion stick formulation remains limited. In particular, differences between soft-shell crab and blue swimming crab shell flours may influence the physicochemical and sensory properties of the resulting product (Romano & Zeng, 2008). The mineral composition, particle characteristics, and inherent sensory properties of the two shell materials may contribute to differences in moisture, ash, color, aroma, flavor, and texture (Islam et al., 2023). Furthermore, the combination of the two types of shell flour may provide an alternative formulation with a different balance of physicochemical and sensory characteristics.

Accordingly, this study investigated the incorporation of soft-shell crab (*Scylla serrata*) and blue swimming crab (*Portunus pelagicus*) shell flours into onion sticks. The study evaluated the effects of different crab shell flour treatments on moisture content, ash content, instrumental color characteristics, descriptive sensory attributes, and consumer acceptance. A control formulation without crab shell flour was included as a reference to determine the changes associated with shell flour incorporation (Krishnani et al., 2023). The specific objective of this study was to determine the differences in physicochemical and sensory characteristics of onion sticks prepared with different crab shell flour sources and to identify the most promising formulation for the development of a value-added food product. The findings are expected to contribute to the valorization of crab shell waste and support the development of sustainable food products based on underutilized marine resources.

Method

1. Materials and Equipment

The main materials used in this study were soft-shell crab (*Scylla serrata*) shells and blue swimming crab (*Portunus pelagicus*) shells obtained from Kongsi, Tanjung Emas Port, Semarang, Indonesia. Other ingredients used for the production of onion sticks included wheat flour, tapioca flour, eggs, margarine, garlic, salt, seasoning powder, baking powder, cooking oil, and water.

The equipment used to produce crab shell flour included a cabinet dryer, mortar and pestle, food processor, and an 80-mesh sieve. The equipment used for onion stick production included a digital balance, mixing bowls, measuring glass, spoon, tray, cutting board, knife, rolling pin, frying pan, stove, and noodle maker (Seitz, 2020). Equipment used for physicochemical analyses included an oven, aluminum dishes, porcelain crucibles, desiccator, furnace, chromameter, spatula, analytical balance, and metal tongs.

2. Experimental Design

The study employed a Completely Randomized Design (CRD) with one experimental factor, namely the type of crab shell flour incorporated into the onion stick formulation. Four treatments were evaluated: control without crab shell flour, soft-shell crab shell flour, blue swimming crab shell flour, and a mixture of soft-shell crab and blue swimming crab shell flours.

The treatments were designated as follows:

- P0 = control onion sticks without crab shell flour;
- P1 = onion sticks containing soft-shell crab (*Scylla serrata*) shell flour;
- P2 = onion sticks containing blue swimming crab (*Portunus pelagicus*) shell flour;
- P3 = onion sticks containing a mixture of soft-shell crab and blue swimming crab shell flours.

Each treatment was prepared in three independent replications, resulting in a total of 12 experimental units. The experimental units were randomly assigned to treatments to minimize the influence of uncontrolled experimental variation (Hungria et al., 2017).

The proportion of crab shell flour incorporated into each treatment was maintained according to the formulation established in the original experimental design. For P3, the ratio of soft-shell crab shell flour to blue swimming crab shell flour was [insert actual ratio, e.g., 1:1]. The detailed formulation of each treatment should be presented in a formulation table to ensure experimental reproducibility.

3. Preparation of Crab Shell Flour

The preparation of soft-shell crab and blue swimming crab shell flours was performed according to the method described by Mahadika et al. (2017), with modifications.

Fresh crab shells were initially washed thoroughly under running water to remove adhering dirt and other foreign materials. Any remaining meat or eggs attached to the shells were manually removed. The cleaned shells were drained and air-dried briefly at room temperature to reduce residual surface moisture.

The shells were then reduced in size by gently crushing them using a mortar and pestle. The crushed shells were evenly distributed on a drying tray lined with non-stick paper and dried using a cabinet dryer at 50 °C for 24 h. After drying, the shells were further ground using a mortar and pestle and subsequently processed using a dry food processor to obtain finer particles.

The resulting shell flour was passed through an 80-mesh sieve to obtain a relatively uniform particle size. The sieved soft-shell crab and blue swimming crab shell flours were stored separately in closed containers until further use.

4. Preparation of Onion Sticks

The onion stick formulation was prepared according to Lestari and Artanti (2021), with modifications. For the control treatment (P0), the onion sticks were prepared without the addition of crab shell flour. For P1, P2, and P3, the corresponding crab shell flour or mixture was incorporated according to the predetermined formulation.

The dry ingredients, consisting of wheat flour, tapioca flour, crab shell flour according to treatment, salt, seasoning powder, and baking powder, were first mixed until homogeneous. Garlic was finely ground and mixed with the eggs and margarine. The mixture was then incorporated into the dry ingredients and mixed thoroughly (Hasan et al., 2024). Water was gradually added until a homogeneous dough with suitable consistency for shaping was obtained.

The dough was flattened using a rolling pin and subsequently passed through a noodle maker to obtain relatively uniform thickness and shape. The shaped dough was then fried in preheated cooking oil over low heat until the onion sticks were completely cooked and developed a crispy texture. The fried products were drained to remove excess oil and allowed to cool to room temperature before physicochemical and sensory analyses.

5. Physicochemical Analysis

a. Moisture Content

Moisture content was determined using the gravimetric method according to AOAC (2005). Aluminum dishes were first dried in an oven at 105 °C for 30 min, cooled in a desiccator for 10 min, and weighed using an analytical balance.

Approximately 2 g of sample was placed in the pre-weighed aluminum dish. The sample was dried in an oven at 105 °C for 24 h. After drying, the dish containing the sample was transferred to a desiccator for 10 min and subsequently weighed. The sample was then returned to the oven for an additional 2 h at the same temperature and reweighed. The drying and weighing process was repeated until a constant weight was obtained.

Moisture content was calculated based on the loss in sample weight during drying:

$$Moisture\ content(\%) = \left(\frac{W_0 - W_1}{W_0}\right) x\ 100$$

where W_0 is the sample weight before drying (g) and W_1 is the sample weight after drying to constant weight (g).

b. Ash Content

Ash content was determined using the dry ashing method according to AOAC (2005). Porcelain crucibles were dried in an oven at 105 °C for 30 min, cooled in a desiccator for 10 min, and weighed using an analytical balance.

Approximately 2 g of sample was placed in the pre-weighed crucible. The crucible containing the sample was transferred to a furnace and incinerated at 550 °C for 4 h. After the ashing process, the crucible was cooled and placed in a desiccator before being weighed. The ash content was calculated using the following equation:

$$Ash\ content\ (\%) = \left(\frac{W_2 - W_1}{W_x}\right) x\ 100$$

where W_1 is the weight of the empty crucible (g), W_2 is the weight of the crucible and ash (g), and W_s is the sample weight (g).

6. Color Analysis

Color characteristics were determined using a chromameter based on the CIELAB color system. The parameters measured were L*, a*, and b*. The L* value represents lightness, with higher values indicating a lighter color. The a* value represents the red–green color dimension, whereas the b* value represents the yellow–blue color dimension.

Measurements were performed on each treatment with three replications. Measurements were conducted at different points on the surface of the onion stick samples to obtain representative values, and the mean values were used for statistical analysis.

Based on the experimental results, the measured color parameters were L* values ranging from approximately 50.99 to 53.33, a* values ranging from 9.28 to 13.02, and b* values ranging from 6.30 to 7.43.

7. Descriptive Sensory Analysis

Descriptive sensory analysis was conducted to characterize the intensity of selected sensory attributes of the onion sticks. The test involved eight trained panelists. Prior to evaluation, the panelists received instructions regarding the sensory attributes, evaluation procedures, and use of the sensory evaluation form.

The evaluated attributes included brown color intensity, lightness, crab aroma, flour aroma, salty taste, crab flavor, sandy texture, and crispness. Each sample was presented to the panelists using appropriate sample coding to minimize potential bias. The intensity of each attribute was evaluated using a 7-cm line scale, where a position closer to 7 represented a higher intensity and a position closer to 0 represented a lower intensity.

The descriptive sensory data were analyzed to determine differences in sensory attribute intensity among the four treatments.

8. Hedonic Test

A hedonic test was conducted to evaluate consumer acceptance of the onion sticks. The test involved 50 untrained panelists. The evaluated attributes included taste, color, aroma, texture, flavor, and overall acceptance.

Each sample was presented using a three-digit random code to minimize bias associated with treatment identity. Panelists evaluated their degree of liking using a five-point hedonic scale:

1 = strongly dislike;
2 = dislike;
3 = slightly like;
4 = like;
5 = strongly like.

The hedonic scores for each sensory attribute were subsequently subjected to statistical analysis.

9. Statistical Analysis

Data obtained from the physicochemical and sensory analyses were analyzed using one-way Analysis of Variance (ANOVA) based on the Completely Randomized Design at a 5% significance level ($\alpha = 0.05$). When the ANOVA indicated a statistically significant difference among treatments ($p < 0.05$), the analysis was followed by Duncan's Multiple Range Test (DMRT) at the 5% significance level to determine differences between treatment means.

The results were expressed as mean ± standard deviation. Different lowercase superscript letters within the same parameter indicate significant differences among treatments according to DMRT ($p < 0.05$). Statistical analyses were performed using SPSS version 22.

Result and Discussion

To present the findings systematically, the results of this study are organized into three main aspects representing the relationship between the characteristics of the raw materials, the resulting product properties, and consumer acceptance. This structure allows the findings to be discussed not only descriptively but also in terms of the relationships between the physicochemical and sensory characteristics of the onion sticks. Accordingly, the discussion is divided into three main topics: (1) the physicochemical characteristics of onion sticks containing different types of crab shell flour, (2) the descriptive sensory profile of the onion sticks, and (3) consumer acceptance and the product development potential of onion sticks enriched with crab shell flour.

1. Physicochemical Characteristics of Onion Sticks Enriched with Crab Shell Flour

The physicochemical characteristics of the onion sticks were evaluated based on moisture content, ash content, and instrumental color parameters (L*, a*, and b*). These parameters are important indicators of product quality because they are closely associated with storage stability, mineral contribution, and visual appearance. The incorporation of crab shell flour may alter the physicochemical properties of the onion sticks because crab shells contain mineral components, particularly calcium-containing compounds, as well as organic materials that may influence moisture retention and product color (Rahman et al., 2018). The results presented below use the experimental data provided as the reference basis for the current discussion and can subsequently be regenerated when the final dataset is established.

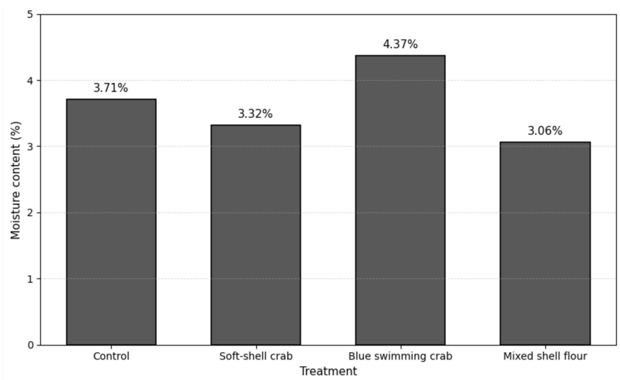

Figure 1. Effect Of Crab Shell Flour Type on the Moisture Content of Onion Sticks

Figure 1 shows that the moisture content of the onion sticks varied among treatments, ranging from

3.06% to 4.37%. The control treatment had a moisture content of approximately 3.71%, while the incorporation of soft-shell crab shell flour resulted in a slightly lower value of 3.32%. The blue swimming crab treatment exhibited the highest moisture content at 4.37%, whereas the mixed shell flour treatment showed the lowest value at 3.06%. The differences may be associated with variations in the composition and particle characteristics of the shell flours, which can influence water distribution within the dough and subsequent moisture loss during frying (Campbell, 2017). In addition, differences in mineral and structural components between the two crab shell materials may affect their interaction with water during dough preparation and thermal processing. The relatively low moisture content observed across the treatments is also consistent with the characteristic of fried snack products, in which substantial water removal occurs during frying (Alam, 2023). Nevertheless, statistical testing is required to determine whether the observed numerical differences represent significant treatment effects.

Moisture content is particularly relevant to the quality and shelf stability of fried snack products. Lower residual moisture generally reduces the availability of water for microbial growth and may contribute to improved crispness. However, excessively low moisture may also affect texture and sensory acceptability if it results in an overly hard or brittle product (Thivya et al., 2023). Therefore, the interpretation of moisture content should not be made independently but should be considered together with the sensory results, particularly texture and crispness. The relatively similar moisture values among the treatments suggest that the incorporation of crab shell flour did not fundamentally disrupt the dehydration process during frying (Chandarana et al., 2025). This finding is important because it indicates that the utilization of crab shell flour can potentially be incorporated into the onion stick formulation without producing substantial changes in the basic moisture characteristics of the product.

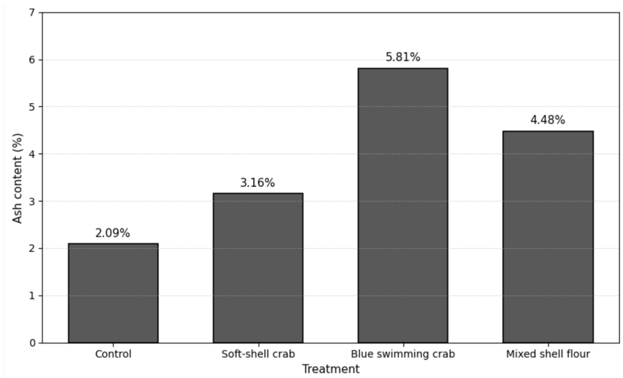

Figure 2. Effect of Crab Shell Flour Type on the Ash Content of Onion Sticks

In contrast to moisture content, ash content exhibited a more pronounced variation among the treatments (Figure 2). The control product showed the lowest ash content, approximately 2.09%, whereas the addition of soft-shell crab shell flour increased the value to 3.16%. The highest ash content was observed in the blue swimming crab treatment, reaching 5.81%, followed by the mixed shell flour treatment at 4.48%. This pattern indicates that the incorporation of crab shell flour can substantially contribute to the inorganic fraction of the final product (Hashmi et al., 2024). The higher ash content in products containing crab shell flour is consistent with the mineral-rich nature of crustacean shells, which are characterized by substantial amounts of calcium and other inorganic constituents. The higher value observed for the blue swimming crab treatment may reflect differences in the mineral composition or proportion of mineralized shell material relative to soft-shell crab material.

The increase in ash content has an important implication for the nutritional potential of the product. While ash does not directly represent a specific nutrient, it is commonly used as an indicator of the total mineral fraction in food materials. Thus, the increased ash content suggests that crab shell flour contributes mineral components to the onion stick formulation (Seitz, 2020). This finding supports the underlying concept of valorizing crab shell waste into food ingredients rather than treating the material solely as a waste product (Kuang et al., 2023). However, increased ash content should also be evaluated in conjunction with sensory characteristics because excessive incorporation of shell-derived material could potentially influence mouthfeel, particularly through the perception of particulate or sandy texture. Therefore, the optimum formulation should balance the potential nutritional advantage associated with mineral enrichment with desirable sensory properties.

The differences between the two crab shell sources are also noteworthy. The blue swimming crab treatment showed a substantially higher ash content than the soft-shell crab treatment, while the mixed treatment exhibited an intermediate value. This pattern suggests that the type of shell material is an important determinant of the mineral contribution of the resulting flour (Sahoo et al., 2024). Nevertheless, the final interpretation should be supported by inferential statistical analysis using ANOVA and an appropriate post-hoc test. In the final manuscript, the mean values should therefore be accompanied by standard deviations and statistical grouping letters to clearly establish whether the differences among treatments are statistically meaningful.

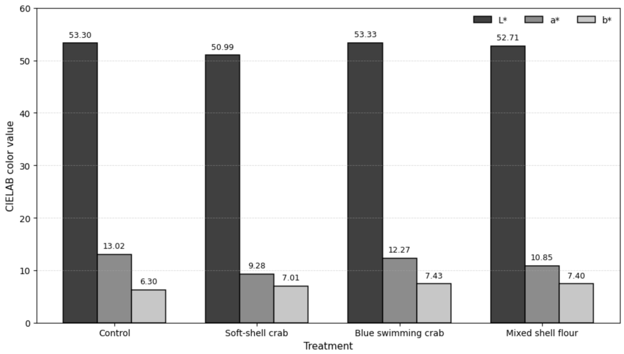

Figure 3. Effect of crab shell flour type on the L, a, and b* color parameters of onion sticks.**

Instrumental color measurements further demonstrated that the incorporation of crab shell flour affected the visual characteristics of the onion sticks (Figure 3). The L* values, which represent lightness, ranged from 50.99 to 53.33. The soft-shell crab treatment showed the lowest L* value (50.99), indicating a relatively darker appearance, whereas the blue swimming crab treatment exhibited the highest L* value (53.33), closely followed by the control (53.30). The mixed treatment showed an intermediate L* value of 52.71. The lower lightness observed in the soft-shell crab treatment may be associated with differences in the color and composition of the shell-derived flour and its interaction with the dough matrix during frying (Fierascu et al., 2019). Thermal processing can also intensify browning reactions, making differences in the initial composition of the formulations more visually apparent.

The a* values ranged from 9.28 to 13.02, indicating a tendency toward the red region of the CIELAB coordinate. The control exhibited the highest a* value, while the soft-shell crab treatment had the lowest value. The b* values ranged from 6.30 to 7.43, indicating a tendency toward the yellow region. The blue swimming crab and mixed treatments showed relatively higher b* values than the control. These changes in color coordinates demonstrate that the addition of crab shell flour can modify the visual profile of the onion sticks, although the magnitude and direction of the changes differ according to the shell source (Huang et al., 2022). Such changes are particularly relevant because color is one of the first sensory attributes perceived by consumers and can influence expectations regarding flavor, degree of cooking, and overall product quality.

Overall, the physicochemical results indicate that crab shell flour has the greatest apparent effect on ash content, whereas its influence on moisture content and instrumental color is comparatively moderate. The increase in ash content provides evidence of the mineral contribution of the shell material, while the color results demonstrate that different shell sources may produce distinct visual characteristics after incorporation and frying (Alexandri et al., 2022). These physicochemical changes should subsequently be interpreted together with the descriptive sensory and hedonic results to determine whether the changes generated by crab shell flour are compatible with consumer preferences (Cilenti et al., 2024). In particular, the potential nutritional advantage associated with increased mineral content needs to be balanced against changes in color, aroma, flavor, and mouthfeel when identifying the most promising formulation.

2. Descriptive Sensory Profile of Onion Sticks Containing Different Crab Shell Flours

Descriptive sensory analysis was conducted to characterize the intensity of selected sensory attributes of onion sticks prepared with different types of crab shell flour. The evaluation involved eight trained panelists and covered eight attributes: brown color, lightness, crab aroma, flour aroma, saltiness, sandy texture, crab flavor, and crispness. These attributes were selected because the incorporation of shell-derived flour may influence both the appearance and the characteristic sensory properties of the product (Satheesh et al., 2025). The results provide an important link between the physicochemical characteristics discussed previously and the subsequent consumer acceptance of the onion sticks.

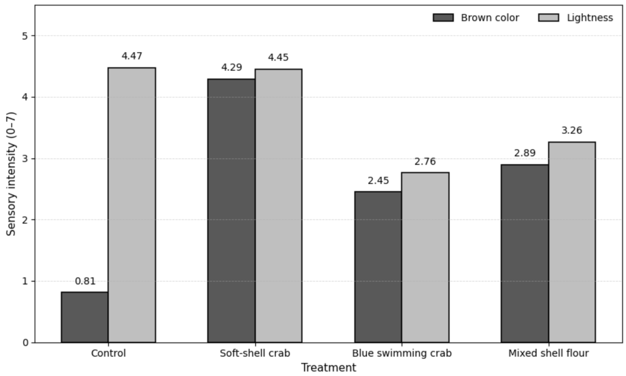

Figure 4. Descriptive Sensory Intensities of Brown Color and Lightness in Onion Sticks Containing Different Crab Shell Flours.

Figure 4 illustrates clear differences in the perceived brown color and lightness of the onion sticks among treatments. The soft-shell crab treatment exhibited the highest brown-color intensity (4.29), substantially exceeding the control (0.81), while the blue swimming crab and mixed treatments showed intermediate intensities of 2.45 and 2.89, respectively. This pattern suggests that the incorporation of shell flour, particularly soft-shell crab flour, can modify the visual appearance of the product. The lower perceived lightness of the blue swimming crab treatment (2.76) compared with the control and soft-shell crab treatment may also indicate a darker or less bright visual appearance. These sensory observations are generally consistent with the instrumental color measurements presented previously, particularly the variation in L* values (Sorach et al., 2013). Thus, the source of crab shell flour appears to contribute to differences in the visual identity of the onion sticks.

The descriptive sensory results for all attributes are summarized in Table 1. The table provides the mean intensity values and their standard deviations, together with statistical grouping based on the reference DMRT results.

Table 1. Descriptive Sensory Characteristics of Onion Sticks Containing Different Crab Shell Flours

Sensory attribute	Control	Soft-shell crab	Blue swimming crab	Mixed shell flour
Brown color	0.81 ± 1.01^{a}	4.29 ± 1.72^{c}	2.45 ± 1.02^{b}	2.89 ± 1.38^{b}
Lightness	4.47 ± 0.79^{a}	4.45 ± 0.90^{c}	2.76 ± 1.15^{b}	3.26 ± 1.63^{bc}
Crab aroma	0.48 ± 0.52^{a}	4.25 ± 1.89^{c}	2.04 ± 1.19^{b}	2.50 ± 1.89^{b}
Flour aroma	2.70 ± 2.50^{a}	2.60 ± 1.73^{a}	3.00 ± 2.19^{a}	3.07 ± 1.86^{a}
Saltiness	2.40 ± 1.65^{a}	3.40 ± 2.42^{a}	2.48 ± 1.11^{a}	3.08 ± 2.05^{a}
Sandy texture	0.43 ± 0.48^{a}	2.48 ± 1.96^{b}	2.29 ± 1.39^{b}	2.38 ± 1.18^{b}
Crab flavor	0.59 ± 1.12^{a}	4.41 ± 1.85^{b}	3.16 ± 2.02^{b}	3.51 ± 1.21^{b}
Crispness	4.91 ± 2.07^{a}	5.28 ± 1.08^{a}	5.16 ± 1.31^{a}	4.81 ± 1.22^{a}

Different superscript lowercase letters within the same row indicate significant differences among treatments according to DMRT at $p < 0.05$.

Table 1 demonstrates that the most pronounced sensory changes occurred in attributes directly associated with the incorporation of crab shell material. Brown color, crab aroma, sandy texture, and crab flavor differed among treatments, whereas flour aroma, saltiness, and crispness showed no significant differences based on the reference statistical grouping. The control consistently exhibited very low intensities of crab-related attributes, as expected because it did not contain crab shell flour (Hungria et al., 2017). In contrast, the soft-shell crab treatment produced particularly strong crab aroma and crab flavor, with values of 4.25 and 4.41, respectively. This indicates that the type of shell flour can substantially modify the sensory identity of the product. The absence of significant differences in crispness is particularly relevant because it suggests that the incorporation of shell flour did not compromise this important quality attribute (Younas et al., 2021).

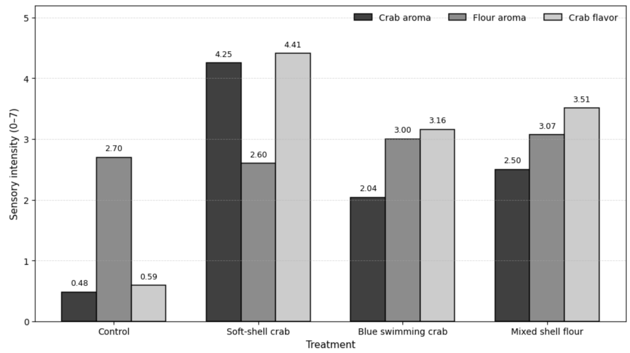

Figure 5. Descriptive Sensory Intensities of Crab Aroma, Flour Aroma, and Crab Flavor in Onion Sticks Containing Different Crab Shell Flours.

Figure 5 provides a more detailed comparison of aroma- and flavor-related attributes. The most notable observation is the substantially higher crab aroma and crab flavor intensity in all formulations containing crab shell flour compared with the control.

The soft-shell crab treatment produced the highest crab aroma (4.25) and crab flavor (4.41), while the mixed treatment and blue swimming crab treatment exhibited intermediate values. In contrast, flour aroma remained relatively similar among treatments, ranging from 2.60 to 3.07, and the statistical results indicated no significant difference. This distinction suggests that the shell flour primarily contributed a specific crab-associated sensory character rather than simply increasing a generic flour aroma (Herman, 2019; Pathak et al., 2023). From a product-development perspective, this finding is important because a stronger crab sensory identity can function as a desirable characteristic when the product is intended to emphasize marine-derived ingredients.

The stronger crab aroma and flavor observed in the shell-flour treatments may be associated with volatile and non-volatile components originating from the crab shell and residual organic material. Processing conditions, including drying and frying, may further modify these compounds and influence their perception (Ray et al., 2023). However, high sensory intensity does not necessarily correspond to high consumer preference. Therefore, these descriptive findings need to be interpreted together with the hedonic results to determine whether the stronger crab characteristics are perceived positively by consumers.

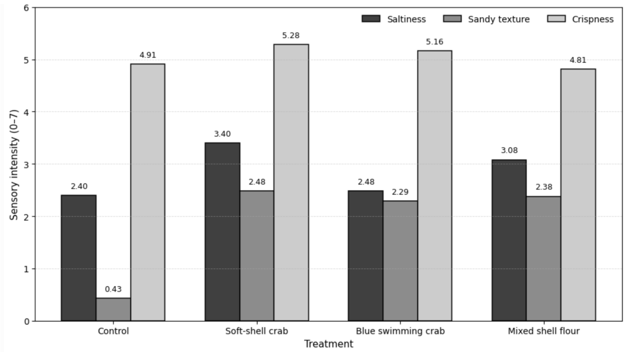

Figure 6. Descriptive Sensory Intensities of Saltiness, Sandy Texture, and Crispness in Onion Sticks Containing Different Crab Shell Flours

Figure 6 shows that the incorporation of crab shell flour increased the perceived sandy-texture intensity relative to the control. The control exhibited a very low sandy-texture score (0.43), whereas all shell-flour treatments showed values above 2.29. This result is reasonable because shell flour contains solid mineral particles that may remain perceptible in the product matrix despite the milling and sieving process. Nevertheless, the crispness scores were relatively high across all treatments, ranging from 4.81 to 5.28, and no significant differences were detected. This finding indicates that the incorporation of shell flour did not substantially alter the characteristic crisp texture of the onion sticks. Saltiness also did not differ significantly among treatments, suggesting that the perceived salty taste was primarily controlled by the formulation of salt and seasoning rather than the type of crab shell flour (Azra et al., 2019).

The combination of these findings provides an important perspective on the sensory functionality of crab shell flour. Although shell incorporation increased the perception of sandy texture, it did not reduce the perceived crispness of the product. The absence of significant differences in saltiness further indicates that the shell flour did not introduce a major confounding effect on this basic taste attribute (García-Bernet et al., 2024). Therefore, the principal sensory contribution of crab shell flour appears to be associated with crab-specific aroma and flavor, visual characteristics, and particulate mouthfeel, rather than with saltiness or crispness.

Overall, the descriptive sensory analysis demonstrates that the type of crab shell flour substantially influences several sensory attributes of onion sticks. Soft-shell crab flour produced the strongest crab-associated sensory characteristics and the highest brown-color intensity, whereas the control maintained very low crab aroma, crab flavor, and sandy-texture intensities. Importantly, crispness remained relatively stable across treatments, indicating that the incorporation of shell flour did not compromise the fundamental textural characteristic of the product (Warne, 2012). These findings suggest that the sensory impact of crab shell flour is multidimensional: it can enhance the identity of a crab-enriched snack while simultaneously introducing a more noticeable particulate texture. The subsequent hedonic analysis is therefore essential for determining whether these descriptive changes translate into increased or decreased consumer acceptance.

3. Consumer Acceptance and Product Development Potential of Onion Sticks Enriched with Crab Shell Flour

The consumer acceptance of the onion sticks was evaluated using a five-point hedonic test involving 50 untrained panelists. Six sensory attributes were assessed, namely taste, color, aroma, texture, flavor, and overall acceptance. The hedonic evaluation is particularly important because descriptive sensory characteristics alone cannot determine whether changes caused by crab shell flour are desirable to consumers (Ghosh et al., 2025). A product may exhibit a stronger crab aroma or flavor but may not necessarily receive a higher liking score. Therefore, the hedonic results were interpreted in relation to the descriptive sensory and physicochemical characteristics discussed in the previous sections.

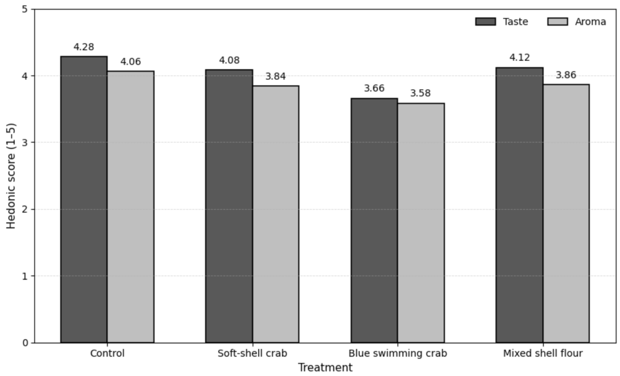

Figure 7. Consumer Acceptance Scores for Taste and Aroma of Onion Sticks Containing Different Crab Shell Flours

Figure 7 indicates that the control treatment obtained the highest scores for both taste (4.28) and aroma (4.06), whereas the blue swimming crab treatment received the lowest scores, with 3.66 for taste and 3.58 for aroma. The soft-shell crab and mixed treatments showed intermediate values and remained relatively close to the control. These results indicate that the incorporation of crab shell flour does not necessarily reduce consumer acceptance, but the magnitude of the effect depends on the source of the shell flour (Romano & Zeng, 2008). The relatively lower scores for the blue swimming crab treatment may be associated with its stronger or more distinctive crab-derived sensory characteristics (Mohammad Ali et al., 2024). In contrast, the soft-shell crab and mixed treatments appeared to provide a more balanced sensory profile that was closer to the control product.

The detailed hedonic results are presented in Table 2. The superscript letters indicate the statistical grouping obtained from the reference DMRT analysis, allowing the numerical differences to be interpreted in conjunction with statistical significance.

Table 2. Hedonic Acceptance of Onion Sticks Containing Different Crab Shell Flours

Sensory attribute	Control	Soft-shell crab	Blue swimming crab	Mixed shell flour
Taste	4.28 ± 0.78^{a}	4.08 ± 0.78^{a}	3.66 ± 0.82^{b}	4.12 ± 0.69^{a}
Color	4.42 ± 0.64^{c}	4.08 ± 0.60^{b}	3.40 ± 0.83^{a}	3.96 ± 0.78^{b}
Aroma	4.06 ± 0.68^{b}	3.84 ± 0.82^{ab}	3.58 ± 0.88^{a}	3.86 ± 0.76^{ab}
Texture	4.14 ± 0.76^{a}	4.08 ± 0.78^{a}	3.84 ± 0.82^{a}	4.06 ± 0.74^{a}
Flavor	4.12 ± 0.77^{a}	3.96 ± 0.73^{ab}	3.76 ± 0.77^{b}	3.86 ± 0.86^{ab}
Overall acceptance	4.24 ± 0.65^{b}	4.16 ± 0.73^{b}	3.78 ± 0.82^{a}	4.02 ± 0.80^{ab}

Different superscript lowercase letters within the same row indicate significant differences among treatments according to DMRT at $p < 0.05$.

Table 2 demonstrates that the response of consumers varied among sensory attributes. Taste, color, aroma, and flavor showed differences in acceptance among treatments, whereas texture did not show a significant difference. The absence of a significant difference in texture is particularly relevant because the descriptive analysis indicated a higher sandy-texture intensity in the products containing crab shell flour (Acquavia, 2023). Despite this increase in perceived particulate texture, consumers still rated the texture relatively favorably, with scores ranging from 3.84 to 4.14. This suggests that the level of shell flour incorporated into the formulation did not substantially compromise the textural acceptability of the product. In contrast, color showed the clearest differentiation, with the control obtaining the highest score (4.42) and the blue swimming crab treatment the lowest (3.40). This finding is consistent with the instrumental and descriptive color results, demonstrating that visual changes associated with shell flour incorporation can influence consumer perception.

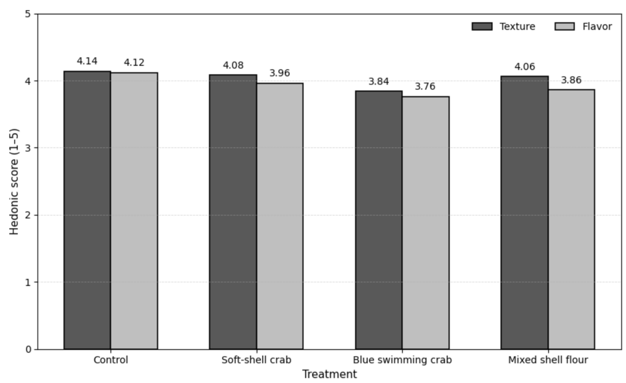

Figure 8. Consumer Acceptance Scores for Texture And Flavor of Onion Sticks Containing Different Crab Shell Flours.

Figure 8 shows that texture acceptance was relatively consistent across all treatments, with mean scores between 3.84 and 4.14. The control received the highest texture score, while the blue swimming crab treatment had the lowest, although the statistical grouping indicated no significant difference among treatments. Flavor acceptance showed a somewhat different pattern. The control scored 4.12, followed by soft-shell crab at 3.96, mixed shell flour at 3.86, and blue swimming crab at 3.76. This pattern corresponds with the descriptive analysis, in which crab flavor intensity was highest in the shell-flour treatments. Thus, increasing the intensity of crab flavor does not necessarily result in increased consumer liking (Versino et al., 2023). The result emphasizes the importance of achieving an appropriate sensory balance rather than maximizing the intensity of a characteristic attribute.

The relationship between sensory acceptance and treatment performance can be further summarized by considering the relative position of each treatment across the six evaluated attributes.

Table 3. Summary of Consumer Acceptance Patterns Across Sensory Attributes

Sensory attribute	Highest-rated treatment	Lowest-rated treatment	Reference score range	Main interpretation
Taste	Control (4.28)	Blue swimming crab (3.66)	3.66–4.28	Crab shell source influences taste acceptance
Color	Control (4.42)	Blue swimming crab (3.40)	3.40–4.42	Visual appearance is sensitive to shell-flour type
Aroma	Control (4.06)	Blue swimming crab (3.58)	3.58–4.06	Stronger crab aroma does not necessarily increase liking
Texture	Control (4.14)	Blue swimming crab (3.84)	3.84–4.14	No significant difference among treatments
Flavor	Control (4.12)	Blue swimming crab (3.76)	3.76–4.12	Moderate crab flavor is more acceptable than stronger intensity
Overall acceptance	Control (4.24)	Blue swimming crab (3.78)	3.78–4.24	Soft-shell crab treatment approaches control acceptance

Table 3 highlights an important product-development pattern. Although the control consistently produced the highest numerical score for most attributes, the soft-shell crab treatment remained close to the control across taste, aroma, texture, flavor, and overall acceptance. In particular, its overall acceptance score of 4.16 was statistically grouped with the control (4.24), indicating that the incorporation of soft-shell crab shell flour did not significantly reduce overall consumer acceptance. This is an important result because it demonstrates the possibility of replacing part of the conventional formulation with a shell-derived ingredient while maintaining a favorable sensory response (Shaker et al., 2021). Conversely, the blue swimming crab treatment consistently occupied the lower end of the acceptance range, suggesting that its sensory characteristics may require further formulation optimization.

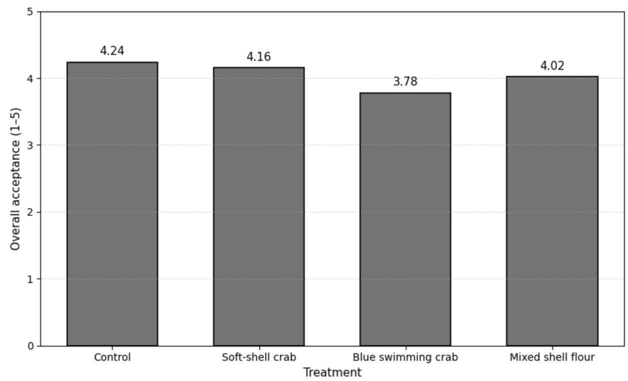

Figure 9. Overall Acceptance of Onion Sticks Containing Different Crab Shell Flours

Figure 9 provides the clearest indication of the overall consumer response. The control achieved the highest overall acceptance score (4.24), followed closely by the soft-shell crab treatment (4.16), mixed shell flour treatment (4.02), and blue swimming crab treatment (3.78). Importantly, the soft-shell crab treatment was statistically grouped with the control, indicating that its lower numerical score did not represent a significant reduction in overall acceptance. The mixed treatment occupied an intermediate position, while the blue swimming crab treatment had the lowest overall acceptance (Sathiadhas et al., 2003). From a product-development perspective, these findings suggest that soft-shell crab shell flour offers the most promising balance between functional utilization of crab shell waste and consumer acceptance.

The relatively favorable acceptance of the soft-shell crab treatment can be interpreted in relation to its descriptive sensory profile. This treatment produced a pronounced crab aroma and crab flavor, which confirms that the shell-derived ingredient successfully contributed a distinctive marine sensory identity (David et al., 2024). At the same time, its texture and overall acceptance remained close to those of the control. Therefore, the sensory characteristics generated by soft-shell crab flour appear to be sufficiently distinctive without causing a substantial negative effect on consumer preference.

The mixed shell flour treatment also demonstrated considerable potential. Its overall acceptance score of 4.02 remained within the "like" range of the five-point hedonic scale and was intermediate between the soft-shell crab and blue swimming crab treatments. The mixed formulation may provide an opportunity to balance the physicochemical and sensory characteristics associated with the two shell sources (Sapna et al., 2025). However, optimization of the mixing ratio would be necessary before drawing conclusions regarding its superiority or practical application.

Overall, the hedonic results indicate that soft-shell crab shell flour is the most promising treatment among the crab-shell formulations evaluated. Its overall acceptance was statistically comparable with the control, while its descriptive sensory profile demonstrated a clear crab-related identity. This finding supports the potential utilization of soft-shell crab shell waste as a value-added ingredient in snack products. Nevertheless, the results should be interpreted alongside nutritional composition, mineral content, processing efficiency, and potential food-safety considerations before the formulation is recommended for broader application (Pathak et al., 2021). The findings also demonstrate that successful food-waste valorization requires not only improving the functional or nutritional properties of a product but also maintaining sensory characteristics that are acceptable to consumers.

Conclusion

This study demonstrated the potential of crab shell waste as a value-added ingredient in onion stick production. The incorporation of soft-shell crab (*Scylla serrata*) and blue swimming crab (*Portunus pelagicus*) shell flours influenced several physicochemical and sensory characteristics of the resulting products. Among the physicochemical parameters, the most pronounced effect was observed in ash content, indicating the contribution of mineral-rich crab shell material to the product. Differences in instrumental color parameters (L*, a*, and b*) also demonstrated that the type of crab shell flour influenced the visual characteristics of the onion sticks, whereas moisture content remained relatively low across the treatments.

Descriptive sensory analysis showed that the incorporation of crab shell flour enhanced crab-related sensory characteristics, particularly crab aroma and crab flavor, while also increasing the perception of sandy texture. However, the incorporation of shell flour did not substantially affect perceived crispness or saltiness. These findings indicate that crab shell flour can provide a distinctive marine sensory identity while maintaining important textural characteristics of onion sticks.

The hedonic evaluation further demonstrated that the type of crab shell flour influenced consumer acceptance, particularly for taste, color, aroma, and flavor. The soft-shell crab treatment showed the most promising overall sensory performance among the crab shell formulations, with an overall acceptance score comparable to the control. In contrast, the blue swimming crab treatment tended to receive lower acceptance scores, particularly for color, taste, aroma, and overall acceptance. Overall, the findings suggest that soft-shell crab shell flour represents a promising ingredient for the valorization of crab shell waste into an acceptable value-added snack product. Further research should optimize the incorporation level and processing conditions and evaluate the nutritional composition, mineral bioavailability, storage stability, and food-safety characteristics of the resulting product to support its potential for broader food applications.

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