OPTIMIZATION OF DRY NOODLES ENRICHED WITH ANCHOVY AND MORINGA USING D-OPTIMAL MIXTURE DESIGN

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Abstract

People in Indonesia like to consume noodles, ranging from dry noodles to ready-to-eat noodles. These habits influence lifestyle and nutritional requirements for growth and health. However, its low protein content necessitates the enrichment of protein sources. Noodle products can increase nutritional content by fortifying anchovy and moringa leaf proteins. This study aimed to determine the optimal formulation using a D-optimal mixture design based on the chemical, physical, and sensory characteristics. A D-optimal mixture design (Design Expert v13) was used to optimize the proportions of sago starch (55-85%), anchovy flour (10-30%), and moringa leaf flour (5-15%). Chemical properties, physical characteristics, and sensory acceptance (5-point hedonic scale) were also evaluated. The results showed that the optimal formulation consisted of 57.72% sago starch, 27.28% anchovy flour, and 15% moringa leaf flour, with a desirability of 0.676. The optimized noodles exhibited higher protein content (16.97%) while maintaining acceptable sensory scores (color 3.30, aroma 3.20, and taste 2.97). These findings demonstrate that sago-based dry noodles enriched with anchovy and moringa can successfully enhance nutritional quality while maintaining acceptable sensory attributes.

Keywords: fish-based protein ingredients, functional noodles, mixture design, nutritional enrichment, sago starch

Optimasi Mi Kering yang Diperkaya Ikan Teri dan Daun Kelor menggunakan D-Optimal Mixture Design

Abstrak

Masyarakat Indonesia gemar mengonsumsi mi, mulai dari mi kering hingga mi instan. Kebiasaan ini memengaruhi gaya hidup dan kebutuhan nutrisi untuk pertumbuhan dan kesehatan. Namun, kandungan protein yang rendah menyebabkan perlunya pengayaan sumber protein. Produk mi dapat ditingkatkan kandungan gizinya dengan fortifikasi protein ikan teri dan daun kelor. Penelitian ini bertujuan untuk menentukan formulasi optimal menggunakan D-optimal mixture design berdasarkan karakteristik kimia, fisik, dan sensorik. D-optimal mixture design (Design expert v13) diterapkan untuk mengoptimalkan proporsi pati sagu (55-85%), tepung ikan teri (10-30%), dan tepung daun kelor (5-15%). Sifat kimia, karakteristik fisik, dan penerimaan sensori (skala hedonik 5 poin) dievaluasi. Hasil menunjukkan bahwa formulasi optimal terdiri dari 57,72% pati sagu, 27,28% tepung ikan teri, dan 15% tepung daun kelor, dengan desirabilitas 0,676. Mi yang dioptimalkan menunjukkan kandungan protein yang lebih tinggi (16,97%) sambil mempertahankan skor sensorik yang dapat diterima (warna 3,30, aroma 3,20, dan rasa 2,97). Temuan ini menunjukkan bahwa mi kering berbahan dasar sagu yang diperkaya dengan ikan teri dan moringa dapat berhasil meningkatkan kualitas nutrisi sambil mempertahankan atribut sensorik yang dapat diterima.

Kata kunci: bahan protein berbasis ikan, mi fungsional, *mixture design*, pengayaan nutrisi, tepung sagu

INTRODUCTION

Indonesia is one of the countries with rapidly growing noodle consumption, which aligns with consumer preferences. Noodles are the most widely consumed product in Indonesia and are often used as an alternative to rice (Amalia *et al*., 2024). Based on data from the World Instant Noodles Association (WINA), the consumption of noodles in Indonesia was 14.26 billion servings, and an increase in 2024 to a total of 14.7 billion. Indonesia ranked second, after China, with a total of 43.8 billion servings consumed. However, in terms of per capita consumption, Indonesia ranks fifth in the world with an average of 51.7 servings per year, higher than Japan and China, with 47.8 and 30.9 servings, respectively. People in Indonesia like to consume noodles ranging from dry noodles to ready-to eat noodles. This habit influences lifestyles and nutritional requirements for growth and health. In addition, this food is a solution to meet food needs because it is supported by the community's productive lifestyle (Mulyani *et al.,* 2020). Noodles are a popular processed food because they are easy to obtain, practical, convenient, inexpensive, and taste good (Canti *et al.,* 2020).

The relatively high consumption of instant noodles in Indonesia has led to an increase in the volume of wheat imports and the consumption of wheat flour. This could potentially reduce the country's foreign exchange reserves owing to the increased demand for noodles (Litaay *et al*., 2024). To reduce dependence on wheat and wheat flour, efforts are being made to develop raw material diversification technologies using local resources such as sago flour, moringa leaves, and tubers. Noodles are generally made from wheat flour and contain gluten, which contributes to the texture and viscoelasticity of the dough used to make them. Gluten also influences the durability of extensibility (Zheng *et al*., 2020). Indonesia is the second-largest sago producer in the world; however, its utilization is still not optimal because of its low protein content. In addition, sago has a gluten-free matrix that requires a protein binder. The addition of fish protein to sago-based products acts as a strengthening and binding agent. Several researchers have studied sago-based noodles, such as Sumarto *et al.* (2022), Martina *et al.* (2019), Litaay *et al.* (2022), Maslin *et al.* (2024), Maemunah *et al.* (2022). Therefore, increasing the protein content of sago-based noodles through fortification with high-protein food ingredients is necessary. Anchovy fortification can increase the nutritional value of sago protein and improve its texture, forming a matrix that strengthens the gel structure or sago dough, making it chewy, dense, and resistant to crumbling.

Wulandari *et al.* (2019) reported that anchovies contain both essential and nonessential amino acids. The essential amino acids are leucine, valine, isoleucine, and lysine, whereas the non-essential amino acids are aspartic acid and glutamic acid. According to Litaay *et al.* (2022), anchovies contain high nutritional content such as calcium 5,930.07 mg/100 g, phosphorus 31,112.0 mg/kg, protein 66.25%, and ash content 14.88%. Putra (2013) reported that the calcium content (Ca) of anchovies was 330.10 mg per 100 g, which was higher than that of cow's milk (106.32 mg per 100 g). Anchovy are small fish that are high in protein. The protein in anchovies, especially after processing into paste or flour, has excellent functional properties as a binder.

Anchovies are unique because all parts of their bodies can be consumed, including the head, meat, and bones. They contain high levels of Ca and P. This is beneficial for increasing bone density and preventing osteoporosis due to their high calcium and phosphorus content (Fadhilah *et al*., 2013). Furthermore, anchovies can serve as a functional dietary source to help meet daily mineral requirements (Rexi *et al*., 2025). The protein in anchovies, especially after processing into paste or flour, has excellent functional properties as a binder. Research has been conducted on noodles with added anchovies, such as noodles made from wheat flour, rice flour, tapioca flour, and anchovies (Ghaisany *et al*., 2018), cassava and anchovy (Winiastri, 2019), noodles made from wheat flour, anchovy flour, and moringa flour (Oppusunggu *et al*., 2023), and sago noodles enriched with anchovy flour (Novianti *et al*., 2024).

In addition to their low protein content, instant noodles also have the disadvantage of being low in fiber and several other nutrients, such as vitamins. This low fiber content can lead to digestive problems, such as constipation, if consumed in excessive amounts and not balanced with other fiber-rich foods. The addition of Moringa leaves to noodle products increases fiber content. Moringa leaf flour is a nutritious food supplement that can be added to food (Anggraini *et al*., 2024). Moringa leaves are functional foods that increase immunity due to their strong antioxidant compounds, such as flavonoids, 7.92% fiber, 2.41% lignin, 11% cellulose, and 10.24% hemicellulose (Fachriyah *et al.,* 2020; Aminah *et al*., 2015; Nisa *et al.,* 2018). Aminah *et al.* (2015) reported that moringa leaf flour has 12.63% fibre. Moringa leaves contain chlorophyll, a green pigment found in green vegetables. This can cause a color change in the noodles. The resulting noodles turn from yellowish white to green (Zakaria *et al*., 2016). One way to overcome the dark green color is to control the drying time and temperature to approximately 60°C. Off-flavor (bitterness) can be overcome by substituting with other flours (such as sago flour), hot water blanching (100°C for 3 min), and optimizing the low concentration of moringa flour.

The method used to determine the optimal combination was the Design Expert program through the D-Optimal Mixture Design. This method was used to optimize the formulations with varying range limitations. The advantage of using a mixture design is that it displays changes in the proportions of dry noodle ingredients owing to changes in the proportions of one or more other ingredients. This information cannot be displayed by factorial research designs, which are often used in research. According to Irianto and Giyatmi (2021), in formula research, it is impossible to vary one ingredient or component while keeping the others constant. If the proportion of one component is changed, at least one other component will change because the sum of all components always equals 1.0. In mixing combinations for a product, a mixture design is used to provide an optimal formula using the response data from the parameters of each preparation (Hidayat *et al.,* 2020). Several studies related to product optimization using mixture design include wet noodles fortified with *Spirulina platensis* L. powder (Setyawan *et al*., 2025), snakehead fish (*Channa striata*) cookies (Salampessy *et al*., 2024), skipjack tuna floss made from banana blossom composites (Dzikri *et al*., 2025), gluten-free cookies made from sago starch, sweet potato paste, and mung bean paste (Haliza & Purwani, 2022), and mackerel tuna (*Euthynnus affinis*) snack bars (Salampessy *et al*., 2023).

The use of mixture design to modify recipes has been studied; however, no study has optimized the combination of sago, anchovy flour, and Moringa leaf flour using a mixture design approach. This study is the first to optimize sago-based noodles incorporating anchovy and moringa flour using a mixture-design approach. This approach can provide the appropriate formulation recommendations for the development of high-protein dry noodle products. The purpose of this study was to obtain an optimal dry noodle formulation with a combination of sago starch, anchovy flour, and moringa leaf flour using a D-Optimal Mixture Design.

MATERIALS AND METHODS

Noodle Making Process

Fresh anchovies were obtained from Blanakan, Subang; sago flour from Ambon, Maluku; and moringa flour from Garut. The noodle-making process, as described by Litaay *et al*. (2023), involves three stages: dough making, molding, and drying. The anchovies were washed under running water and soaked in 0.8% sodium bicarbonate for 45 min. The next step involved boiling the anchovies for 15 min at 80°C, pressing for 10 min, drying for 5 h at 55°C, and grinding to a flour size that passed through a 60-mesh sieve.

The processing of noodles begins with sago flour (55-85%) added anchovy meal (10-30%), and moringa leaf flour (5-15%) of a total weight of 500 g, then added 25% of water and 2% of salt, and the batter is mixed with a mixer (Philips, Netherlands) at a speed of 600 rpm for 15 min. Next, the starch pre-gelatinization process was carried out at 80 °C for 30 min, the formation of strands of noodles with extruders 70 °C (130 rpm, die diameter 2 mm, screw barrel 40 cm) and then tempered at room temperature 27 °C (48 hours).

The upper and lower limit values used in the mixture design were as follows: sago starch, limit–55-85%, anchovy flour 10-30%, and moringa leaf flour 5-15%. The formulation combination was based on Design Expert 13.0, as shown in Table 1. The acceptance of noodle products from mixture design I and II formulas was determined based on a hedonic test. The hedonic test involved 30 untrained panelists. The test consisted of three assessment attributes: color, aroma, and taste.

Proximate Test

The chemical analysis of dry noodles was performed for moisture, ash, fat, and protein content using the methods of the Association of Official Analytical Chemists (AOAC, 2015). Proximate analyses were carried out to determine the moisture, ash, fat, and protein content according to SNI 3551:2018 (BSN, 2018).

Physical Test

Rehydration capacity

The physical properties of dry noodles were analyzed for rehydration capacity (Ko *et al.*, 2015). Rehydration capacity is the ability to bind water through hydrogen bonds and is expressed as the ratio of the mass of noodles before and after cooking. The steps in testing rehydration capacity included weighing the noodle sample to determine its initial

Table 1 Formula combinations of sago starch, anchovy flour, and moringa leaf flour based on design expert 13.0

Run	Sago starch (%)	Anchovy flour (%)	Moringa leaf flour (%)
1	65	30	5
2	75	10	15
3	75	20	5
4	70	20	10
5	65	20	15
6	55	30	15
7	85	10	5
8	65	25	10
9	65	30	5
10	80	10	10
11	85	10	5
12	55	30	15
13	70	20	10
14	60	30	10

n=3; The range = sago starch 55-85%; anchovy flour 10-30%; moringa leaf flour 5–15%.

weight before cooking, and then adding 10 g of noodles to 200 mL of boiling water for 5 min. The boiled noodles were then drained for 3 min and weighed to determine the final noodle weight. The rehydration capacity was calculated as follows:

$$\text{Rehydration capacity (\%)} = \frac{A-B}{B} \times 100$$

where:
A = cooked noodles weight (g)
B = raw noodle weight (g)

Elongation

The physical properties of dry noodles were analyzed for elongation (Chen *et al.*, 2002). Elongation was measured using a TAXT2 texture analyzer at a speed of 3 mm/s and a force of 100 g. One strand of noodles that had been boiled for 4 min was wrapped around the probe, with a distance between probes of 2 cm and a probe speed of 0.3 cm/s. The percent elongation was calculated using the following formula:

$$\text{\% Elongation} = \frac{\text{sample dropond time(s)0.3 cm/s}}{\text{2 cm}} \times 100$$

Color

The physical properties of dry noodles were analyzed for color (Gaurav, 2003). Color testing was performed using a Minolta chromameter (type CR 200, Japan). The chromameter was first calibrated using the white standard found on the instrument. Several samples were placed in a flat container. The measurements produced values of L, a, and b. L represents the brightness parameter (achromatic color, 0 = black to 100 = white). The chromatic color of the red-green mixture is indicated by the value of a (a+ = 0-100 for red, a- = 0–(-80) for green. The chromatic color of the blue-yellow mixture is indicated by the value of b (b+ = 0-70 for yellow; b- = 0–(-70) for the color blue). Measurement of color using the equation:

$$W = 100 - \sqrt{((100-L)2+a2+b2)}$$

where:
W = degree of whiteness L = brightness
a = red if it is + and green if it is
b = yellow if it is + and blue if it is –

Organoleptic Test

The organoleptic response to the dried noodle product was a hedonic test (like test) as an acceptance test using a hedonic scale transformed into a numeric scale of 1-5 according to SNI 01-2346-2006 with the following criteria: 1 (dislike extremely), 2 (dislike), 3 (neutral), 4 (like), and 5 (like very much), using 30 panelists. The products were presented one by one, and the panelists were asked to rate them using a provided scale without comparing one product to another. Sensory testing was conducted at the Organoleptic Laboratory of Pasundan University. The tests were anonymous, and the order of the samples was randomized when served at 30°C.

Data Analysis

Sago starch, anchovy flour, and moringa leaves, the main components of the noodle formula, were the variables studied using a mixture-design approach. The analysis design conducted in Design Expert 13.0 with three replications consists of the following stages: model selection is statistically significant if its P-value is less than 0.05 (<0.05), while p-value is higher than 0.05 (>0.05) is not statistically significant. The model summary statistics are a higher R2 value, a smaller PRESS value, and a smaller standard deviation (Nurhalimah, 2018). Analysis of variance (ANOVA) was performed after the model selection. The program then provided recommendations for the optimum formula. The optimum solution yielded desirability values ranging from 0 to 1. The closer it is to 1, the more difficult it is to achieve, given the complexity of the test variables, and the higher the optimization target value. Optimization was performed to achieve maximum desirability. However, the primary goal of optimization is not to achieve a desirability value of 1, but rather to find the right combination of various ingredient compositions (Rezkywianti 2016). The selected formulation underwent a verification stage (n=3), which compared the program results with laboratory analysis to measure the degree of accuracy (Ghozaly *et al.*, 2018). In this study, 14 formulations were offered to produce an optimal formulation (selected). The selected product was analyzed for chemical responses (moisture, ash, fat, protein, and carbohydrate content) and additional physical responses (cooking time, rehydration power, elongation, and color).

RESULTS AND DISCUSSION

Chemical Composition

Moisture

The moisture content test results ranged from 10.64-11.4±0.21%. ANOVA results showed a significant special quartic model at the 5% level (p = 0.0285 < 0.05). The chosen special quartic model for moisture content showed R^2 = 0.91, adj-R^2 = 0.76, and lack-of-fit was (F = 0.82, p = 0.41). This indicates that the combination of sago starch, anchovy flour, and moringa leaf flour significantly influences the moisture content of dry noodles. This model had a standard deviation of 0.1012 and a mean of 11.06.

The analysis of the 3D graph (Figure 1) indicates an interaction between each component that can influence the response. The optimal results are represented by a green to yellow color gradation. The components with the greatest influence on the graph are highlighted in red. As shown in the graph below, sago starch is a component with a relatively high concentration that influences the water response. The greater the addition of sago starch, the greater the moisture content of the dry noodles because the amylopectin content in sago starch has hydrophilic properties, allowing it to retain water during heating. The increase in moisture content corresponded to an increase in temperature due to the absorption of water into the starch granules during the pregelatinization process. This results in changes in the starch structure, namely, an increased starch swelling capacity. According to Fitriani *et al.* (2023), starch swelling occurs due to increased water absorption into starch granules. The higher the degree of starch gelatinization, the more significant the particle change. As the heating temperature increases during the gelatinization process, starch particles absorb a large amount of water, resulting in changes in the starch structure (Ma *et al.*, 2022).

The higher the amylose content, the drier, less sticky, and more easily absorbable the starch. However, if the amylopectin content is high, the starch will be wetter and tend to absorb less water (Saripudin, 2006). According to Hasroni *et al.* (2016), instant noodles with 95% sago starch have a moisture content of 9.72%, whereas Yuliani *et al.* (2015) found that dry noodles with 95.3% sago starch had a moisture content of 11.76%.

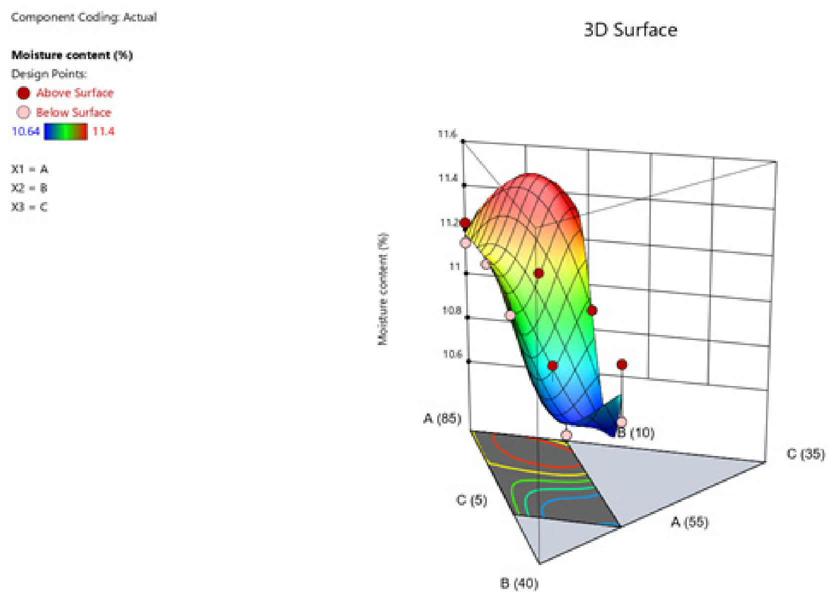

Figure 1 Response surface and contour plot of moisture content (%) as affected by sago starch (A), anchovy flour (B), and moringa leaf flour (C).

The interaction between sago starch and anchovy and moringa leaf flour also influenced the moisture content. Anchovy flour is hygroscopic, which means that it absorbs water. The higher the fish meal addition, the lower was the moisture content. Irsalina *et al.* (2016) showed that noodles supplemented with 20% muttonfish flour had a moisture content of 10.42%, which was lower than that of the control (15.33%). Moringa leaf flour contains crude fiber, which is insoluble and can bind water. The crude fiber content of Moringa leaf flour is 16.9% (Saloko *et al.*, 2020). According to SNI 3551:2018 (BSN, 2018), noodles have a maximum moisture content limit of 14.5%.

Ash

The ash content test results ranged from 5.89-12.63±2.25%. The ANOVA results showed that the recommended special quartic model was significant at the 5% level ($p = 0.0001 < 0.05$). The chosen special quartic model for ash content showed $R^2 = 0.99$, adj-$R^2 = 0.98$, and lack-of-fit was ($F = 6.11$, $p = 0.06$). This indicates that the proportions of sago starch, anchovy flour, and moringa leaf flour significantly influenced the ash content of the dry noodles. This model had a standard deviation of 0.2379, with a mean of 9.20.

The 3D graph (Figure 2) shows the interaction between each component that can influence the response. Optimal results were achieved with a color gradient between green and yellow. In the graph, the components with the greatest influence on the ash content were anchovy flour and moringa leaf flour, as indicated by the green line. Based on the research by Irsalina *et al.* (2016), the increase in ash content in dry noodles was due to the addition of muttonfish flour, where the ash content ranged from 13.56% to 16.45%. This value is still quite high compared to the study by Silaban (2022), which found that the ash content in snakehead fish noodles with the addition of 9% *porang* flour was 4.63%. The increase in ash content was due to the relatively high mineral content of fish flour. Litaay *et al.* (2021) explained that anchovy flour soaked in sodium bicarbonate for 15 minutes had a calcium content of 5701.52 mg/100 g and a phosphorus content of 24,469.99 mg/kg, respectively.

In addition to fish meal, the addition of moringa leaf flour may also influence the ash content. Kurniawati and Fitriyya (2018) found that moringa leaf flour has an ash content of 11.67%. In addition to its other ingredients, moringa leaf flour is suspected to contain high levels of mineral compounds. According to Rahmi *et al.* (2019), the increase in ash content in moringa wet noodles corresponds to an increase in calcium content, with moringa leaf flour containing 2.003 mg/100 g of calcium. According to SNI 3551:2018 (BSN, 2018), noodles do not have ash content standards.

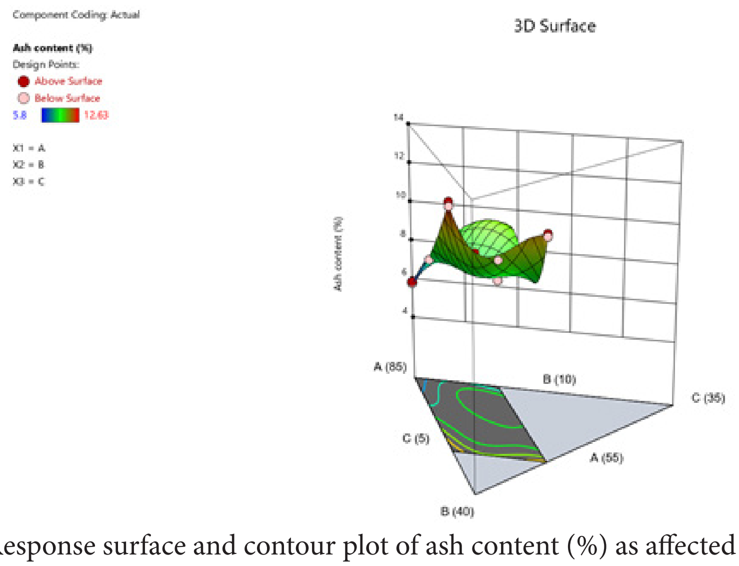

Figure 2 Response surface and contour plot of ash content (%) as affected by sago starch (A), anchovy flour (B), and moringa leaf flour (C).

Fat

The results of the dry noodle fat content test ranged from 0.64-1.07±0.15%. The ANOVA results show that the special quartic model is significant at 5 % ($p = 0.0001 < 0.05$). The chosen special quartic model for fat content showed $R^2 = 0.99$, adj-$R^2 = 0.97$, and lack-of-fit ($F = 4.91$, $p = 0.09$). This value shows that the proportion of the combination of sago starch, anchovy flour, and moringa leaf flour in the ingredients provides a significant difference in the fat content of dry noodles. This model had a standard deviation of 0.0245 and an average value of 0.8721.

The 3D graph (Figure 3) analysis shows the interaction between each component that can influence the response of the sensor. Optimal results were obtained in the green-yellow gradation. In the graph, the component with the greatest influence on the fat content was anchovy flour, as indicated by the red line. Fat content is suspected to be influenced by the composition of the anchovy flour, as preliminary analysis showed a fat content of 0.74%. This value is consistent with the research conducted by Litaay *et al.* (2023), who showed that the fat content of noodles with the addition of 9% anchovy flour (1.97%) was higher than that of the control (0% anchovy flour) and other anchovy flour fortifications. However, this value was still quite low compared to research (Silaban, 2022) which showed the fat content of snakehead fish noodles (2.06%) reported by Silaban (2022). These findings illustrate the importance of incorporating fish and moringa proteins, which significantly influence the ash content of enriched noodles. According to SNI 3551:2018 (BSN, 2018), noodles do not yet have fat content standards.

Protein

The results of testing the protein content of the dried noodles ranged from 4.55-17.99±5.34%. The ANOVA results show that the quadratic model is significant at 5 % ($p = 0.0001 < 0.05$). The chosen quadratic model for protein content showed $R^2 = 0.99$, adj-$R^2 = 0.98$, pred-$R^2 = 0.98$, PRESS = 7.44, and lack-of-fit ($F = 6.38$, $p = 0.05$). This value indicates that the combination of sago starch, anchovy flour, and moringa leaf flour provides a protein content that significantly affects dry noodles. This model had a standard deviation of 0.5718 and an average value of 12.84.

The 3D graph (Figure 4) shows the interaction between each component that can influence the response. The optimal results are represented by a green-yellow color gradation. In the graph, the components with the greatest

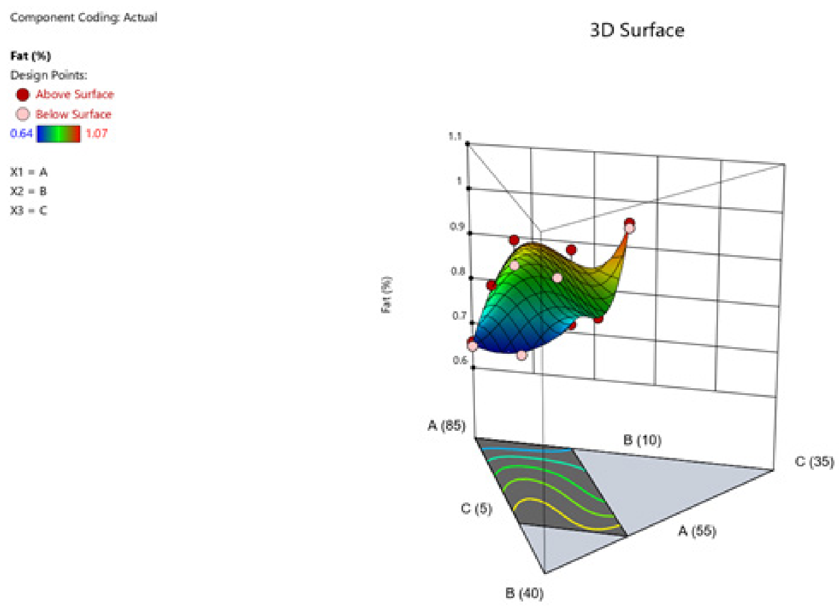

Figure 3 Response surface and contour plot of fat content (%) as affected by sago starch (A), anchovy flour (B), and moringa leaf flour (C).

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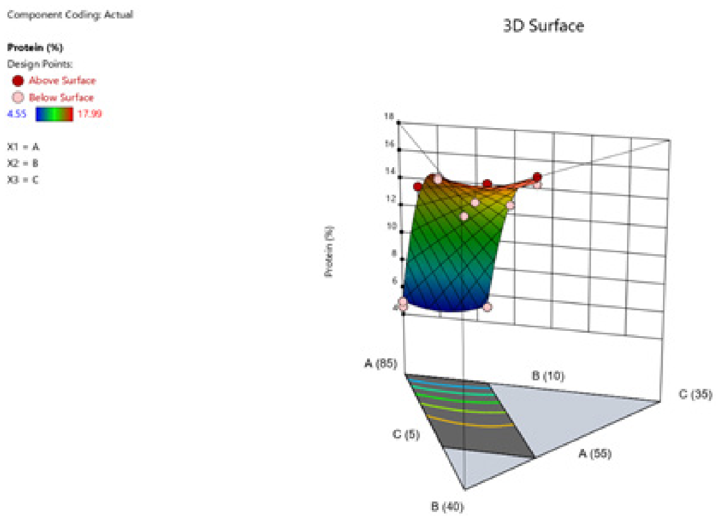


Figure 4 Response surface and contour plot of protein content (%) as affected by sago starch (A), anchovy flour (B), and moringa leaf flour (C).

influence on protein content are anchovy flour and moringa leaf flour, as indicated by the red lines. Consistent with preliminary research, the protein content of anchovy flour was 67.04%. According to Litaay *et al.* (2023), the protein content of noodles without anchovy flour fortification is 0.37-8.59%. The highest protein content was found in sago noodles with 9% anchovy flour (8.59 %) compared to the 0% control noodles (0.37%). The protein content of dried sago noodles with skipjack fish meal fortification was 1.78–7.70% (Litaay *et al.*, 2022a). In comparison, the protein content of snakehead fish noodles with the addition of 9% porang flour was 11.04% (Silaban 2022).

Moringa leaf flour has a high protein content, and the moringa plant has a high essential amino acid content. Kurniawati and Fitriyya (2018) reported that the protein content of Moringa leaf flour is 23.37%. This value is in accordance with the research of Saloko *et al.* (2020), who reported that the protein content of moringa leaf flour is 26.09%. The higher the concentration of moringa leaf flour, the higher the protein content in the noodles. Salman *et al.* (2016) reported that wet noodles with the addition of tempeh flour and moringa leaf flour had a protein content ranging from 18.31-25.90%. Therefore, noodles made from local sago enriched with fish meal and moringa flour can enhance the nutritional value of noodles, which is known for its higher protein content. SNI 3551:2018 (BSN, 2018) mandates a minimum protein content of 6.0% for instant noodles.

Carbohydrates

The results of the test of the carbohydrate content of these dried noodles ranged from 57.79-77.66±7.44%. The ANOVA results show that at the 5% level, the special quartic model is significant with $p = 0.0001 < 0.05$. This indicates that the combination of sago starch, anchovy flour, and moringa leaf flour significantly affected the dry noodles. This model had a standard deviation of 0.2475 and an average value of 66.03.

Based on the obtained equation, the addition of A (sago starch), B (anchovy flour), and C (moringa leaf flour) significantly affected the carbohydrate content of the dry noodles. The interaction between the two components, ABC2, resulted in a decrease in carbohydrate content, as indicated by a negative value.

The 3D graph (Figure 5) shows the interaction between each component that can influence the response. Optimal results were achieved with a color gradient between green and yellow. The component with the greatest influence on the carbohydrate content was sago starch, as indicated by the red line. Sago starch has a high carbohydrate content. According to Akbar (2023), sago

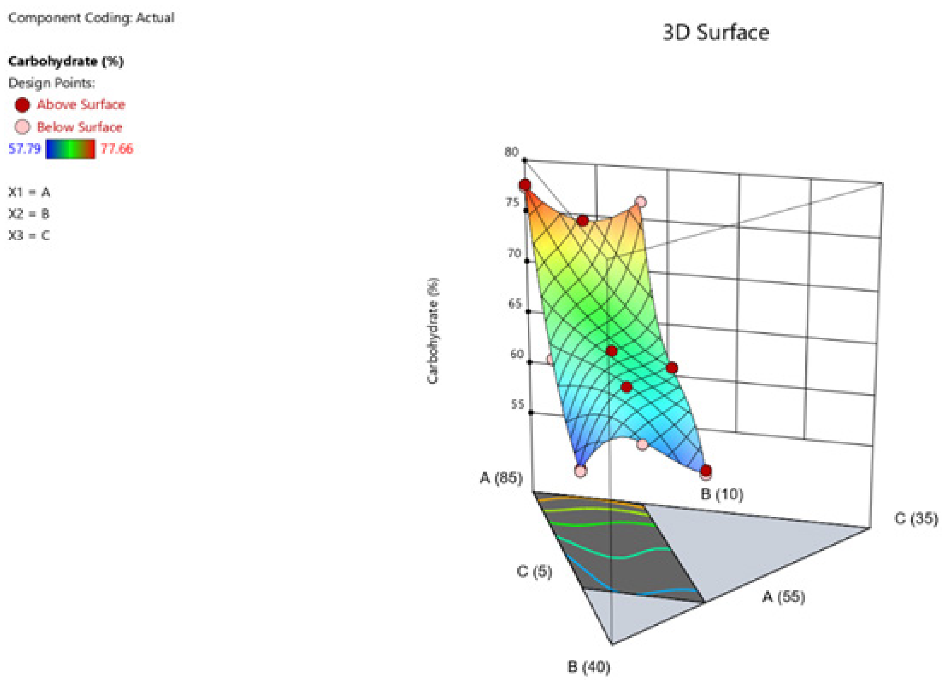


Figure 5 Response surface and contour plot of carbohydrate content (%) as affected by sago starch (A), anchovy flour (B), and moringa leaf flour (C).

starch carbohydrates comprise 89.09% of its composition. The carbohydrate content of dried sago noodles was 86.63%. In addition, Moringa leaves can increase the carbohydrate value of Engelen's (2023).

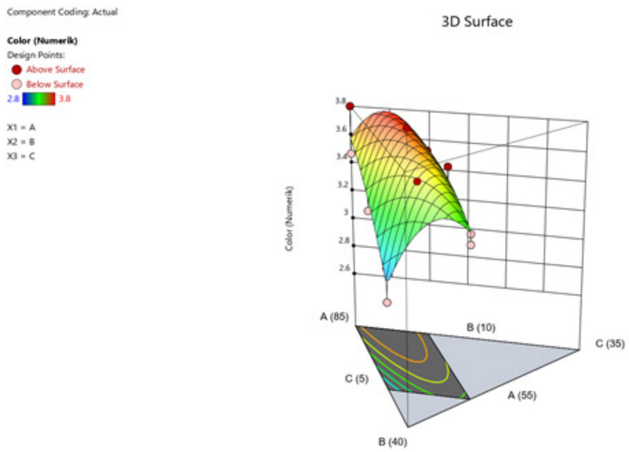
In Lanita's (2023) study, moringa noodles exhibited increased nutrient content after the addition of moringa, including carbohydrates, protein, fat, fiber, iron, calcium, and several vitamins. The addition of anchovy flour tends to reduce the carbohydrate content. Irsalina *et al.* (2016) argue that the decrease in carbohydrate content in dry noodles with the addition of motan fish is due to the ability of carbohydrates to combine with other compounds. Carbohydrates often combine with other compounds, such as proteins, to form glycoproteins. The heat process during printing using an extruder can cause a Maillard reaction between amino compounds and reducing sugars, resulting in a decrease in carbohydrate content. Based on 3551:2018 (BSN, 2018), noodles do not yet have carbohydrate content standard.

Dried Noodle Sensory

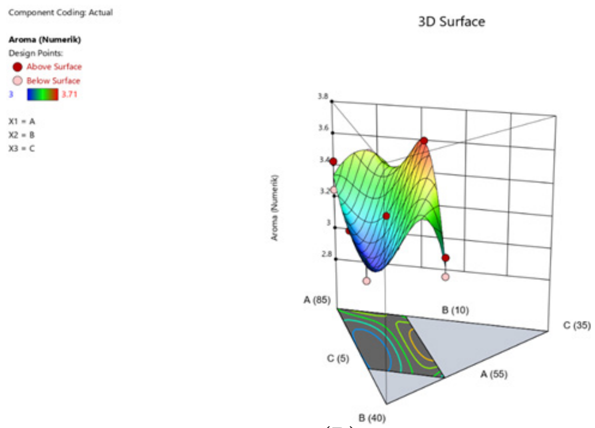
The hedonic response for the color attribute of these dried noodles ranged from 2.8–3.8. The ANOVA results showed significance at the 5% level, with $p = 0.0073 < 0.05$ (Figure 6). This indicates that the combination of sago starch, anchovy flour, and Moringa leaf flour resulted in significantly different color response values in the dry noodle model. This model had a standard deviation of 0.1513 and an average value of 3.42.

Optimal results were achieved with a green-to-yellow gradation. The maximum color sensory response was observed in the color of the moringa leaf flour, which significantly influenced the hedonic test of the color attribute. The red line indicates this value. The green color of moringa leaf flour is due to chlorophyll. This compound plays a role in the photosynthesis process by absorbing and converting sunlight energy into chemical energy (Salman *et al.*, 2016). The greater the amount of moringa leaf flour added, the darker the noodle color (blackish green).

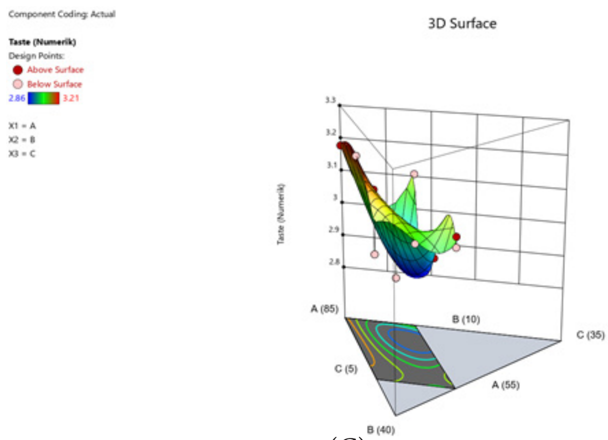
The hedonic response for the aroma of these dry noodles ranged from 3.00 to 3.71. ANOVA results showed no significance at the 5% level with $p = 0.0816 > 0.05$ (Fig. 6). This value indicates that the proportions of sago starch, anchovy flour, and moringa leaf flour



(A)



(B)



(C)

Figure 6 Mixture design graph showing the sensory response characteristics of noodles: color (A); aroma (B); taste (C).

in the ingredients did not significantly differ in aroma response values in the dry noodle model. This model had a standard deviation of 0.1130 and an average value of 3.26.

The optimal result is in the gradient of green and yellow on the graph of the component that has a great influence on the hedonic test of aroma attributes, namely, moringa leaf flour, which is marked with a red line. The musty smell produced in noodles comes from the moringa leaf powder because moringa leaves contain lipoxygenase enzymes, which are enzymes found in green vegetables. Lipoxygenase enzymes hydrolyze or decompose fats into compounds that cause musty odors, which are classified into hexanal 7 and hexanol groups (Wulantika & Fakhry, 2022). The interaction between sago starch, anchovy flour, and moringa leaf flour did not significantly affect aroma. The addition of anchovy flour will give rise to a very strong characteristic aroma of fish, and the addition of moringa leaf flour will create an aroma similar to that of typical moringa leaves.

The hedonic response to the flavor attributes of these dried noodles ranged from 2.86 to 3.21. The ANOVA results show a significant 5% level with $p = 0.3388 > 0.05$ (Fig. 6). This value indicates that the proportion of the combination of sago starch, anchovy flour, and moringa leaf flour in the ingredients provides an aroma response value that is not significantly different in the dry noodle model. The model had a standard deviation of 0.0882 and an average value of 3.07.

The interaction between each component can affect the responses. The optimal result is represented by a gradient of green and yellow. In the graph, the component that has a great influence on the hedonic test of taste attributes is anchovy flour, which is marked with a red line. Anchovy flour added to noodles at various concentrations imparts a typical savory taste. However, there was a slight bitter aftertaste that varied according to the concentration of moringa leaf flour added. The addition of more moringa leaves can indirectly affect the taste of the noodles. The typical bitter taste of moringa leaves is due to the presence of tannin compounds (Mukarromah *et al.*, 2021).

Determining The Optimal Formulation

After the response analysis, the formula optimization stage was performed using Design Expert 13. The best noodle formulation was the one with a desirability value close to 1. A desirability value close to 1 indicates that the formulation has reached its optimum value, according to the desired response variables. Table 2 shows the optimized components, target values, limits, and importance values at the formulation stage.

The optimization phase yielded the best formula solution from several suggested formulas with optimum desirability values. Desirability is the degree of certainty of an optimal solution or formulation. The closer the value is to one, the higher the certainty of the formulation. Therefore, a desirability value of 1.00 indicates that the resulting formulation has a high certainty. The optimization phase yielded five formulae. The results of the

Table 2 Optimized components and responses, targets, limits, and importance at the formula optimization stage

Component/Response	Goals	Lower limit (%)	Upper limit (%)	Importance
Sago starch (%)	3	55	85	Low
Anchovy flour (%)	5	10	30	High Importance
Moringa leaf flour (%)	5	5	15	High Importance
Water (%)	5	10.64	11.4	High Importance
Ash (%)	5	5.8	12.63	High Importance
Fat (%)	3	0.64	1.07	Low
Protein (%)	5	4.55	17.99	High Importance
Carbohydrate (%)	3	57.79	77.66	Low
Color (Hedonic scale)	4	2.8	3.8	Medium
Aroma (Hedonic scale)	5	3	3.71	High Importance
Taste (Hedonic scale)	5	2.86	3.21	High Importance

Optimization criteria established in Design-Expert 13.

http://dx.doi.org/10.17844/1gvhcc48

Table 3 Optimal formula solution results from design expert program 13

No	Sago starch %	Anchovy flour %	Moringa leaf	Importance	
1	57.72	27.29	15.00	0.68	Selected
2	62.80	26.48	10.70	0.65	
3	73.99	11.00	7.62	0.37	

Predicted values generated by D-optimal mixture model

formula solution are presented in Table 3.

The optimization formula had a desirability value of 0.676, indicating that this formula produced a product with characteristics that met the optimization target of 67.6%. This formula is predicted to have a moisture content of 10.60%, ash content of 9.177%, fat content of 0.951%, protein content of 17.392%, carbohydrate content of 61.679%, color content of 3.374, aroma content of 3.408, and flavor content of 3.108. The desirability values and target optimization for each dry product formula are shown in Figure 7 and 8.

Verification of Optimization Results

The selected formulation is the optimal solution predicted by the design expert using

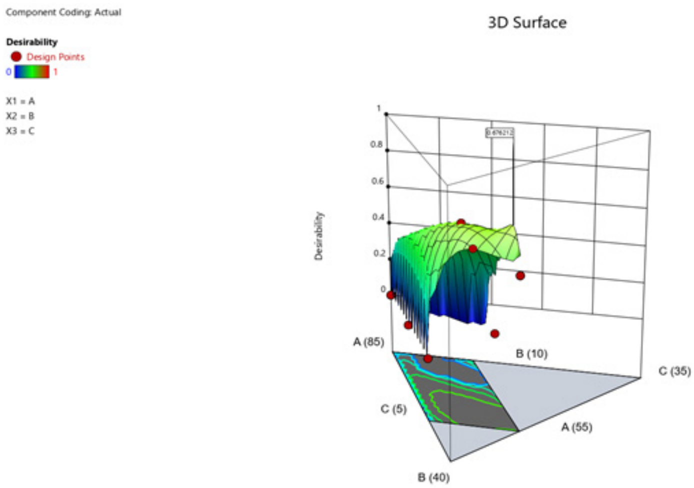


Figure 7 3D desirability graphic of all dry noodle formula

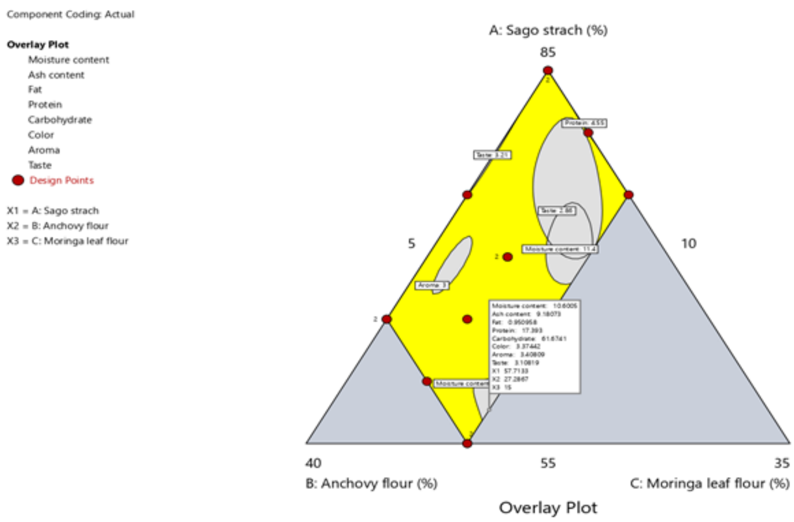


Figure 8 Target optimization for each dry product formula

the d-optimal mixture design method, which is based on analyzing chemical responses (moisture, ash, fat, protein, and carbohydrate) and hedonic test responses (color, aroma, and flavor attributes).

Based on the desirability of the optimal sago starch noodle formulation with the addition of anchovy flour and moringa leaf flour, one formulation yielded 57.72% sago starch, 27.28% anchovy flour, and 15% moringa leaf flour. Table 4 compares the analysis results of the design expert program using the d-optimal mixture design method with laboratory analysis.

Based on the verification conducted, the laboratory analysis results are in agreement with the predicted results not significantly different. The resulting values met the 95% Confidence Interval (CI) and 95% Prediction Interval (PI) predicted by the Design Expert 13 program.

Physical Characterization of The Optimal Formula

The selected optimal formulation was subjected to physical analysis, including cooking time, rehydration capacity, elongation, and color. The results of the research on the optimal formulation obtained a cooking time of 3.01 min. The addition of protein can affect the cooking time of the resulting noodles because carbohydrates and proteins compete for water absorption. Proteins prevent water from entering starch granules. The water used to gelatinize the starch is also bound by the protein, requiring a longer cooking time due to this competition. Dried gelatinized starch can absorb significant amounts of water. The protein content of food can affect the ability of noodles to absorb water (Sari *et al*., 2022). The formation of complex bonds between starch and protein is due to the high protein content of noodle products. This can affect the water absorption of noodles (Canti *et al*., 2022). The interaction between proteins and starch polysaccharides significantly influences food structure. The addition of large amounts of fish protein results in competition between carbohydrates and water molecules (Litaay, 2012; Tuhumury *et al*., 2020).

High water absorption reduces the cooking time (Yustriani, 2000). In addition, the process of mixing fishmeal in the dough disrupts the bonds between starch molecules, allowing water to enter more easily. The faster the penetration of water, the shorter the cooking time (Litaay, 2012). Research conducted by Litaay *et al*. (2023) showed that noodles with added anchovy flour had a cooking time of 7.12-6.86 minutes. The higher the concentration, the shorter the cooking time. Husna (2017) study on sago starch noodles with added moringa leaf extract ranged from 5.13-7.59 minutes, but compared with Utami (2021) found cooking time for instant moringa noodles ranged from 3.78-4.03 minutes.

The rehydration capacity of the optimal formulation was 68.32%. This value indicates that the water absorption ability is influenced by the protein content of the product. As the protein content increases, complex bonds

Table 4 Comparison of research response values with design expert 13 predictions

Analysis	Prediction	Mean±Std.Dev	Error (%)	p-value
Moisture	10.600	11.06±0.10	0.14	0.02
Ash	9.177	9.20±0.24	0.34	0.00
Fat	0.951	0.87±0.02	0.04	0.00
Protein	17.392	12.84±0.57	0.67	0.00
Carbohydrates	61.678	66.03±0.25	0.35	0.00
Color	3.374	3.42±0.15	0.18	0.00
Aroma	3.408	3.26±0.11	0.16	0.08
Taste	3.108	3.07±0.09	0.13	0.34

Values are means ± SD (n=3). Differences tested by paired t-test are formed between proteins and starch, which can affect water absorption (Irsalina *et al.*, 2016). The water absorption values of dried noodles with the addition of 0% motan fishmeal (control) and 20% motan fishmeal were 139.13% and 152.20%, respectively. In addition to protein content, the fiber content of moringa leaves is thought to influence the rehydration capacity of the noodles. The fiber in Moringa leaf meal can absorb water. This finding is consistent with that of Husna *et al.* (2017), who found that the absorption capacity of sago starch noodles with the addition of moringa leaf extract ranged from 324.43% to 335.33%.

The optimally formulated noodles had an elongation value of 27.72. This indicates that the addition of fish meal is influenced by the protein content, which influences the resulting noodle texture. Irsalina *et al.* (2016) found that the protein used in flour affects noodle texture. The more protein added, the stiffer the noodles and the lower the elasticity. The elongation value for the dry noodle control was 31.00%, whereas that for 20% Motan fish meal was 17.00%. This statement aligns with the study of Stevani (2015) on wet noodle production using snakehead fish bone meal. The higher the amount of snakehead fish bone meal added, the lower was the elongation value.

Color greatly affects the appearance of the produced noodles and plays an important role in attracting consumer interest in determining a product. The color measurement results showed that the optimal formulation noodles had a brightness (L) of 48.76 on a scale of 100, indicating that the color of the noodles tended to be dark. The reddish value (a+) was 1.85, whereas the yellowish value was 23.93 (b+).

The resulting noodles were dark green owing to the dominant green pigment, chlorophyll, in the fish meal. Saloko *et al.* (2020) found that the brightness value of noodles with 15% moringa leaf flour was 48.61, while that without the addition of moringa leaf flour was 27.21. In addition, the addition of anchovy flour resulted in a dark noodle color. According to Litaay *et al.* (2022b), the higher the anchovy flour content in the dough, the more it affects the decrease in brightness value. Anchovy flour contains protein and reduced sugars, which undergo a Maillard reaction during the noodle molding process in the extruder. The Maillard reaction occurs when primary amino groups react with reducing sugars, resulting in a brown color (Ihsan, 2020).

The redness and yellowness of the noodles decreased because the brownish-green color of the moringa leaf and anchovy flours masked them. This statement aligns with the research conducted by Irsalina *et al.* (2016), who found that the chroma value of dry noodles with the addition of mutton fish flour ranged from 12.9 to 23, and the hue value ranged from 62.9 to 73.5, which can be categorized as yellow red.

CONCLUSION

The optimal formulation recommended by the D-optimal mixture design for sago-based dry noodles enriched with anchovy and moringa leaf flour consisted of 57.72% sago starch, 27.28% anchovy flour, and 15% moringa leaf flour, with a desirability of 0.676. The optimized noodles showed a higher protein content (16.97%) while maintaining acceptable sensory scores (color 3.30, aroma 3.20, and taste 2.97), with standards SNI 3551:2018 (BSN, 2018) mandating a minimum protein content of 6.0% instant noodles.

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