Effects of modified casava flour (MOCAF) substitution on physicochemical properties and sensory attributes of threadfin bream (*Nemipterus* sp.) meatballs

Sukoso[1*], *Erlangga* Dharmawangsa[1], *Hartati* Kartikaningsih[1], *Yahya*[1], *and Nurul* Huda[1,2]

[1]Faculty of Fisheries and Marine Science, Universitas Brawijaya, Malang, 65145, East Java, Indonesia
[2]Faculty of Sustainable Agriculture, Universiti Malaysia Sabah, Sandakan 90509, Sabah, Malaysia

Abstract. Currently, the utilization of threadfin bream is limited to basic processing methods, resulting in low consumer acceptance. This study investigated the effects of modified cassava flour (MOCAF) substitution on the physicochemical and sensory properties of threadfin bream (*Nemipterus* sp.) meatballs. A completely randomized design was employed with seven treatments: MOCAF substitution at 0%, 20%, 40%, 60%, 80%, 100%, and a commercial product as a positive control. Results demonstrated significant effects ($p < 0.05$) of MOCAF substitution across all evaluated parameters. The optimal formulation, determined through sensory evaluation, was achieved with 40% MOCAF substitution, yielding the following characteristics: sensory scores for appearance (4.50 ± SE), aroma (4.31 ± SE), texture (4.52 ± SE), and taste (4.37 ± SE); proximate composition of moisture (67.53%), protein (14.47%), ash (1.64%), lipid (0.55%), and carbohydrate content (15.81%); textural properties with elasticity of 60.97 N; and instrumental colour measurement with lightness (L*) value of 60.97. The optimal formulation consisted of 60% tapioca and 40% MOCAF, which exhibited superior mechanical and sensory attributes.

1 Introduction

Threadfin bream (*Nemipteru*s sp.) is a low-value fish species that exhibits schooling behavior. The species demonstrates superior gel-forming properties compared to red-meat fish due to its high myofibrillar protein content (77%), which functions as a primary coagulating agent. Currently, the utilization of threadfin bream is limited to basic processing methods, resulting in low consumer acceptance. Value-added processing, such as the production of fish meatballs, represents a potential strategy to enhance consumer acceptance. Conventional fish meatball formulations typically incorporate tapioca starch as a binding agent, which serves multiple functions: stabilization, volume enhancement, water retention, and reduction of cooking losses. However, tapioca starch presents several technological

* Corresponding author: alislah@ub.ac.id

limitations, including distinctive cassava aromatics, reduced product luminosity, and poor cold-water solubility [1]. Modified cassava flour (MOCAF) offers potential advantages as an alternative binding agent to address these technological constraints.

Modified Cassava Flour (MOCAF) is derived from cassava (*Manihot esculenta* Crantz) through microbial fermentation utilizing either yeast or lactic acid bacteria. During fermentation, the enzymatic degradation of starch occurs through the hydrolysis of α-1,4 and α-1,6 glycosidic bonds in amylose and amylopectin molecules, respectively, resulting in lower molecular weight compounds that enhance digestibility [2]. MOCAF exhibits superior functional properties compared to conventional tapioca flour, including enhanced gelation capacity, increased viscosity, and improved solubility. Additionally, MOCAF demonstrates enhanced physicochemical characteristics, including higher brightness values, improved textural properties, and reduced volatile organic compounds responsible for the characteristic cassava aroma. The reduced starch content in MOCAF, compared to tapioca flour, contributes to improved digestibility due to the decreased complexity of its molecular structure [1].

The incorporation MOCAF as a substitute binding agent in threadfin bream (*Nemipterus* sp.) meatball formulations is hypothesized to enhance the physicochemical and sensory attributes of the final product. The enhanced product will increase the commercial viability of both threadfin bream and cassava as indigenous food resources. Given the current absence ofstudies the utilization of threadfin bream and MOCAF in fish meatball processing, this research aims to evaluate the effects of MOCAF substitution on the physicochemical properties and sensory characteristics of threadfin bream meatballs (*Nemipterus* sp).

2 Materials and methods

2.1 Raw materials

The primary materials utilized in this study comprised threadfin bream (*Nemipterus* sp.) and two types of flour: tapioca starch and modified cassava flour (MOCAF). The threadfin bream specimens were sourced from the coastal waters of Brondong, Lamongan Regency, East Java, Indonesia (6°53'S, 112°17'E). Commercial tapioca starch (Gajah Tani™, CV. Sago Farmers, Bogor, West Java, Indonesia) and MOCAF (Mocafine™, Rumah Mocaf, Banjarnegara, Central Java, Indonesia) were procured from local suppliers.

2.2 Sample preparation and processing

2.2.1 Sample preparation

Raw threadfin bream (*Nemipterus* sp.) specimens were cleaned, descaled, and filleted to obtain muscle tissue. The experimental formulation consisted of fish muscle tissue (200 g), crushed ice (30 g), egg albumen (20 mL), sucrose (3.6 g), sodium chloride (3.6 g), Allium sativum (6 g), and Allium cepa (6 g). Six treatment groups were established based on MOCAF substitution levels: L (0%), M (20%), N (40%), O (60%), P (80%), and Q (100%), with commercial meatballs (K) serving as a reference sample.

2.2.2 Product processing

The ingredients were homogenized in a food processor under the following conditions: initial comminution of fish muscle with crushed ice, followed by sequential addition of albumen and seasonings, and final incorporation of the flour blend according to treatment specifications. The resulting emulsion was formed into spherical units (diameter: X mm) using a standardized portioning method. The samples underwent thermal processing in water at 100°C for 15 minutes, followed by drainage and equilibration to ambient temperature prior to analysis.

2.3 Sensory evaluation

A quantitative descriptive analysis was conducted using a seven-point hedonic scale (1 = extremely dislike, 2 = strongly dislike, 3 = dislike, 4 = neither like nor dislike, 5 = like, 6 = strongly like, 7 = extremely like). Sensory attributes evaluated included visual appearance, aroma, textural characteristics, and flavor profile. The evaluation was performed by trained panelists (n = 30) in individual booths under controlled environmental conditions.

2.4 Proximate composition analysis

Proximate composition analysis was performed according to the Indonesian National Standards (SNI) to determine moisture content, total ash, crude protein (N × 6.25), crude fat (lipid content), and total carbohydrates by difference.

2.5 Textural properties

Textural properties were evaluated using a texture analyzer (*Brookfield*) equipped with a cylindrical probe (TA 44 stainless steel). The maximum force required for deformation was measured and recorded by the instrument's data acquisition system, with force values expressed in newtons (N).

2.6 Colorimetric analysis

Colorimetric analysis was performed using the CIELAB color space system (also known as L*a*b*), measured with a calibrated chromameter. The L* parameter quantifies lightness on a scale from 0 (black) to 100 (white). The a* coordinate represents the red-green axis, where positive values indicate redness and negative values indicate greenness. The b* coordinate represents the yellow-blue axis, where positive values indicate yellowness and negative values indicate blueness. The hue angle (h°) was calculated from the chromatic coordinates using the equation:

$$h^\circ = \tan^{-1}(b^*/a^*) \quad (1)$$

where h° represents the angular displacement from the +a* axis in the CIELAB color space.

2.7 Yield analysis

Product yield represents the ratio of actual output mass to theoretical input mass, expressed as a percentage. A higher yield coefficient correlates directly with increased product conversion efficiency. The yield (η) is calculated using the following mass-based stoichiometric relationship:

$$\eta = (mf/mi) \times 100\% \quad (2)$$

Where:

- η = yield percentage (%)
- mf = final mass of product (units of mass)
- mi = initial mass of reactants (units of mass)

2.8. Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics (Version 22.0). The study employed a Completely Randomized Design (CRD). Prior to analysis, data were tested for normality using the Shapiro-Wilk test and homogeneity of variance using Levene's test. For variables meeting both assumptions ($p > 0.05$), one-way Analysis of Variance (ANOVA) was conducted, followed by Tukey's Honest Significant Difference (HSD) post-hoc test for multiple comparisons. For variables violating either assumption ($p < 0.05$), the non-parametric Kruskal-Wallis H test was performed, with subsequent Dunn's test for pairwise comparisons with Bonferroni correction. The relationship between mocaf flour substitution levels and measured parameters was assessed using regression analysis, with the coefficient of determination (R^2) calculated to quantify the strength of these associations. Product optimization was conducted using the De Garmo weighted attribute index method to identify the most preferred formulation based on multiple sensory and physicochemical parameters.

3 Result and discussion

3.1 The proximate composition analysis of raw materials

The proximate composition analysis of the primary ingredients, including tapioca flour (Manihot esculenta), modified cassava flour (MOCAF), and threadfin bream (*Nemipterus* sp.) muscle tissue, was conducted to determine their macronutrient composition. The quantitative measurements of total carbohydrates, crude protein, lipid content, moisture content, and ash content are presented in Table 1.

Table 1. Proximate composition of mocaf subtituted meatball formulation.

No	Parameters	Tapioca	Mocaf	*Nemipterus* sp
1.	Carbohydrate	83.50	82.95	1.28
2.	Protein	7.18	8.79	21.27
3.	Lipid	0.35	0.29	2.03
4.	Moisture	7.23	8.11	73.89
5.	Ash	0.19	1.41	1.53

The protein content in threadfin bream (*Nemipterus* sp.) ranges from 16.85% to 19.66% (w/w). In addition to its high protein content, kurisi fish is characterized by a relatively low lipid content of <5% (w/w) [3]. Tapioca flour composition analysis revealed: starch (88.2 g/100g), lipids (0.6 g/100g), ash (1.1 g/100g), protein (1.1 g/100g), and moisture content (9.1 g/100g). Modified cassava flour (MOCAF) exhibited the following composition: starch (85.0 g/100g), lipids (0.5 g/100g), ash (1.3 g/100g), protein (1.2 g/100g), and moisture content (11.9 g/100g) [4].

3.2 Organoleptic evaluation of mocaf-substituted meatballs

The sensory attributes of meatballs formulated with modified cassava flour (MOCAF) substitution and commercial reference samples were evaluated by trained panelists, with results summarized in Table 2.

Table 2. Result of sensory analysis of mocaf subtituted meatball.

Sample	**Parameter**			
	Appearance	**Aroma**	**Texture**	**Flavor**
K	3.24 ± 0.87c	2.83 ± 0.85a	3.43 ± 1.24a	3.09 ± 1.29a
L	4.14 ± 0.57a	4.08 ± 0.62b	3.94 ± 0.81ab	4.13 ± 0.80bc
M	4.28 ± 0.68ab	4.24 ± 0.59b	4.50 ± 0.72d	4.27 ± 0.72bc
N	4.50 ± 0.50b	4.31 ± 0.65b	4.52 ± 0.69d	4.37 ± 0.69b
O	4.12 ± 0.70a	3.94 ± 0.70bc	4.09 ± 0.78bcd	3.81 ± 0.87cde
P	4.01 ± 0.80a	3.87 ± 0.72bc	3.91 ± 0.98ac	3.73 ± 0.89ce
Q	4.03 ± 0.80a	3.63 ± 1.11c	3.80 ± 0.79ab	3.61 ± 1.19ae
(R^2)	0.980	0.879	0.895	0.829
Correlation (R)	0.959	0.773	0.800	0.687

K (Commercial) L (0% mocaf), M (20% mocaf), N (40% mocaf), O (60% mocaf), P (80% mocaf), dan Q (100% mocaf). Data are shown as mean ± standard deviation. Same superscript letter within column show there is no significant difference ($p>0.05$).

The substitution of MOCAF at varying concentrations demonstrated a statistically significant effect ($p < 0.05$) on the visual attributes of *Nemipterus* sp. meatballs. Organoleptic evaluation data (Table 2) indicated that formulation N (60% tapioca: 40% MOCAF) received optimal sensory acceptance, characterized by its luminous appearance with slight yellow undertones. However, increasing MOCAF concentrations resulted in enhanced product whiteness, correlating with decreased sensory acceptance scores. These findings align with Hajriatun et al. [5], who reported an inverse relationship between MOCAF substitution levels and sensory acceptance due to increased product brightness. The luminosity of the meatballs can be attributed to the intrinsic colorimetric properties of MOCAF, which exhibits higher brightness ($L^* = 95.43$) compared to tapioca flour ($L^* = 93.33$). Statistical analysis revealed a strong positive correlation coefficient ($r = 0.980$) between MOCAF substitution levels and visual attributes of *Nemipterus* sp. meatballs. The coefficient of determination ($R^2 = 0.959$) indicates that 95.9% of the variation in meatball appearance can be explained by MOCAF substitution, with the remaining 4.1% attributable to unexamined variables in this study.

The incorporation of modified cassava flour (MOCAF) at varying concentrations demonstrated a statistically significant effect ($p < 0.05$) on the olfactory attributes of *Nemipterus* sp. meatballs. Sensory evaluation data (Table 2) revealed that formulation N (60% tapioca : 40% MOCAF) achieved the highest mean acceptance score (4.31 ± 0.65 SD), while the control formulation K exhibited the lowest acceptance (3.83 ± 0.85 SD). The superior organoleptic acceptance of formulation N was attributed to its moderated fish volatile compounds. This moderation effect can be explained by the presence of organic acids, particularly lactic acid, produced during the fermentation process of MOCAF production, which contributes to its neutral volatile profile and subsequent ability to attenuate fish-associated volatile compounds [6]. However, sensory acceptance demonstrated an inverse relationship with increasing MOCAF concentration beyond the optimal level, correlating with the diminished characteristic fish volatiles. Statistical analysis revealed a strong positive correlation coefficient ($r = 0.879$) between MOCAF substitution levels and olfactory attributes of *Nemipterus* sp. meatballs. The coefficient of determination ($R^2 = 0.773$) indicates that 77.3% of the variation in meatball aroma can be explained by MOCAF substitution, with the remaining 22.7% attributable to unexamined variables in this study.

Substitution of MOCAF with different concentrations had a significant effect on the sensory texture of *Nemipterus* sp meatballs (Sig < 0.05). Based on Table 2, it is known that the most preferred texture is the N treatment (60% tapioca : 40% mocaf) with a mean of 4.52 ± 0.69. Then the least preferred texture was treatment K (control) with a mean of 3.43 ± 1.24. Sample N (60% tapioca : 40% MOCAF) was preferred by the panelists because it had a level of elasticity that met the panelists' wishes, namely not too chewy. The higher the mocaf flour substitution given, the panelists' level of preference decreases, this is because the texture formed becomes more easily broken. The elasticity of fish meatballs is influenced by the amylose content of tapioca flour and MOCAF. Tapioca flour has a higher amylose content than MOCAF, so the chewy texture is better [7]. Regression and correlation tests showed that the correlation value (R) was 0.895, which means that there is a very strong relationship between the substitution of MOCAF for the texture of *Nemipterus* sp meatballs. The coefficient of determination (R2) value of 0.800 means that 80% of the texture of the *Nemipterus* sp meatballs is influenced by the substitution of MOCAF, while the remaining 20% is influenced by other factors not examined in this study.

The incorporation of modified cassava flour (MOCAF) at varying concentrations demonstrated a statistically significant effect ($p < 0.05$) on the gustatory attributes of *Nemipterus* sp. meatballs. Sensory evaluation data (Table 2) indicated that formulation N (60% tapioca : 40% MOCAF) achieved the highest mean hedonic score (4.37 ± 0.69 SD), while the control formulation K exhibited the lowest acceptance (3.09 ± 1.29 SD). The optimal sensory acceptance of formulation N was attributed to its balanced flavor profile, characterized by moderate fish taste intensity.

A negative correlation was observed between increasing MOCAF concentration and sensory acceptance scores, attributed to the predominance of starch-derived flavor compounds at higher substitution levels. These findings corroborate those of Hajriatun et al. [5], who reported that excessive MOCAF substitution results in starch-dominant organoleptic properties, consequently reducing hedonic scores. Statistical analysis revealed a strong positive correlation coefficient ($r = 0.829$) between MOCAF substitution levels and gustatory attributes of *Nemipterus* sp. meatballs. The coefficient of determination ($R^2 = 0.687$) indicates that 68.7% of the variation in meatball taste can be explained by MOCAF substitution, with the remaining 31.3% attributable to unexamined variables in this study.

De Garmo's effectiveness index analysis revealed that formulation N (60% tapioca : 40% MOCAF) exhibited optimal sensory acceptance scores. Conversely, the control formulation (K) demonstrated minimal acceptance, while formulation O (40% tapioca : 60% MOCAF) showed intermediate acceptability values. These three formulations, along with formulation L (100% tapioca : 0% MOCAF), were subsequently subjected to comprehensive physicochemical characterization to evaluate their compositional and structural properties.

3.3. Proximate compositional analysis of mocaf-substituted *Nemipterus* sp. meatballs

The proximate analysis data, including moisture content, crude protein, total ash, crude lipids, and total carbohydrates of selected *Nemipterus* sp. meatball formulations with varying MOCAF substitution levels are summarized in Table 3. Statistical analysis revealed that varying mocaf flour substitution ratios significantly influenced the water content of kurisi fish meatballs ($p < 0.05$). As presented in Table 2, treatment O (40% tapioca : 60% mocaf) exhibited the highest mean water content of 68.17% ± 0.16%, while the control treatment K demonstrated the lowest mean water content of 64.43% ± 0.24%. The elevated water content in treatment O can be attributed to the higher fiber content of mocaf flour compared to tapioca flour. Previous research by Asmoro et al. [4] reported fiber contents of 6.0 g and 0.9 g for mocaf and tapioca flour, respectively. The enhanced water retention capacity is primarily due to the structural properties of dietary fiber, which contains numerous hydroxyl groups within its large polymer matrix, facilitating increased water absorption in food systems [6].

Additionally, the inherent moisture content of mocaf flour (8.11%) exceeds that of tapioca flour (7.23%), further contributing to the observed differences. Notably, the water content values of all kurisi fish meatball formulations remained within the acceptable range specified by SNI 7266:2017 standards for fish meatballs, which stipulates a maximum water content of 70%. Statistical analysis of the data presented in Table 3 demonstrated a strong positive correlation ($r = 0.883$) between mocaf flour substitution levels and water content in kurisi fish meatballs. The coefficient of determination ($R^2 = 0.779$) indicates that 77.9% of the observed variance in water content can be explained by mocaf flour substitution, while the remaining 22.1% is attributable to unexamined variables not included in this experimental design.

Table 3. Chemical composition analysis mocaf subtituted meatball

Sample	Water (%)	Protein (%)	Ash (%)	Fat (%)	Carbohydrate (%)
K	64.43±0.24a	15.05±0.12c	1.73±0.05bc	0.74±0.02c	18.04±0.36c
L	67.36±0.11b	14.27±0.06a	1.52±0.04a	0.62±0.04b	16.22±0.06b
N	67.53±0.05b	14.47±0.04b	1.64±0.04b	0.55±0.05b	15.81±0.13b
O	68.17±0.16c	14.62±0.04b	1.76±0.04c	0.43±0.03a	15.02±0.16a
SNI	Max 70	Min 7	Max 2.5	-	-
(R^2)	0.883	0.916	0.919	0.995	0.956
Correlation (R)	0.779	0.838	0.843	0.990	0.913

K (Commercial), L (0% mocaf), N (40% mocaf), O (60% mocaf).; Data are shown as mean ± standard deviation. Same superscript letter within column show there is no significant difference ($p>0.05$).

The substitution of mocaf flour at varying concentrations significantly affected the protein content of kurisi fish meatballs ($p < 0.05$). Analysis of protein content across treatments revealed that the control treatment (K) exhibited the highest protein content (15.05 ± 0.12%), while treatment L (100% tapioca : 0% mocaf) showed the lowest protein content (14.27 ± 0.06%). A positive correlation was observed between mocaf flour concentration and protein content in the meatballs, which can be attributed to the higher protein content of mocaf flour (8.79%) compared to tapioca flour (7.18%). The elevated protein levels in mocaf flour result from the fermentation process involving lactic acid bacteria, whose extracellular enzymes are secreted into the cassava matrix, leading to protein enrichment [8]. Notably, all treatments, including those with mocaf flour substitution, met the Indonesian National Standard (SNI 7266:2017) requirement for fish meatballs, which specifies a minimum protein content of 7%. Statistical analysis revealed a strong positive correlation ($r = 0.916$) between mocaf flour substitution and protein content in kurisi fish meatballs. The coefficient of determination ($R^2 = 0.838$) indicates that mocaf flour substitution accounts for 83.8% of the variance in protein content, while the remaining 16.2% can be attributed to unexamined variables.

The substitution of mocaf flour at different concentrations significantly influenced the ash content of kurisi fish meatballs ($p < 0.05$). Analysis revealed that treatment O (40% tapioca : 60% mocaf) exhibited the highest ash content (1.76 ± 0.04%), while treatment L (60% tapioca : 40% mocaf) showed the lowest ash content (1.52 ± 0.04%). A positive correlation was observed between mocaf flour concentration and ash content in the meatballs, which can be attributed to the higher ash content of mocaf flour (1.41%) compared to tapioca flour (0.19%). These findings align with previous research by Andragogi et al. [9], who demonstrated that ash content in food products is predominantly determined by the composition of raw materials used. Additionally, Hidayat et al. [10] reported similar differential ash content between mocaf flour (1.44%) and tapioca flour (0.6%), corroborating our observed trends. Statistical analysis of the data presented in Table 3 revealed a strong positive correlation ($r = 0.919$, $p < 0.05$) between mocaf flour substitution levels and ash content in kurisi fish meatballs. The coefficient of determination ($R^2 = 0.843$) indicates that 84.3% of the variance in ash content can be explained by mocaf flour substitution. The remaining 15.7% of variance may be attributed to uncontrolled variables not investigated in the present study.

The incorporation of modified cassava flour (mocaf) at varying concentrations significantly affected the fat content of kurisi fish (*Nemipterus* sp.) meatballs ($p < 0.05$). Analysis of variance revealed that the control treatment (K, 100% tapioca flour) exhibited the highest fat content (0.74 ± 0.02%), while treatment O (40% tapioca : 60% mocaf) showed the lowest fat content (0.43 ± 0.03%). A negative correlation was observed between mocaf flour concentration and fat content in the meatballs. This variation in fat content can be attributed to the inherent differences in the lipid composition of the flour types, with tapioca flour containing 0.35% fat compared to mocaf flour's 0.29%. The reduced fat content in mocaf flour is primarily due to microbial activity during fermentation, where lipase-mediated hydrolysis converts triglycerides into fatty acids and glycerol, resulting in decreased total lipid content. Statistical analysis revealed a strong positive correlation ($r = 0.995$) between mocaf flour substitution levels and fat content in kurisi fish meatballs (Table 3). The coefficient of determination ($R^2 = 0.990$) indicates that 99.0% of the variance in fat content can be explained by mocaf flour substitution. The remaining 1.0% of variance may be attributed to unexamined variables not included in this analysis.

The substitution of mocaf at varying concentrations significantly influenced the carbohydrate content of *Nemipterus* spp. meatballs ($p < 0.05$). Analysis of variance revealed that the control treatment (K) exhibited the highest carbohydrate content (18.04 ± 0.36%), while treatment O (40:60 ratio of tapioca:mocaf) demonstrated the lowest carbohydrate content (15.02 ± 0.16%). A negative correlation was observed between mocaf flour concentration and carbohydrate content in the meatballs. This inverse relationship can be attributed to the differential carbohydrate compositions of the flour types, with mocaf containing 82.95% carbohydrates compared to 83.50% in tapioca flour. The reduced carbohydrate content in mocaf flour is primarily due to the microbial fermentation process, during which starch undergoes hydrolysis to serve as a carbon source for bacterial growth and metabolism. The regression analysis revealed a highly significant correlation coefficient ($r = 0.956$, $p < 0.05$) between mocaf flour substitution and carbohydrate content in kurisi fish (*Nemipterus* spp.) meatballs, indicating a strong positive linear relationship. The coefficient of determination ($R^2 = 0.913$) demonstrates that 91.3% of the total variation in carbohydrate content can be explained by mocaf flour substitution levels, while the remaining 8.7% is attributable to uncontrolled variables in the experimental system.

3.4 Physical properties analysis: Textural profile, colorimetric parameters, and color space values of mocaf flour-substituted meatballs

The physical characterization results, including texture profile analysis (TPA), colorimetric measurements (L*a*b*), and color space coordinates of meatballs formulated with modified cassava flour (mocaf) substitution are presented in Table 4. The incorporation of modified cassava flour (mocaf) at varying substitution levels demonstrated a statistically significant effect ($p < 0.05$) on the textural properties of *Nemipterus* sp. meatballs. Texture profile analysis revealed that the control treatment (K) exhibited the highest elasticity value (9.31 ± 0.10 N), while treatment O (40:60 ratio of tapioca:mocaf) showed the lowest elasticity measurement (7.12 ± 0.05 N). A negative correlation was observed between mocaf flour substitution levels and meatball elasticity. The observed textural variations can be attributed to the differential amylose content between tapioca flour (20-27%) and mocaf flour (11.07%) [11]. Amylose contributes significantly to the formation of three-dimensional gel networks during thermal gelatinization, resulting in enhanced structural integrity and cohesiveness of the matrix. The higher amylose content in tapioca flour promotes the development of a more consolidated protein-starch network, consequently yielding improved textural characteristics. Statistical analysis revealed a strong positive correlation ($R = 0.993$) between mocaf flour substitution and meatball textural properties. The coefficient of determination ($R^2 = 0.986$) indicates that 98.6% of the variation in textural characteristics can be explained by mocaf flour substitution levels, while the remaining 1.4% may be attributed to unexamined variables not included in this study.

Table 4. Physical characterization of mocaf subtituted meatball

Sample	Texture Profile	Color (L*)	°*Hue*
K	9.31±0.10d	53.77±0.62a	101.124
L	8.82±0.06c	56.33±0.24b	93.939
N	7.87±0.07b	60.97±0.30c	92.737
O	7.12±0.05a	64.48±0.82d	99.207
(R^2)	0.993	0.995	-
Correlation (R)	0.986	0.989	-

K (Commercial), L (0% mocaf), N (40% mocaf), O (60% mocaf).
Data are shown as mean ± standard deviation. Same superscript letter within column show there is no significant difference ($p>0.05$).

Substitution levels of modified cassava flour (mocaf) exhibited a statistically significant effect ($p < 0.05$) on the luminosity (L* value) of *Nemipterus* sp. meatballs. Colorimetric analysis demonstrated that treatment O (40:60 ratio of tapioca:mocaf) yielded the highest L* value (64.48 ± 0.82), while the control treatment (K) displayed the lowest L* value (53.77 ± 0.62). Meatballs formulated with mocaf flour substitution consistently exhibited higher luminosity compared to the control formulation. The observed variation in brightness can be attributed to the inherent colorimetric properties of the flour components, with mocaf flour displaying a higher L* value (95.43) compared to tapioca flour (L* = 93.33). The enhanced luminosity of mocaf flour is primarily due to its production methodology, which incorporates a fermentation process. This fermentation step effectively inhibits the Maillard reaction between reducing sugars and proteins, thereby preventing the formation of melanoidin compounds that typically occur during conventional cassava processing [12].

Statistical analysis of the data presented in Table 4 revealed a linear relationship between modified cassava flour (mocaf) substitution levels and luminosity (L* value) of *Nemipterus* sp. meatballs. The correlation coefficient ($R = 0.995$) indicates a strong positive correlation between mocaf flour incorporation and product luminosity. Regression analysis yielded a coefficient of determination ($R^2 = 0.989$), suggesting that 98.9% of the variation in L* values can be explained by mocaf flour substitution levels, while the remaining 1.1% of variance may be attributed to unexamined variables not included in the experimental design.

Analysis of chromatic parameters presented in Table 5 demonstrates the hue angle (h°) values of the formulated samples. The colorimetric data indicated that treatments K (control), L (100:0 tapioca:mocaf ratio), N (60:40 tapioca:mocaf ratio), and O (40:60 tapioca:mocaf ratio), along with *Nemipterus* sp. muscle tissue, exhibited hue angles within the range of 90° - 126°, corresponding to the yellow region of the CIELAB color space. The modified cassava flour (mocaf) displayed a hue angle of 38.45°, indicating positioning in the red chromatic region, while tapioca flour exhibited a hue angle of 60.60°, corresponding to the yellow-red transitional zone.The chromatic characteristics of the final product are influenced by both the primary protein source (fish muscle) and the binding agents (flour components) [12]. Despite the varying hue angles of individual components - mocaf flour (red region), tapioca flour (yellow-red region), and *Nemipterus* sp. tissue (yellow region) - their combination in the formulation resulted in a product predominantly characterized by yellow chromatic properties.

Table 5. Chromatic parameters of mocaf subtituted meatball.

Sampel	L*	a*	b*	°*Hue Value*	Color Range
Mocaf	95.43	2.62	2.08	38.45	Red
Tapioca	93.33	2.4	4.26	60.60	Yellowish red
Nemipterus sp. tissue	45.47	-3.46	7.22	115.60	Yellow
K Treatment	53.77	-2.02	10.29	101.12	Yellow
L Treatment	56.33	-0.92	13.31	93.94	Yellow
N Treatment	60.97	-0.65	13.60	92.74	Yellow
O Treatment	64.48	-1.89	11.66	99.21	Yellow

3.5 Product yield analysis

The muscle tissue yield of *Nemipterus* sp. was determined by calculating the ratio of processed muscle mass (997 g) to whole fish mass (3,197 g), resulting in a yield coefficient of 31.19%. The processing yield of meatballs was calculated as the ratio of post-thermal processing mass (276 g) to pre-thermal processing mass (259 g), yielding a coefficient of 106.25%. The observed mass increase aligns with findings reported by Wijayanti et al. [13], attributing the enhanced yield to starch-protein interactions during thermal processing. This phenomenon can be explained by the water-binding capacity of the flour components, leading to gelatinization and subsequent structural expansion of the protein-starch matrix during thermal treatment [14, 15].

4 Conclusion

This investigation demonstrated that varying proportions of modified cassava flour (mocaf) significantly affected the physicochemical properties and organoleptic characteristics of *Nemipterus* sp. meatballs. Statistical analysis revealed that the optimal formulation consisted of 60% tapioca and 40% mocaf (Treatment N), which exhibited superior mechanical and sensory attributes. This formulation yielded the following quantitative parameters: elasticity (7.87 N), L* value (brightness) of 60.97, moisture content (67.53% w/w), crude protein (14.47% w/w), ash content (1.64% w/w), crude fat (0.55% w/w), and total carbohydrates (15.81% w/w). Sensory evaluation using a 5-point hedonic scale indicated favorable acceptance scores for appearance (4.50 ± SD), aroma (4.31 ± SD), texture (4.52 ± SD), and taste (4.37 ± SD).

Acknowledgments

This work was supported by the Professor Grant Program (Grant No. 3708/UN10.F06/KS/2024) from the Faculty of Fisheries and Marine Sciences, Brawijaya University, Indonesia. The authors express their sincere appreciation to the institution for providing essential research facilities and technical infrastructure. We would also like to acknowledge the valuable support of the laboratory staff during the experimental phase. No funding conflicts or competing interests were reported by the authors.

References

1. Z. Mushthofa, S. Achadiyah, Sunardi, Perbandingan tepung mocaf dan tepung tapioka dalam pembuatan siomai dengan penambahan tepung jamur tiram (Pleurotus ostreatus) sebagai sumber protein. Agroforetech. **1(2)**, 1147-1168 (2023)
2. E. Nazriati, S. Wahyuni, H. Herisiswanto, R. Rofika, Z. Zulharman, R. Endriani, Pembuatan tepung mocaf (modified cassava flour) sebagai upaya optimalisasi pemanfaatan singkong pada kelompok tani. Comsep: Jurnal Pengabdian Kepada Masyarakat. **2(3),** 305-310 (2021). https://doi.org/10.54951/comsep.v2i3.158
3. N.A. Marantika, S. Haryati, S. Sudjatinah, Konsentrasi garam terhadap sifat kimia, fisik dan organoleptik bekasam ikan kurisi (*Nemipterus* nemathophorus). Jurnal Teknologi Pangan dan Hasil Pertanian. **15(**1), 40-46 (2020). http://dx.doi.org/10.26623/jtphp.v15i1.2326
4. N.W. Asmoro, Karakteristik dan sifat tepung singkong termodifikasi (mocaf) dan manfaatnya pada produk pangan. Journal of Food and Agricultural Product. **1(1)**, 34-43 (2021). https://doi.org/10.32585/jfap.v1i1.1755
5. N. Hajriatun, R. Sofiyatin, I.S. Jaya, I.N. Widiada, Pengaruh penambahan tepung mocaf terhadap sifat organoleptik dan kadar air bakso jamur tiram (muram). Jurnal Gizi Prima (Prime Nutrition Journal). **2(1)**, 22-29 (2019). https://doi.org/10.32807/jgp.v2i1.84
6. E.A. Simanjuntak, R. Effendi, R. Rahmayuni, Kombinasi pati sagu dan modified cassava flour (mocaf) dalam pembuatan nugget ikan gabus. Jurnal Online Mahasiswa Faperta. **4(1),** 1-15 (2017).
7. K. Jayanti, E. Suroso, S. Astuti, N. Herdiana, Pengaruh perbandingan tepung mocaf (modified cassava flour) dan tapioka sebagai bahan pengisi terhadap sifat kimia, fisik, dan sensori nugget ikan baji-baji (Grammoplites scaber). Jurnal Agroindustri Berkelanjutan. **2(2)**, 250-263 (2023). http://dx.doi.org/10.23960/jab.v2i2.8150
8. S. Dasir, S. Agustini, A. Robi, Karakteristik fisik, kimia dan organoleptik pempek dengan substitusi tepung mocaf (modifie cassava flour). Jurnal Dinamika Penelitian Industri. **33(1)**, 37-49 (2022).
9. V. Andragogi, V.P. Bintoro, S. Susanti, Pengaruh berbagai jenis gula terhadap sifat sensori dan nilai gizi roti manis. Jurnal Teknologi Pangan. **2(2)**, 163-167 (2018). https://doi.org/10.14710/jtp.2018.22108
10. R. Hidayat, Tamrin, D. Wahab, Pengaruh subtitusi tepung ubi kayu fermentasi terhadap nilai sensorik dan proksimat nugget ikan gabus. Jurnal Sains dan Teknologi Pangan. **4(2)**, 2118-2132. (2019). http://dx.doi.org/10.33772/jstp.v4i1.7189
11. A.V. Yani, M. Akbar, Pembuatan tepung mocaf (modified cassava flour) dengan berbagai varietas ubi kayu dan lama fermentasi. Jurnal Edible. **7(1)**, 40-48 (2018). https://doi.org/10.32502/jedb.v7i1.1655
12. C. Hetharia, Y. Loppies, H. Handu, Sifat organoleptik bakso pada berbagai rasio perbandingan daging sapi dan babi. Median: Jurnal Ilmu Ilmu Eksakta. **13(1)**, 15-23 (2021). http://doi.org/md.v13i1.191
13. A. Wijayanti, D. Emilyasari, S.H. Rahmawati, M.H. Qulubi, Karakteristik dan uji organoleptik bakso ikan gabus (channa striata) dengan penambahan tepung porang (amorphophallus oncophyllus). Jurnal Lemuru. **5(1)**, 73-82 (2023). https://doi.org/10.36526/lemuru.v5i1.2526.
14. M.M. Heydari, T. Najib, V. Meda, Investigating starch and protein structure alterations of the processed lentil by microwave-assisted infrared thermal treatment and their correlation with the modified properties. Food Chemistry Advances. **1**, 100091 (2022). https://doi.org/10.1016/j.focha.2022.100091.

15. Z, Ma, J.I. Boye, B.K. Simpson, S.O. Prasher, D. Monpetit, D. Malcolmson, Thermal processing effects on the functional properties and microstructure of lentil, chickpea, and pea flours. Food Research Internasional., **44(8)**, 2534-2544 (2011). https://doi.org/10.1016/j.foodres.2010.12.017