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Proximate composition, fatty acid profile, and sensory evaluation of meatballs as processed food from duck with fermented seaweed waste feed treatment

Siti Susanti[1], Agus Setiadi[2], Budi Hartoyo[3], Anang Mohamad Legowo[1], Ahmad Ni'matullah Al-Baarri[1], Fatma Puji Lestari[3*]

[1]Food Technology, Department of Agriculture, Faculty of Animal and Agricultural Science, Diponegoro University, Semarang, 50275, Central Java, Indonesia.
[2]Department of Agribusiness, Department of Agriculture, Faculty of Animal and Agricultural Science, Diponegoro University, Semarang, 50275, Central Java, Indonesia.
[3]Faculty of Agricultural Technology, University of 17 Agustus 1945, Semarang, 50135, Central Java, Indonesia

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*Correspondence:

Corresponding author: Fatma Puji Lestari
E-mail address: fatma-pujilestari@untagsmg.ac.id

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ABSTRACT

A previous study, seaweed (*Glacilaria* sp.) waste containing its symbiont (*Brotia* sp.) was utilized as Pegging duck feed supplement. This study investigated the impact of using fermented seaweed waste (FSW) as a Pegging duck feed supplement on the proximate composition, fatty acid profile, and sensory properties of duck meatballs. The result showed that ducks fed with fermented seaweed waste (FSW) had carcass with low fat content. Meatballs from duck fed with 12.5 % FSW for 30 days starting from 15-weeks-old, had lower fat content and higher unsaturated fatty acid [Palmitoleic (omega-7), Eicosapentaenoic (omega -3), Linolenic (omega-3), and Oleic (omega -9)] significantly than control meatballs (without SW feed treatment). However, Linolelaidic (omega-6) as a trans fatty acid was significantly lower in duck meatballs treatment than control. There was no effect of SW treatment on the saturated fatty acid of duck meatballs. Sensory test demonstrated that duck meatballs of treatment group was preferable than control and had similar preferences to commercial. The treated duck meatballs had a desirable meat aroma, were tender and had good taste and springiness. In conclusion, supplementing duck feed with fermented seaweed waste can produce healthier, low-fat duck meatballs with improved sensory qualities, supporting their potential as a functional food product.

Introduction

Protein is a critical nutrient for the human body, supporting essential processes such as cell regeneration, tissue repair, muscle development, enzyme function, and energy storage. Based on the World Health Organization (WHO, 2007), the average daily protein intake is around 0.83 grams per kilogram of body weight per day or equivalent to 10-15% of total daily energy intake. Protein can be derived from both plant-based sources, such as legumes, and animal-based sources, such as meat and fish (Pudjihastuti *et al*., 2018). Chemically, the supply of essential amino acids from animal sources is more effective and optimal for the body health (Richter *et al*., 2015).

Animal protein is nutritionally valuable, but the consumption of protein derived from red meat will increase the risk of cardiovascular disease. Research conducted by Zhubi-Bakija *et al*. (2021) found that red meat contributes to increased levels of low-density lipoprotein (LDL-C) and triglyceride (TG) cholesterol, both of which can trigger the risk of heart disease, stroke, and cancer. So, the selection of animal protein sources needs to be varied with white meat. This is proven by research (Romero-Garay *et al*., 2022) which shows that the consumption of poultry products is able to reduce lipid activity, improve blood vessel function, and increase bioactive peptides.

In Indonesia, chicken is the most widely consumed poultry. However, duck meat is also gaining popularity due to its adaptability and richer nutritional profile. Ducks are more resilient than chickens, thriving in diverse environments, which makes them a favorable option for local farmers (Kasiyati *et al*., 2016). According to data from the Central Statistics Agency of the Republic of Indonesia, duck meat production has increased from 45,681 tons in 2021 to 49,267 tons in 2023. One of the local breed ducks that is easy to find is the Pegging duck. The duck is the result of extensive crossbreeding to improve the quality of meat, eggs and the ability to adapt better. Thus, Pegging duck has the potential to be developed massively to meet the needs of national ducks.

Duck meat has a distinctive taste and unique nutritional content, especially because its essential amino acid profile is higher than that of chicken. In 100 grams of duck meat contains about 28 grams of fat, 10 grams of saturated fat, and 84 milligrams of cholesterol (Suryanti *et al*., 2014). This relatively high fat content is what makes the taste of duck meat fatter, thus reducing the level of consumer acceptance. Research by Santoso *et al*. (2016) shows that feeding based on fermented seaweed waste (FSW) is able to reduce fat content by 12.5% while increasing antioxidant levels by up to 15%. This is because FSW contains polyunsaturated fatty acids (PUFAs), including omega-3s, which can compete with the process of trans fat synthesis in metabolism. As a result, the level of trans fats in duck meat decreases and there is an increase in the accumulation of healthy fats, such as oleic acid (omega-9), linolenic acid (omega-3), and eicosapentaenoic acid (EPA) (Morais *et al*., 2020). Thus, FSW supplementation in duck feed is able to improve the fatty acid profile of meat through a more favorable increase in the nutrient content of seaweed (Zhao *et al*., 2021).

FSW supplementation has been shown to significantly lower a harmful trans fatty acid of linolelaidic acid. In line with that, palmitoleic (omega-7), eicosapentaenoic (omega-3), and oleic (omega-9) are increasing as unsaturated fatty acids. The fermentation process improves the availability of nutrients in the FSW for duck feed. This helps ducks metabolize fats better and decreases overall trans fatty acid content (Supriya *et al*., 2023). These findings show that FSW supplementation not only reduces harmful fatty acids but also enriches the nutritional quality of meat, making it a healthier option for consumers.

The sustainability of duck farming, particularly with local breeds like the Pegging duck, is further supported by opportunities for food innovation. Meatballs, a popular food product in Indonesia, offer an ideal avenue for diversification. Based on the Indonesian Statistical Center Agency, meatball consumption has steadily increased by 20% per year between 2019 and 2022, making it a staple in Indonesian cuisine. Though originally introduced by Chinese traders in the 1980s, meatballs have become a beloved food across the country (Swastawati *et al*., 2018) Given the growing demand for healthier and more diverse meat products, the development of duck meatballs represents a promising opportunity to expand functional food offerings.

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This study aimed to develop duck meatballs using FSW-fed ducks and evaluate their sensory properties, proximate composition, and fatty acid profile. By exploring the effects of FSW supplementation, the research contributes to the growing field of functional food development and provides insights into healthier meat production practices that could benefit both consumers and producers.

Materials and methods

Research was conducted during March-July 2024 at Food and Agricultural Products Engineering Laboratory, Diponegoro University. This study used a completely randomized design (CRD) with three treatments and three replications. The treatments group included: T1 (Control) duck meatballs made from duct fed with basal diet, T2 (FSW Treatment) duck meatballs made from duck fed with 12,5% fermented seaweed waste (FSW) and T3 (Commercial) a commercial duck meatball. The commercial duck meatballs were used as a comparison group (T3) in the sensory evaluation. The product was sourced from a local supermarket in Semarang, Central Java, and selected based on its popularity and consistent market presence. This design was applied to evaluate differences in proximate composition, fatty acid profile, and sensory characteristics.

Breeding and slaughtering ducks

Pegging ducks as local variety were purchased from Cultivation Center of Non-Ruminant Livestock Breeding in Ambarawa, Central Java, Indonesia. Two types of duck feeding were used with basal diet and fermented seaweed waste (FSW). Ducks feeding with FSW were prepared by adopting methods from Santoso *et al*. (2016). The experimental feed consisted of the following ingredients (%w/w): corn (46.76%), soybean meal (19.80%), FSW (12,5%), bran (12%), fish meal (5.06%), *Brotia costula* (1.00%), oil (1.00%), lime (1.00%), methionine (0.30%), lysine (0.30%) and premix (0.25%). The FSW supplementation began when the ducks reached 15 weeks of age and continued for 30 days until slaughter. The slaughtering was performed in the poultry slaughterhouse Penggaron located in Semarang, Central Java, Indonesia. Both treated and not treated duck were 19 weeks age, with an approximate live weight of 1.2–1.3 kg. The duck carcasses were immediately frozen at –20°C and stored for no longer than 24 hours prior to further processing for meatball production and analysis.

Duck meatball preparation

Two different duck fillets were used in this research with total amount of meat in meatball formulation is 68.3%. Duck meat was obtained from breast and thigh meat of the carcasses, without skin and visible fat. Equal proportions of breast and thigh meat (1:1 w/w) were used for all treatments and replications. Other ingredients used were shown in Table 1. The mixing process was carried out in two steps by using Oxone food processor OX-293 (Octa Utama, Jakarta, Indonesia). Firstly, dough was made from the mixing of meat, ice water and salt until it was fine. Continued with addition of tapioca flour, palm oil, fried onion, fried garlic and pepper powder mixed evenly. The blend was shaped into balls manually and the balls were set at 60°C for 20 min to retain its shape. The meatballs were cooked at 90°C for 20 min and immediately cooled down in ice water.

Sensory evaluation

Twenty-five trained panelists were asked to evaluate three different samples of meatball made from duck without FSW, duck with FSW treatment, and commercial meatballs. Panelist score on a 4-point scale described their like or dislike of aroma, hardness, taste, springiness and overall acceptability.

Table 1. Standard recipe for duck meatball dough from two feeding types: basal diet and Fermented Seaweed Waste (FSW).

Ingredients	Basal diet (%)	FSW (%)
Ducks fillet	68.5	68.5
Palm oil	13.5	13.5
Tapioca flour	7	7
Ice water	4	4
Fried onion	4	4
Fried garlic	2	2
Salt	0.7	0.7
Pepper powder	0.3	0.3
Total	100	100

Proximate composition

The proximate composition of duck meatballs was performed by using AOAC (1990) method. The analysis including moisture, protein, fat and ash content, was determined using the following methods: a hot air oven (105°C), the Kjeldahl method, a Soxhlet apparatus, and a furnace (550°C), respectively.

Fatty acid profile

The fatty acid profile analysis was carried out in two stages: sample preparation and testing with Gas Chromatography-Mass Spectrometry (GC-MS) (Shimadzu GCMS-QP2010 SE). Sample preparation followed the method of Salamah *et al*. (2022) with some modifications. This method involves two steps: extraction and esterification. The extraction process begins by weighing 4 grams of each sample (without FSW and FSW treatment). The sample was placed into a polypropylene centrifuge tube. 15 mL Chloroform-methanol (1:2 v/v) was added and heated at 60°C for 10 minutes. Sample solution was vortexed for 5 minutes and centrifuged at 3000 rpm for 10 minutes. The oily layer was decanted, filtered with Whatman paper and heated. The solution was ready to be used for esterification.

50 µL of fat or oil extracted from the sample was added with 1.0 mL of n-hexane and 200 µL of sodium methoxide and heated in a water bath at 70°C for 15 minutes, shaking every 3 minutes. The mixture was cooled, added 1.5 mL of BF_3 solution, vortexed and heated in a water bath at 70°C for 15 minutes, shaking every 3 minutes. The mixture was re-cooled and 1.5 mL of saturated NaCl was added. The supernatant containing methyl esters (the derivatives of fatty acids) was placed into a vial, and 1 µL of the supernatant was injected into the GC-MS for analysis.

The fatty acid (FA) composition was analyzed by using methods from Sugiharto *et al*. (2010) with some modifications. GC-MS equipped with an autosampler, flame ionization detector (FID), and fused-silica capillary column SPTM 2560 (100 m x 0.25 mm x 0.2 µm film thickness) was used.

Statistical analysis

Non-parametric data from sensory evaluation was analyzed using the Kruskal-Wallis test. Significant results from the sensory evaluation were further examined using the Mann-Whitney U-test to identify significant differences between treatments.

Results

Sensory evaluation

Table 2 presents the sensory attributes (aroma, hardness, taste, elasticity, and overall hedonic) of three meatball samples: T1 (no FSW treatment), T2 (FSW-treated duck meatballs), and T3 (commercial duck meatballs as a control). The commercial duck meatballs (T3) received

Table 2. Sensory evaluation of different duck meat treatment.

Sensory parameters	Meatball criteria			Interpretation of 1 to 4 score
	T_1	T_2	T_3	
Aroma	1.93±0.842^{a}	2.00±0.886^{b}	3.14±0.974^{bc}	not duck typical to duck typical
Hardness	2.66±0.974^{a}	2.28±0.702^{ab}	1.48±0.785^{c}	tender to hard
Taste	2.24±0.912^{a}	2.03±.0823^{b}	2.86±0.875^{c}	not tasty to tasty
Elasticity	2.00±1.00^{a}	2.31±0.806^{b}	1.59±0.867^{c}	not springy to springy
Hedonic	2.37±1.11^{a}	2.41±0.68^{b}	3.20±.094^{bc}	unfavored to favor

T1=Meatballs made from duck meat with basal feed, T2=Meatballs made from duck meat with fermented seaweed waste feed, T3=Commercial meatballs. Means with different superscripts as a, b, c are different significantly ($p<0.05$ or $p<0.01$)

a significantly higher aroma score (3.14) compared to the untreated duck meatballs (T1, 1.93), with no significant difference between T3 and FSW-treated meatballs (T2, 2.00). The hardness measurements showed an inverse trend, with T1 being the hardest (2.66) and T3 the most tender (1.48). The FSW-treated meatballs (T2) demonstrated intermediate hardness (2.28), possibly due to the impact of FSW treatment in maintaining the texture of the meatballs.

Taste scores showed significant differences among all treatments, T3 rated as the most flavorful (2.86). The elasticity of T2 was higher than both T1 and T3, indicating that the FSW treatment positively influenced the springiness of the meatballs. Hedonic scores, representing overall acceptability, were highest for T3, with T2 receiving similar scores to T3 and significantly higher scores than T1, suggesting that FSW-treated meatballs are comparable to commercial products in consumer preference.

Proximate composition

Figure 1 illustrates the proximate composition of both control and FSW-treated duck meatballs, represented as percentages of moisture, ash, fat, carbohydrate, and protein. The FSW-treated meatballs exhibited slightly higher moisture content (approximately 70%) compared to the control (around 65%), while both samples had very low ash content (less than 2%). The fat content of the control meatballs was considerably higher (approximately 15%) than that of the FSW-treated meatballs (around 10%). Carbohydrate levels remained low in both samples (just above 5%). The protein content was notably higher in the FSW-treated meatballs (nearly 20%), while the control meatballs contained around 15% protein. These results indicate that the FSW treatment successfully reduced fat content while increasing the protein content in duck meatballs.

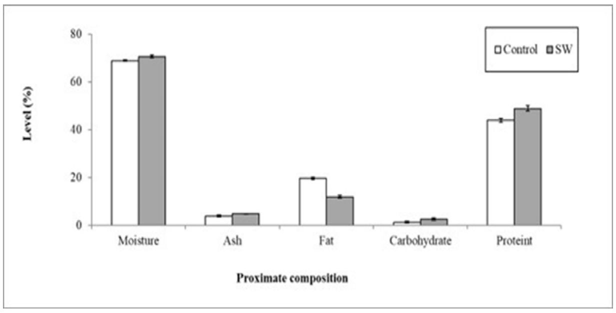

Fig 1. Proximate composition of duck meat with FSW treatment meatballs and duck meat with basal diet meatballs. Two samples Control = Basal Diet; SW= Fermented Seaweed Waste Treatment. Column shows mean values of two treatment and bar shows the standard error of means. Means are different significantly ($p<0.05$ or $p<0.001$).

Fatty Acid Profile

Table 3 compares the fatty acid profiles of duck meatballs from ducks fed with FSW to those fed with a basal diet (control). The FSW-treated meatballs showed a slight increase in myristic (0.55±0.08) and palmitic acids (1.72±0.35) compared to the control (0.51±0.047 and 1.50±0.27, respectively). However, the differences in docosanoate and tricosanoate levels between the two treatments were minimal, with FSW-treated meatballs having 0.57±0.09 and 0.68±0.25, respectively, compared to 0.48±0.06 and 0.71±0.29 in control.

Significant differences were observed in the unsaturated fatty acid profiles. The FSW-treated meatballs exhibited notably higher levels of palmitoleic acid (28.49±1.10*) and eicosatrienoic acid (3.24±0.95*) compared to the control (19.29±1.59 and 0.35±0.08, respectively). Additionally, the omega-3 fatty acid, linolenic acid, was significantly increased in the FSW-treated meatballs (6.48±1.12*) compared to the control (3.31±0.42). In contrast, the omega-6 fatty acid, linoleic acid, was lower in the FSW-treated meatballs (6.11±0.78) than in the control (7.55±1.78). FSW-treated meatballs also contained higher oleic acid (61.71±1.65*) compared to the control (45.95±9.17) and significantly lower levels of the trans fatty acid linolelaidic acid (15.04±2.21*), compared to the control (27.04±1.76).

Table 3. Fatty acid profile of duck meatballs.

Fatty Acid	Meatballs	
	Control	Treatment
Saturated fatty acid		
Myristate	0.51±0.047	0.55±0.08
Palmitate	1.50±0.27	1.72±0.35
Docosanoate	0.48±0.06	0.57±0.09
Tricosanoate	0.71±0.29	0.68±0.25
Unsaturated fatty acid		
Palmitoleate	19.29±1.59	28.49±1.10*
Eicosatrieonic	0.35±0.08	3.24±0.95*
Lenolenate (omega 3)	3.31±0.42	6.48±1.12*
Lenoleate (omega 6)	7.55±1.78	6.11±0.78
Docosadienoic	0.31±0.05	0.29±0.08
Oleic (Omega 9)	45.95±9.17	61.71±1.65*
Lenolelaidic	27.04±1.76	15.04±2.21*

Discussion

The sensory evaluation of FSW-treated duck meatballs revealed significant improvements in key sensory attributes such as aroma, elasticity, and overall acceptability compared to untreated duck meatballs. T2 had a similar aroma score to T3 with no significant difference. This suggests that FSW treatment did not create any off-flavor changes. Previous research by Liu *et al.* (2024) shows that volatile compounds like hexanal and octanal contribute to their unique aroma. This aroma usually had lower consumer preferences, so that during FSW process these compounds were altered resulting in acceptable aroma profile as the commercial meatballs. This aroma acceptability is crucial for consumers to perceive the products, as it plays a key role in determining the overall desirability of meat products.

Regarding meatballs texture, T2 performed better than T1 and T2 in elasticity, an important attribute for processed meat products. The high elasticity score for T2 comes from the interaction between seaweed components and meat's protein matrix. Seaweed, such as *Glacilaria* sp., contains polysaccharides which may contribute to the gel-forming properties of the meatballs, enhancing their springiness (Yasin *et al.*, 2023). Additionally, the mix of starch and water in the meatball matrix creates a stable gel network. This result suggests that FSW treatment not only enhances the nutritional profile but also positively influences the textural properties of duck meatballs, making them more appealing to consumers.

The overall hedonic scores show T2 are very similar to commercial duck meatballs (T3). The combination of improved aroma, enhanced elasticity, and balanced flavor contributed to the higher acceptability of T3. T2 showed no significant difference in taste from commercial products for taste parameters. These findings align with previous studies that have demonstrated how seaweed-based supplements can improve the sensory qualities of meat products by enhancing both flavor and texture through their nutrient-rich profiles (Laksanawati *et al*., 2024). The high acceptance of T2 suggests that they hold significant potential for commercialization as a healthier alternative.

The analysis of proximate composition resulted that T2 had significantly higher moisture content compared to T3, with values of approximately 70% versus 65%, respectively. This higher moisture content is from water holding capacity of protein content in duck meat. The moisture content contributes to the juiciness and tenderness of the meatballs, which are desirable attributes in meat products. Moreover, increased moisture can improve the texture of the meatballs, making them more palatable and potentially extending their shelf life by slowing down drying.

T2 demonstrated a higher protein content compared to T3. This increase is due to the nutrient-rich profile of fermented seaweed, which is a known source of essential amino acids (Rosemary *et al*., 2019) and has been shown to enhance nitrogen content and nutrient bioavailability. The fermentation of the seaweed not only boosts nutritional value but also increases protein deposition in muscle tissue. Higher protein content is important for consumers health concern so the product acceptability increases. Protein is a crucial macronutrient required for muscle maintenance, tissue repair, and overall metabolic function, making FSW-treated duck meatballs a more nutritious option.

The most notable difference in the proximate composition was the fat content. T2 contains approximately 12% fat, significantly lower than T3, which had about 20% fat. According to the findings by Santoso *et al*. (2016), ducks fed without FSW had a total fat mass of 21.78 g per carcass, while duck fed with 12.5% FSW had a markedly reduced fat mass of 13.33 g. The lower carcass fat is reflected in the decreasing of since the same lean muscle portions were used consistently across all treatments. The lower fat content in FSW-treated meatballs is beneficial for consumers seeking low-fat, healthier food options, as excessive fat intake is linked to an increased risk of cardiovascular diseases and obesity (Zhubi-Bakija *et al*., 2021). This reduction in fat along with higher moisture and proteins level enhances the overall nutritional profile of T2. This was making them a functional and health-conscious alternative to conventional meat products.

The lower fat content in T2 provides substantial nutritional benefits, especially in reducing the risk of diet-related diseases such as cardiovascular disorders. Research has highlighted reducing fat intake, particularly saturated fats, to improve cardiovascular health. T2 meatballs not only reduce fat content but also contain a higher proportion of unsaturated fatty acids, which are known to provide protective cardiovascular effects. The fatty acid profile of T2 reveals a significant increase in beneficial unsaturated fatty acids, including omega-3 (linolenic acid) and omega-7 (palmitoleic acid), compared to the control. Seaweed has been recognized as a rich source of polyunsaturated fatty acids, particularly omega-3s, which are vital for reducing inflammation and promoting heart health (Valente *et al*., 2006). T2 fatty acids are incorporated into the meat during duck metabolism. Additionally, the presence of alpha-linolenic acid (ALA) in seaweed is converted by the ducks into longer-chain polyunsaturated fatty acids such as eicosatrienoic acid (C20:3), further improves the meat nutritional value (Frasiska *et al*., 2016).

T2 exhibited a significant reduction in trans fatty acids, particularly linolelaidic acid, which is associated with negative cardiovascular effects. It is particularly impressive that seaweed-based feed supplements can lower trans fatty acid production in ducks. Seaweeds are rich in polyunsaturated fatty acids, which compete with trans fats during metabolism, leading to lower trans-fat deposition in the meat (Morais *et al*., 2020). The reduction in trans fats, along with the increase in beneficial unsaturated fats, makes T2 as a healthier alternative to conventional meat products.

The fermentation process used to treat seaweed waste improves how good its nutrients are absorbed. Fermentation breaks down complex carbohydrates and releases bioactive compounds that are more easily absorbed and utilized by the ducks (Zhao *et al*., 2021). This process not only enhances the fatty acid composition but also boosts the overall nutritional value, making T2 a functional food product with enhanced health benefits. Fermentation also promotes the production of short-chain fatty acids, which contribute to the higher levels of unsaturated fatty acids found in the meatballs (Supriya *et al*., 2023).

Conclusion

This study showed a significant increase in the nutritional and sensory content of duck meatballs treated with fermented seaweed waste (FSW). T2 shows higher moisture content, lower fat content, and an increased fatty acid profile. The most significant difference in the proximate composition is the fat content in T2 12% lower than T1 20%. The T2 fatty acid profile showed an increase in omega-3 and omega-7 fatty acids as well as a decrease in trans fatty acids. Sensory evaluations revealed that FSW-treated meatballs were comparable to commercial meatballs in aroma, texture, and overall acceptability, making them a healthier and appealing alternative to food products. These findings suggest that FSW-treated duck meatballs could serve as a functional, health-conscious food product, offering both nutritional benefits and market potential. Future studies should explore optimizing the fermentation process and further investigating the long-term health benefits of FSW supplementation.

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Conflict of interest

The authors have no conflict of interest to declare.

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