

Effects of *Moringa oleifera* leaf flour on antioxidant activity, lipid oxidation, and fat content of oven-dried chicken sausage chips

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ABSTRACT

This study evaluated the effects of incorporating *Moringa oleifera* leaf flour (0%, 2%, 4%, and 6%) into oven-dried chicken sausage chips on DPPH radical-scavenging activity, thiobarbituric acid (TBA) values, and Soxhlet-extractable fat content. A completely randomized design with four treatments and four replicates was used, and data were analyzed using one-way analysis of variance followed by Duncan's multiple range test. Chicken sausage batters were prepared, steamed, frozen, sliced into 4–5 mm thickness, and oven-dried at 100°C for 65 minutes. Antioxidant activity increased significantly from 29.56% in the control to 63.82% at 6% inclusion, while TBA values decreased from 1.46 to 0.41 mg malondialdehyde/kg meat. Fat content was significantly lower in all moringa-containing formulations (4.76–4.87%) compared with the control (6.26%), though values did not differ significantly among the 2%, 4%, and 6% treatments. By jointly evaluating radical-scavenging activity and lipid oxidation in an oven-dried sausage-chip matrix, this study demonstrates that *Moringa oleifera* leaf flour serves as an effective natural antioxidant and functional ingredient. Among the formulations tested, the 6% inclusion level produced the highest DPPH activity and lowest TBA value while maintaining a stable reduced fat content.

INTRODUCTION

The Broiler chicken meat is a highly nutritious food source, featuring a delicious taste and aroma, a tender texture, and a relatively low price, making it widely consumed by the public. The ease of processing makes broiler chicken meat one of the primary choices for meeting nutritional needs (Hariono et al., 2024). According to Sihombing et al. (2026), broiler chicken is the largest contributor to protein adequacy in East Nusa Tenggara. Chicken meat holds great potential for development into a variety of processed products, such as meatballs, nuggets, sausages, and meat rolls. This processing sector is now increasingly in demand and growing rapidly, both on a large industrial

scale and within micro, small, and medium-sized enterprises (MSMEs). Through the application of appropriate processing and preservation technologies, the shelf life of processed meat products can be extended without drastically reducing their nutritional value. In addition to reducing the risk of economic losses due to spoilage of raw materials, these processed product innovations also make it easier for the public to prepare delicious, convenient, and hygienic meals that still optimally meet a family's daily nutritional needs.

Sausage is a processed meat product (beef, chicken, or fish) made from finely minced meat that is seasoned with spices and herbs and then stuffed into a cylindrical casing (Wijaya et al., 2025). Sausage is known as a ready-to-



eat source of animal protein that is readily available on the market. Sausage is a processed product that is quite popular among the public, particularly among the middle and upper classes (Rahmaputra et al., 2026). According to Masyithoh et al. (2025) the consumption rate of sausage among the Indonesian population has grown at an average rate of 4.46%. However, despite its convenience, chicken sausage has several drawbacks, particularly regarding the content of additives such as preservatives and synthetic dyes, which can have negative health effects if consumed in excess over the long term (Pereira et al., 2026). Chicken sausage also has several other drawbacks, including a relatively short shelf life and a decrease in emulsion system stability during processing and storage. Further processing into value-added products such as chicken sausage chips can serve as an innovation to enhance the diversity of chicken meat products. Kurniawati et al. (2025) reported that the addition of moringa leaf flour imparts a moringa leaf aroma to the chicken sausage chips, which was still well-received by the panelists.

Moringa leaves (*Moringa oleifera*) are considered an economical vegetable in East Nusa Tenggara (NTT). Moringa leaves possess excellent nutritional value, making them a viable alternative for addressing nutritional issues (Kou et al., 2018). In addition to enhancing nutritional value, *moringa* also contain very high levels of antioxidants. Munir et al. (2025) reported that the *moringa* plant contains essential nutrients such as minerals, protein, β -carotene, amino acids, vitamin C, and vitamin E, which acts as an antioxidant. This is supported by research findings from Afinesta et al. (2026), who reported that adding 5% *Moringa oleifera* leaf powder to chicken meatballs significantly increased antioxidant activity, reaching 47.58%. Aris et al. (2024) also reported that fortifying chicken nuggets with moringa leaves reduced fat content (by 9.90%).

Lindasari et al. (2021) examined the incorporation of 0–3% *Moringa oleifera* leaf flour into chicken sausage chips, primarily assessing proximate composition and nutritional-label information. However, their study did not evaluate 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical-scavenging activity or lipid oxidation using the thiobarbituric acid (TBA) assay. Thus, the effects of higher moringa inclusion levels

on these oxidation-related quality indicators in oven-dried chicken sausage chips remain unclear. To address this gap, the present study evaluated the simultaneous responses of DPPH radical-scavenging activity, TBA values, and Soxhlet-extractable fat content to 0%, 2%, 4%, and 6% moringa leaf flour. The novelty lies in examining antioxidant activity and lipid oxidation together in this product at inclusion levels extending beyond those previously studied, rather than in the addition of moringa itself. It was hypothesized that increasing moringa inclusion would be associated with greater radical-scavenging activity and lower TBA values, while fat content was assessed as a separate compositional outcome.

MATERIALS AND METHODS

Materials

The materials used in this study included broiler chicken breast meat purchased from a local market and *Moringa oleifera* leaf flour obtained from a commercial supplier in Kupang City, East Nusa Tenggara, Indonesia. Other ingredients included tapioca flour, wheat flour, cornstarch, garlic, shallots, pepper, nutmeg, ginger, salt, granulated sugar, powdered milk, cooking oil, and ice cubes. The equipment used included a food processor, digital weighing scale, sausage stuffer, sausage casings, steamer, freezer, and drying oven.

Methods

The procedure for making chicken sausage chips followed a modified version of the study by Lindasari et al. (2021). Broiler chicken breast meat (1 kg) was cut into smaller pieces and ground with ice cubes using a food processor for approximately 1 minute until a homogeneous mixture was obtained. Subsequently, the remaining ingredients, including tapioca flour, wheat flour, cornstarch, garlic, shallots, pepper, nutmeg, ginger, salt, granulated sugar, powdered milk, and cooking oil, were added and mixed for approximately 2 minutes. Broiler chicken breast meat was purchased from a local commercial market; therefore, direct live animal experimentation was not involved, complying with institutional standard bioethics guidelines for food product development.

Moringa oleifera leaf flour was then incorporated directly into the sausage batter at concentrations of 0% (T0), 2% (T1), 4% (T2), and 6% (T3), calculated based on the weight of chicken meat (1 kg). Accordingly, 0, 20, 40, and 60 g of moringa leaf flour were added to the respective treatment formulations. Each treatment batter was mixed again using a food processor for approximately 2 minutes to ensure uniform distribution of moringa leaf flour.

The resulting batter was stuffed into sausage casings using a manual sausage stuffer and tied into approximately 5 cm segments. The sausages were then steamed until the internal temperature reached approximately 80°C. After steaming, the sausages were frozen for

approximately 24 hours and subsequently sliced into pieces with a thickness of 4–5 mm. The slices were oven-dried at 100°C for 65 minutes to produce chicken sausage chips.

The study employed a completely randomized design (CRD) consisting of four treatments based on the addition of *Moringa oleifera* leaf flour: T0 (0%), T1 (2%), T2 (4%), and T3 (6%). Each treatment was replicated four times, resulting in a total of 16 independent experimental units. Each replication consisted of a separately prepared batch of chicken sausage batter to ensure independence among experimental units. The data of ingredients for chicken sausage chips are presented in Table 1.

Table 1. Ingredients for chicken sausage chips (g/batch)

Ingredient	T0 (0%)	T1 (2%)	T2 (4%)	T3 (6%)
Chicken meat (kg)	1	1	1	1
Tapioca flour (%)	25	25	25	25
All-purpose flour (%)	6	6	6	6
Cornstarch (%)	4	4	4	4
Moringa leaf flour (%)	0	2	4	6
Garlic (%)	2	2	2	2
Red onion (%)	2	2	2	2
Pepper (%)	0.5	0.5	0.5	0.5
Nutmeg (%)	0.5	0.5	0.5	0.5
Ginger (%)	0.5	0.5	0.5	0.5
Salt (%)	2	2	2	2
Granulated sugar (%)	1.5	1.5	1.5	1.5
Dancow milk (%)	2	2	2	2
Cooking oil (ml)	40	40	40	40
Ice cubes (g)	250	250	250	250

Source: Lintasari et al. (2021)

Parameters

The parameters observed were antioxidant activity, lipid oxidation, and fat content. The antioxidant assay used the DPPH method by measuring color absorbance at $\lambda=517$ nm (Pratiwi et al., 2025). The percentage of DPPH radical-scavenging activity was calculated using the following equation:

$$\text{DPPH scavenging activity (\%)} = \left(\frac{A_{\text{control}} - A_{\text{sample}}}{A_{\text{control}}} \right) \times 100$$

Lipid oxidation was measured using the TBA method based on the formation of

malondialdehyde complexes at $\lambda=532$ nm (Abeyrathne et al., 2021). The TBA value (mg malondialdehyde/kg sample) was calculated as follows:

$$\text{TBA value (mg MDA/kg)} = \frac{A_{\text{sample}} \times \text{dilution factor}}{\text{sample weight (g)}}$$

Meanwhile, fat content was analyzed gravimetrically using the Soxhlet extraction method with a non-polar solvent (Asmariyani et al., 2017).

Data Analysis

Data on antioxidant activity, lipid oxidation, and fat content were analyzed using one-way analysis of variance (ANOVA) to determine the effect of *Moringa oleifera* leaf flour addition. When significant treatment effects were detected ($P<0.05$), Duncan's multiple range test (DMRT) was performed to compare treatment means. The results were expressed as mean $\pm$ standard deviation. Statistical significance was determined

at $P<0.05$, while $P<0.01$ was considered highly significant.

RESULTS AND DISCUSSIONS

The data on the antioxidant activity, fat oxidation, and fat content of chicken sausage chips treated with moringa leaf flour are presented in Table 2.

Table 2. Effect of *Moringa oleifera* leaf flour addition on the chemical quality of chicken sausage chips

Parameter	Moringa leaf flour addition level				P (value)
	T0 (0%)	T1 (2%)	T2 (4%)	T3 (6%)	
Antioxidant activity (%)	29.56 $\pm$ 0.86 ^a	47.61 $\pm$ 1.99 ^b	48.46 $\pm$ 1.05 ^b	63.82 $\pm$ 1.61 ^c	<0.001
TBA (mg.mal/kg)	1.46 $\pm$ 0.16 ^d	0.96 $\pm$ 0.11 ^c	0.62 $\pm$ 0.09 ^b	0.41 $\pm$ 0.06 ^a	<0.001
Fat (%)	6.26 $\pm$ 0.93 ^b	4.80 $\pm$ 0.85 ^a	4.87 $\pm$ 0.34 ^a	4.76 $\pm$ 0.25 ^a	0.02

Note: ^{a,b,c,d} Values are presented as Mean $\pm$ Standard Deviation. Means in the same row with different superscript letters differ significantly ($P<0.05$) or highly significantly ($P<0.01$) based on Duncan's multiple range test. MDA = Malondialdehyde

Antioxidant Activity of Chicken Sausage Chips

The addition of moringa leaf flour significantly affected DPPH radical-scavenging activity ($P<0.01$). The lowest activity was recorded in the control (29.56%), and the highest in T3 (63.82%). The 2% and 4% treatments were not significantly different, whereas 6% was higher than all other treatments. This pattern is consistent with previous findings that moringa-derived ingredients may enhance antioxidant-associated measurements in processed meat (Apriantini et al., 2022). Natural compounds such as phenolics and flavonoids have been proposed as contributors to the antioxidant capacity of moringa leaves (Rasak et al., 2023).

The research results in Table 2 show significantly higher antioxidant activity compared with the studies by Janggu et al. (2023) on processed products with 3% moringa leaf flour added, which only reached 6.38% using the DPPH method. This difference is likely due to the raw material composition, which is dominated by blood and fat, a more intensive heating process; and possible differences in extract concentration and analytical conditions, all of which reduce the ability to scavenge free radicals. Conversely, the antioxidant activity value in this study was slightly higher than that

of tempeh enriched with 9% moringa leaf flour, which was 58.72%, as reported by Puyanda et al. (2023) the higher value in the chicken sausage chips indicates that the meat matrix and product formulation are able to retain the antioxidant compounds from moringa leaves more effectively. These findings are also supported by a study by Ibrahim et al. (2022), which reported that the addition of *Moringa oleifera* leaf flour or extract significantly increased the antioxidant capacity of chicken burger products, due to the high content of phenolic compounds and flavonoids capable of inhibiting lipid oxidation during storage.

Lipid Oxidation (TBA Value) of Chicken Sausage Chips

TBA values differed significantly among treatments ($P<0.01$). The highest TBA value was observed in the control (1.46 mg malondialdehyde/kg), followed by T1 (0.96), T2 (0.62), and T3 (0.41 mg malondialdehyde/kg). The decrease across moringa inclusion levels is consistent with lower levels of TBA-reactive oxidation products. Previous research has associated moringa-based ingredients with improved lipid oxidation-related measurements in meat products. Olan et al. (2026), which states that the addition of moringa leaf powder

reduces lipid oxidation in beef patties. This is because moringa leaf powder has the ability to inhibit free radicals. Domínguez et al. (2019) also reported that increased antioxidant activity in processed meat products can lower fat oxidation values. This is because there is an inverse relationship between fat oxidation values and antioxidant activity; if the fat oxidation value is low, the antioxidant activity value is higher.

The research results in Table 2 show slightly higher lipid oxidation values compared to those reported by Kabir et al. (2025) for chicken sausages treated with moringa leaf extract, which recorded oxidation stability levels ranging from 0.32 to 0.47. This difference is believed to be related to the characteristics of the product matrix and the effectiveness of moringa leaf phenolic compounds in optimally suppressing the initial rate of oxidation. Conversely, the fat oxidation values in this study were significantly lower compared to those in the control study on processed chicken meat products without optimal antioxidant protection or at the lowest level, where fat oxidation values (TBARS) could surge to over 1.46.

The lower values observed in chicken sausage chips supplemented with moringa leaf flour indicate that the fat content in processed meat products can be effectively protected by the antioxidant capacity of moringa leaves. As supported by Hingrajiya et al. (2025), there is an inverse relationship between the level of fat oxidation and antioxidant activity; the higher the concentration of active compounds (such as phenolics and flavonoids) in moringa leaf flour, the stronger its ability to inhibit free radicals and suppress the rate of increase in fat oxidation values in chicken burgers.

Fat Content of Chicken Sausage Chips

The addition of moringa leaf flour affected Soxhlet-extractable fat content overall ($P = 0.020$). The control (T0) had 6.26% fat, compared with 4.80%, 4.87%, and 4.76% in T1, T2, and T3, respectively. According to the reported superscripts, all three moringa treatments differed from the control, but did not differ significantly from one another. Therefore, the numerically lowest result at 6% is not statistically superior to 2% or 4%. Earlier literature has discussed antioxidant and food-structure phenomena in other food

matrices (Petropoulos et al., 2019). In addition, moringa leaf polyphenols bind directly to the structural proteins of meat, thereby forming a more compact gel network with a higher water-binding capacity. This enhances the stability of fat emulsions, reduces fat release during the cooking process, and results in a more homogeneous distribution of fat globules within the sausage matrix.

Previous work on moringa-containing meat products has reported fat-content or other compositional differences, including studies of Kartikasari et al. (2023) on beef burger products with added moringa leaf flour, which recorded a total fats content ranging from 4.9% to 3.28%. This difference is likely due to variations in the meat-to-fat ratio of the raw materials, the concentration of moringa leaf flour used, and the intensity of the processing methods, which affect the product's fat retention and release. In contrast, the fat content in this study was significantly lower compared to conventional processed meat products without the addition of fiber-rich ingredients, where fat content can exceed 6% due to poor emulsion stability.

The controlled fat content in the chicken sausage chips indicates that the meat matrix and moringa leaf flour formulation are able to maintain emulsion stability more effectively. These findings are also supported by the study by Munir et al. (2025), which reported that moringa leaf flour improved the interaction between myofibrillar proteins and fiber components, thereby forming a compact gel network, reducing fat release during cooking, and distributing fat globules more homogeneously in rabbit meat nuggets.

CONCLUSIONS

The incorporation of *Moringa oleifera* leaf flour significantly enhanced DPPH radical-scavenging activity, reduced lipid oxidation (TBA value), and lowered Soxhlet-extractable fat content in oven-dried chicken sausage chips compared to the control. Among all evaluated formulations, 6% *Moringa oleifera* leaf flour demonstrated the most optimal functional performance by providing the highest antioxidant capacity and lowest lipid oxidation rate while maintaining reduced fat levels similar

to the 2% and 4% treatments. Therefore, a 6% inclusion level of moringa leaf flour is recommended as a functional ingredient in chicken sausage chip production to extend shelf stability and improve health-related attributes.

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