Effect of Moringa Oleifera leaf extract supplementation on productive performance and meat quality in broiler

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Research Article

Keywords: Moringa oleifera leaf extract, broiler chicken, meat quality, production performance, antioxidant

Posted Date: June 5th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9532985/v1

Abstract

Moringa oleifera Lam. leaves are rich in nutrients and possess high levels of antioxidant compounds, demonstrating potential as a functional feed ingredient for promoting animal health and productivity. However, *Moringa oleifera* leaf also contain certain anti-nutritional factors, which may adversely affect animals if included in excessive amounts. Therefore, this study aimed to investigate the effects of dietary supplementation with spray-dried *Moringa oleifera* leaf extract on feed intake, growth performance, feed conversion ratio, carcass characteristics and meat quality in broiler chickens. A total of 120 Ross 308 broilers were allocated into five groups in a completely randomized design: a control group, a placebo group, and three treatment groups supplemented with 0.25, 0.5, and 1.0% of spray-dried *Moringa oleifera* leaf extract. The trial was conducted over a 21-day period (from day 7 to day 28 of age). Results showed that supplementation with spray-dried *Moringa oleifera* leaf extract had no significant effect ($p > 0.05$) on feed intake, body weight, growth rate, feed conversion ratio, carcass traits or meat quality. However, the extract exhibited a high total phenolic content (8.12 mg GAE/g sample) and strong antioxidant activity (63.71%), indicating its potential use as a natural feed additive, particularly in antibiotic-free broiler production systems.

Introduction

The poultry industry is one of the fastest-growing sectors in the global livestock economy, driven by increasing demand for chicken meat as an affordable and accessible source of animal protein. To meet this demand, producers are required to enhance production efficiency and meat quality while maintaining animal health and welfare. However, the long-term use of antibiotic growth promoters in poultry diets has contributed to the emergence of antimicrobial resistance, leading to regulatory restrictions and increased interest in natural alternatives to replace antibiotics in animal production (Gadde et al. 2017).

Moringa oleifera Lam., a tropical tree species, has gained considerable attention in animal nutrition due to its high nutritional value. Moringa leaves contain approximately 27–30% crude protein and are rich in essential amino acids, vitamins, and minerals. Moreover, Moringa leaves are abundant in bioactive compounds such as flavonoids, tannins, and phenolic acids, which possess antioxidant, antimicrobial, and anti-inflammatory properties. These characteristics may contribute to improved gut health and growth performance in broiler chickens (Moyo et al. 2011; Karthivashan et al. 2015).

Nevertheless, Moringa leaves also contain anti-nutritional factors, including saponins, tannins, and phytates, which may interfere with nutrient digestion and absorption when used at high inclusion levels. This may negatively affect feed intake and growth performance in poultry (Makkar and Becker 1996; Ogbe and Affiku 2011). Although numerous studies have investigated the use of Moringa leaf meal in broiler diets, the reported results remain inconsistent. Some studies have demonstrated improved growth performance (Gakuya et al. 2014), whereas others reported no significant improvement or even adverse effects at higher inclusion levels. These variations may be attributed to differences in anti-nutritional factor content, processing methods, broiler strains, and environmental conditions.

In contrast, Moringa leaf extract offers several advantages over leaf meal. The extraction process can concentrate bioactive compounds such as polyphenols, flavonoids, and antioxidant constituents while reducing anti-nutritional factors (Sreelatha and Padma 2009; Makkar and Becker 1996). Furthermore, extracts provide greater chemical consistency than leaf meal, allowing better control of supplementation levels and more accurate evaluation of biological effects. Additionally, lower inclusion levels of extracts may produce comparable or even superior biological responses compared with leaf meal.

Although several studies have reported the biological activities of Moringa leaf extracts, including antioxidant properties and gut health improvement, limited information is available regarding their direct effects on growth performance, carcass characteristics and meat quality of broiler chickens under practical production conditions. Therefore, this study aimed to evaluate the effects of dietary supplementation with spray-dried Moringa leaf extract on feed intake, growth performance, feed conversion ratio, carcass characteristics and meat quality in broiler chickens. The findings of this study may provide useful information for developing safe and effective natural feed additives for sustainable broiler production.

Materials and Methods

Animal ethics approval This study was conducted in accordance with the guidelines for the use of animals in scientific research and was approved by the Institutional Animal Care and Use Committee (IACUC), Ubon ratchathani University, approval number 25/2024/IACUC.

Animal

A total of 120 one-day-old Ross 308 broiler chicks were used in this study. All birds were fed a commercial diet containing 21% crude protein and ≤ 12% moisture until 7 days of age. At day 7, chicks were randomly assigned to five treatments in a completely randomized design, with four replicates of six birds each. All birds were individually identified using small cable ties attached to their legs.

Preparation of spray-dried Moringa oleifera leaf extract

Fresh *Moringa oleifera* leaves (without petioles) were weighed and dried in a hot-air oven at 65°C for 48 h. The dried leaves were then weighed again and ground into a fine powder. The powder was extracted with 95% ethanol using the maceration method for 24 h. The extract was filtered through Whatman No. 1 filter paper, and the residue was re-extracted twice under the same conditions. The combined filtrates were concentrated using a rotary vacuum evaporator (Heidolph, Hei-VAP model) at 50°C to obtain a crude extract. Subsequently, 100 g of Moringa leaf extract was mixed with 75 g maltodextrin and 25 g whey protein as carrier agents. The mixture was thoroughly homogenized and spray-dried using a spray dryer (EUROBEST, SED-5 Euro Workshop). The resulting spray-dried powder was stored in airtight, light-protected bags at − 20°C until incorporation into the experimental diets.

Experimental diets

Five dietary treatments were used in this study. Treatment 1 consisted of a commercial diet containing 21% crude protein and ≤ 12% moisture (control). Treatment 2 consisted of the same commercial diet supplemented with 1% maltodextrin and whey protein as a placebo. Treatments 3 to 5 consisted of the commercial diet supplemented with spray-dried Moringa leaf extract at levels of 0.25%, 0.5%, and 1.0%, respectively.

Experimental procedure

The experiment was conducted in an evaporative cooling house divided into 20 pens (1 × 1 m each) with rice husk as bedding material. The trial started when the birds were 7 days old. Six birds were randomly assigned to each pen, individually identified with leg bands, and weighed at the beginning of the experiment. Body weight was subsequently recorded at 14, 21, and 28 days of age. Birds had free access to clean drinking water and were fed the experimental diets *ad libitum* throughout the study. At the end of the experiment, two birds (one male and one female) were randomly selected from each pen for carcass and meat evaluation. The experiment was conducted from October to November 2024 at the Poultry Farm, Training and Experimental Farm Office and Central Laboratory, Faculty of Agriculture, Ubon Ratchathani University, Warin Chamrap, Ubon Ratchathani, Thailand.

Chemical analysis of experimental diets

The experimental diets from all five treatments were analyzed for dry matter (DM), crude protein (CP), crude fiber (CF), ether extract (EE), and ash content using proximate analysis according to the methods of Association of Official Analytical Chemists (AOAC 2000).

Determination of total phenolic compounds by Folin–Ciocalteu method

Total phenolic compounds in the spray-dried Moringa leaf extract were determined using the Folin–Ciocalteu method. One gram of sample was dissolved in 5 mL of 95% ethanol:water (50:50 v/v) solution and stirred for 30 min. The mixture was then centrifuged at 7,500 rpm for 10 min at 10°C. The supernatant was collected and stored at − 4°C until analysis. The Folin–Ciocalteu reagent (10% v/v) was prepared by diluting the stock Folin–Ciocalteu reagent with distilled water at a ratio of 1:9. For the reaction, 200 µL of sample solution was transferred into a test tube, followed by the addition of 1,000 µL of 10% Folin–Ciocalteu reagent and mixed thoroughly. After 5 min, 800 µL of 7.5% (w/v) sodium carbonate (Na_2CO_3) solution was added and mixed well. The mixture was incubated at room temperature in the dark for 30 min. Absorbance was measured at 750 nm using a spectrophotometer. The total phenolic content was calculated from a gallic acid standard curve and expressed as milligrams of gallic acid equivalents per gram of sample (mg GAE/g).

Determination of antioxidant activity by 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay

The antioxidant activity of the spray-dried Moringa leaf extract was determined using DPPH radical scavenging method. The DPPH solution was prepared by dissolving 9.85 mg of DPPH (molecular weight 394.32 g/mol) in 99.9% methanol and adjusting the final volume to 250 mL. Sodium phosphate buffer (pH 7.0) was prepared by dissolving 14.196 g of reagent in distilled water. For the assay, three mixtures were prepared: background (1 mL sample + 1 mL sodium phosphate buffer), Control (1 mL sodium phosphate buffer + 1 mL DPPH solution), and Sample (1 mL sample + 1 mL DPPH solution). All mixtures were vortexed thoroughly and incubated in the dark at room temperature for 30 min. Absorbance was measured at 517 nm using a spectrophotometer. Antioxidant activity was expressed as DPPH radical scavenging capacity (%) of the sample.

Meat quality evaluation

Breast muscle samples (pectoralis major) were collected for meat quality evaluation. Meat pH after thawing was measured using a pH meter (Model 191, Knick, D-Berlin). Meat color was determined using a HunterLab ColorFlex EZ colorimeter, and values of lightness (L*), redness (a*), and yellowness (b*) were recorded. Water-holding capacity was evaluated by measuring drip loss after storing meat samples at 4°C for 24 h, cooking loss, and shear force. For shear force determination, moist-cooked meat samples were prepared and five cores (1.27 cm diameter) were removed parallel to the muscle fiber direction using a hollow cylindrical corer. The Warner–Bratzler blade attachment was connected to a Texture Analyzer (model TA.XT plus), and the maximum shear force per sample thickness (force/distance) was recorded. Lipid oxidation was determined using thiobarbituric acid reactive substances (TBARS) analysis. Finely ground breast meat samples were packed in sealed plastic bags and stored at 4°C for 0, 3, 6, and 9 days according to the method of Rossell (1994). TBARS values were expressed as mg of malondialdehyde (MDA) per kg of meat.

Statistical analysis

Data on feed intake, body weight, growth rate, feed conversion ratio, carcass characteristics and meat quality were analyzed using analysis of variance under a completely randomized design. When significant differences among treatments were detected ($p < 0.05$), mean comparisons were performed using the Least Significant Difference. All statistical analyses were conducted using SAS OnDemand for Academics (SAS 2023).

Results and Discussion

Diet chemical composition

The chemical composition of the experimental diets for the five treatments was similar. The dry matter ranged from 86.70 to 87.98%, CP from 21.17 to 21.95%, CF from 3.19 to 4.72%, EE from 3.79 to 4.38%, and ash content from 5.51 to 6.91%, as shown in Table 1. These results indicate that supplementation of spray-dried Moringa leaf extract at levels of 0.25–1.0% did not affect the chemical composition of the experimental diets. This suggests that the inclusion levels used in the present study did not significantly alter the nutritional value of the basal diet. Therefore, all five experimental diets contained comparable levels of major nutrients. In addition to the chemical components analyzed in this study, previous reports have indicated that *Moringa oleifera* leaf extract contains several essential amino acids, including lysine, methionine, and cysteine, at concentrations ranging from 14.06–18.09, 1.13–4.97, and 1.00–3.39 mg/g dry matter, respectively, which may contribute to improved nutritional value and biological activity when used as a feed additive.

Table 1
The proximate composition of experimental diet

Item (%)	**Spray-dried Moringa leaf extract (%)**					**SEM**[2]	***p*-value**
	0	**Placebo**[1]	**0.25**	**0.5**	**1.0**		
DM	87.74	87.00	87.51	86.70	87.98		
CP	21.53	21.95	21.17	21.48	21.69	0.21	0.2509
CF	3.19	4.37	3.64	3.57	4.72	0.09	0.0756
EE	3.96	3.79	4.21	4.19	4.38	0.82	0.9943
Ash	6.41	6.91	6.88	6.24	5.51	0.45	0.2994

[1] placebo is a basal diet supplemented with 1% of maltodextrin and whey protein

[2] SEM stands for standard error of the mean

Total phenolic compounds in spray-dried Moringa leaf extract

Total phenolic content in the spray-dried Moringa leaf extract was determined using the Folin–Ciocalteu method and compared with a gallic acid standard. Both the gallic acid standard solutions and the spray-dried Moringa extract were reacted with Folin–Ciocalteu reagent, and absorbance was measured at 750 nm. The analysis was performed in triplicate, and the absorbance values were used to calculate total phenolic content expressed as gallic acid equivalents per gram of sample. The results showed that the spray-dried Moringa oleifera leaf extract contained 8.12 ± 0.38 mg gallic acid equivalents per gram of sample (mg GAE/g), as presented in Table 2.

Phenolic compounds in *Moringa oleifera* leaves consist of several groups, particularly phenolic acids, flavonoids, and tannins, which are known for their antioxidant and antimicrobial properties. Previous

studies have reported that fresh leaves with stems and dried Moringa leaves contain total polyphenols ranging from 1.13 to 4.43% (average 2.89%), with major flavonoids including quercetin, kaempferol, and apigenin (Gupta et al. 1989; Makkar and Becker 1996, 1997; Moyo et al. 2011; Leone et al., 2015a, b). Similarly, Sreelatha and Padma (2009) reported that extracts from mature and young Moringa leaves contained phenolic compounds of 45.81 ± 0.02 and 36.02 ± 0.01 mg GAE/g, respectively, and flavonoids of 27 ± 0.03 and 15 ± 0.02 mg quercetin equivalents/g, respectively. Furthermore, Vongsak et al. (2013) found that extraction of dried Moringa leaves with 70% ethanol yielded total phenolic content of 5.35 ± 0.09 g chlorogenic acid equivalents per 100 g of spray-dried extract, while extraction with 50% ethanol produced 2.93 ± 0.15 g per 100 g. The corresponding total flavonoid contents were 2.51 ± 0.11 and 1.23 ± 0.11 g quercetin equivalents per 100 g, respectively. In addition, Sulastri et al. (2018) reported total phenolic content of 2.5–3.0 mg GAE per 100 mg dried leaves and flavonoid content of 8.1–9.6 mg quercetin equivalents per 100 mg extract. Polyphenolic compounds are well recognized for their antioxidant properties; therefore, higher polyphenol content generally indicates stronger antioxidant activity. However, the concentration of bioactive compounds in Moringa leaves may vary depending on several factors, including genetic variation, plant maturity, cultivation practices, environmental conditions, sunlight exposure, drying method, grinding process, storage conditions, and laboratory analytical techniques (Ogbe and Affiku 2011; Förster et al. 2015; Leone et al. 2015a, b).

In the present study, the phenolic content of the spray-dried Moringa leaf extract was at a moderate level (8.12 ± 0.38 mg GAE/g) compared with previous reports. The relatively lower value compared to some studies may be attributed to dilution of the extract with carrier agents such as maltodextrin and whey protein. Although these carriers help stabilize bioactive compounds during spray drying, they may reduce the overall concentration of phenolic compounds. Additionally, partial degradation of phenolic compounds during the spray-drying process at elevated temperatures may also contribute to the reduced phenolic content.

Table 2
Total phenolic compound in spray-dried *Moringa oleifera* leaf extract

Sample	**Absorbance at 750 nm**	**Total phenolic (mg GAE/g sample)**
Rep1	0.464	7.71
Rep2	0.468	8.46
Rep3	0.459	8.19
Average		8.12
SD		0.38

Antioxidant activity of spray-dried Moringa oleifera leaf extract

The antioxidant activity of the spray-dried Moringa leaf extract was evaluated using the DPPH radical scavenging assay by measuring absorbance at 517 nm and comparing the results with an ascorbic acid standard. The results showed that the spray-dried Moringa leaf extract exhibited antioxidant activity of 63.71% (Table 3), which was higher than the value reported by Peñalver et al. (2022), who found antioxidant activity of 41.40 ± 8.66%.

Previous studies have also evaluated antioxidant activity using the half-maximal inhibitory concentration (IC50), defined as the concentration required to scavenge 50% of DPPH radicals. Reported IC50 values vary widely depending on extraction methods and plant material used. Sreelatha and Padma (2009) reported that mature Moringa leaves had an IC50 value of 18.15 ± 0.92 µg/mL, indicating stronger antioxidant activity compared to young leaves, which had an IC50 value of 19.12 ± 0.75 µg/mL. In contrast, Sulastri et al. (2018) reported higher IC50 values ranging from 134.5 to 146.7 µg/mL, suggesting lower antioxidant activity.

The extraction solvent also plays an important role in antioxidant activity. Vongsak et al. (2013) reported that extraction with 70% ethanol yielded an IC50 value of 62.94 ± 7.05 µg/mL, which showed stronger antioxidant activity compared to extraction with 50% ethanol, which had an IC50 value of 164.57 ± 13.41 µg/mL. Meanwhile, Ibrahim et al. (2022) reported an IC50 value of 30.08 ± 0.02 µg/mL, indicating relatively high antioxidant activity.

The findings of the present study suggest that the spray-dried Moringa leaf extract prepared using 95% ethanol extraction and maltodextrin and whey protein as carrier agents effectively preserved bioactive compounds during spray drying. As a result, the extract demonstrated satisfactory antioxidant activity, which was higher than some previously reported values. Differences among studies may be attributed to variations in raw material sources, leaf maturity, extraction solvents, and processing conditions. The antioxidant activity observed in this study may contribute positively to meat quality, particularly by reducing lipid oxidation and extending the shelf life of meat products.

Table 3
Antioxidant activity of spray-dried *Moringa oleifera* leaf extract with DPPH method

Item	Absorbance at 517 nm	% of antioxidant activity
Background	0.019	
Control	0.602	
Sample	0.237	63.710

Calculation of Antioxidant activity of *Moringa oleifera* with DPPH; % of antioxidant activity

= [(control absorbance–(sample absorbance–background absorbance))/control absorbance]*100; % of antioxidant activity = [(0.602–(0.237–0.019))/0.602]*100; % of antioxidant activity = 63.710%

Productive performance of broiler chickens

Broiler chickens fed the control diet, placebo diet and diets supplemented with spray-dried Moringa leaf extract at 0.25, 0.5, and 1.0% showed no significant differences ($p > 0.05$) in body weight at all stages of the experiment. The average final body weight was approximately 1.5 kg (Table 4). Similarly, feed intake, average daily gain, and feed conversion ratio were not significantly different among treatments. These findings are consistent with the results reported by Gul et al. (2024), who investigated supplementation of Moringa leaf extract at 0, 0.8, and 1.2% in broiler diets and found no significant effects on feed intake, growth performance, or feed conversion ratio during a 5-week trial. Likewise, Karthivashan et al. (2015) reported that supplementation of Moringa leaf extract at levels of 0.5, 1.0, and 1.5% did not significantly affect growth rate; however, the supplemented groups showed numerically higher values compared to the control group. In contrast, Marupanthorn et al. (2024) reported that supplementation of spray-dried Moringa leaf extract at 3% and 4% improved growth performance and reduced thiobarbituric acid reactive substances (TBARS) in Mae Hong Son chickens compared with the control and placebo groups. However, hematological parameters and carcass characteristics were not significantly affected.

Studies using Moringa leaf meal have also demonstrated variable effects on productive performance depending on inclusion level. Akib et al. (2024) reported that supplementation with 3% Moringa leaf meal significantly improved body weight gain and feed conversion ratio. Similarly, Essien et al. (2022) found that supplementation of Moringa leaf meal at 7.5% did not negatively affect growth performance, carcass characteristics, or hematological parameters. However, Olugbemi et al. (2010) reported that inclusion levels above 5% may negatively affect productive performance, possibly due to anti-nutritional factors such as tannins, saponins, and phytates that interfere with nutrient digestion and absorption.

Additionally, Akib et al. (2024) reported that Moringa supplementation reduced fat and cholesterol content in broiler meat and improved antioxidant capacity, likely due to bioactive compounds such as phenolics and flavonoids. Similarly, Liaqat et al. (2016) found that broilers fed 2% and 4% Moringa leaf meal showed better feed conversion ratio compared with those fed 6% and 8%, suggesting that excessive supplementation may reduce nutrient utilization efficiency. These findings are consistent with the observations of Makkar and Becker (1996, 1997), who reported that high levels of anti-nutritional factors in Moringa leaves may negatively affect animal performance when used at excessive levels.

Table 4
Productive performance of broilers fed spray-dried *Moringa oleifera* leaf extract diet

Traits	Spray-dried Moringa leaf extract (%)						
	0	Placebo[1]	0.25	0.5	1.0	SEM[2]	*p*-value
Body weight (g)							
d-7	165.21	166.88	162.79	159.83	164.92	2.97	0.5255
d-14	540.42	557.92	537.50	535.00	556.25	11.45	0.4906
d-21	1,026.67	1,052.50	1,028.34	1,031.29	1,059.17	17.14	0.5573
d-28	1,510.42	1,509.59	1,541.92	1,528.25	1,517.08	32.74	0.9482
Feed intake (g/bird)							
d 7–14	63.87	74.76	67.74	69.70	68.51	2.88	0.1685
d 14–21	93.99	98.57	96.84	97.56	100.48	2.86	0.6069
d 21–28	110.36	117.68	118.08	116.74	116.73	3.60	0.5612
overall	89.40	97.00	94.22	94.67	95.24	1.66	0.0579
Average daily gain (g/bird/d)							
d 7–14	53.60	55.86	53.53	53.59	55.90	1.34	0.4973
d 14–21	69.47	70.65	70.12	70.90	71.84	1.43	0.8169
d 21–28	69.11	65.30	70.50	68.96	65.42	4.79	0.9099
overall	64.06	63.94	65.66	65.12	64.39	1.54	0.9170
Feed conversion ratio							
d 7–14	1.19	1.34	1.27	1.30	1.22	0.04	0.1284
d 14–21	1.35	1.40	1.38	1.37	1.40	0.03	0.8502
d 21–28	1.59	1.80	1.72	1.72	1.81	0.11	0.6279
overall	1.39	1.52	1.44	1.46	1.48	0.04	0.3538

[1] Placebo is a basal diet supplemented with 1% of maltodextrin and whey protein

[2] SEM stands for standard error of the mean

Carcass characteristics of broiler chickens

Broiler chickens fed the control diet, placebo diet and diets supplemented with spray-dried Moringa leaf extract at 0.25, 0.5, and 1.0% showed no significant differences ($p > 0.05$) in carcass weight and carcass

percentage. The carcass percentage ranged from 72.94 to 74.41%. Similarly, breast, wing, drumstick, thigh, liver, gizzard, and heart weights were not significantly different among treatments (Table 5).

These findings are consistent with the results reported by Marupanthorn et al. (2024), who observed no significant effects of spray-dried Moringa leaf extract supplementation at 0–4% on carcass percentage and carcass parts of Mae Hong Son native chickens. Although no statistical differences were observed in carcass traits, Moringa oleifera supplementation may influence metabolism at the cellular level through bioactive compounds such as flavonoids, phenolic acids, and vitamin E, which possess antioxidant properties and help reduce oxidative stress in animals (Vergara-Jimenez et al. 2017). These effects may contribute to improved health and productive performance in the long term. However, the supplementation levels used in the present study may have been too low to produce measurable changes, particularly under conditions where birds were not exposed to environmental or disease-related stress.

In addition, Moringa leaves have been reported to enhance digestion and nutrient absorption by stimulating digestive enzyme activity and improving gut microbial balance (Moyo et al. 2011; Nouman et al. 2014). These mechanisms may indirectly improve protein utilization and meat quality. However, such physiological effects may not be reflected in carcass characteristics during a relatively short experimental period. Therefore, further studies focusing on physiological and biochemical changes at the cellular level are recommended.

The present results are also consistent with the findings of Nkukwana et al. (2014), who reported no differences in carcass percentage in broilers supplemented with Moringa leaf meal at 0.001–0.025%, although some carcass parts such as thigh weight varied slightly with supplementation level. In contrast, David et al. (2012) reported that low-level supplementation (0.05% and 0.1%) improved carcass percentage compared to the control group, suggesting that appropriate inclusion levels may enhance carcass quality. Similarly, Liaqat et al. (2016) and Gadzirayi et al. (2012) reported that supplementation of Moringa leaf meal did not negatively affect carcass characteristics, supporting the potential use of Moringa oleifera as a safe feed additive in poultry production.

Table 5
Carcass characteristics of broilers fed spray-dried *Moringa oleifera* leaf extract diet on 28 d of age

Spray-dried Moringa leaf extract (%)							
Traits	0	Placebo[1]	0.25	0.5	1.0	SEM[2]	*p*-value
Live weight (g)	1,465.00	1,402.50	1,450.00	1,393.75	1,395.00	34.81	0.4696
Carcass weight (g)	1,048.75	1,021.25	1,080	1,041.25	1,018.75	22.83	0.3590
% Carcass	72.94	72.78	74.48	74.71	73.08	0.57	0.0799
External and internal organ (% carcass weight)							
Wing	10.47	10.62	11.14	10.94	11.29	0.22	0.0897
Breast	29.33	29.35	29.13	30.13	27.70	0.53	0.0648
Thigh	16.31	16.36	16.58	15.34	15.54	0.52	0.3948
Drumstick	12.87	12.97	13.47	13.58	13.75	0.44	0.5587
Liver	2.29	2.32	2.38	2.39	2.37	0.12	0.9758
Gizzard	2.59	2.79	2.61	2.44	2.96	0.17	0.3113
Heart	0.60	0.70	0.53	0.55	0.66	0.07	0.4414

[1] Placebo is a basal diet supplemented with 1% of maltodextrin and whey protein

[2] SEM stands for standard error of the mean

Meat quality

The moisture content of breast meat ranged from 62 to 64%, with no significant differences among treatments ($p > 0.05$). Similarly, cooking loss, pH, shear force, and drip loss were not significantly affected by dietary supplementation with spray-dried Moringa leaf extract (Table 6).

Regarding meat color, no significant differences were observed in lightness (L*) among treatments. However, breast meat from broilers supplemented with 1% Moringa leaf extract showed significantly higher redness (a*) compared with the control and placebo groups ($p < 0.05$). No significant differences in redness were observed among the groups supplemented with 0.25, 0.5, and 1.0% Moringa extract. For yellowness (b*), broilers supplemented with 1% Moringa extract showed the highest value ($p < 0.05$), while the 0.5% supplementation group had higher yellowness compared with the control group. However, the 0.25%, placebo, and control groups were not significantly different ($p > 0.05$).

Thiobarbituric acid reactive substances (TBARS) values measured on the day of thawing (day 0) showed no significant differences among treatments ($p > 0.05$). Similarly, TBARS values measured after 3, 6, and 9 days of storage showed no significant differences among the experimental groups, indicating that

supplementation with spray-dried Moringa leaf extract did not significantly affect lipid oxidation during storage.

In the present study, supplementation of spray-dried Moringa leaf extract did not significantly affect moisture content, cooking loss, pH, shear force, drip loss, or lipid oxidation of broiler breast meat. These findings indicate that inclusion of Moringa extract at levels of 0.25–1.0% did not markedly influence the physicochemical properties of broiler meat under normal rearing conditions. Similar findings were reported by Sebola et al. (2018), who observed that dietary supplementation of *Moringa oleifera* leaf meal did not significantly affect pH, cooking loss, and some color parameters, although interactions between diet, strain, and gender influenced certain meat quality traits. These results suggest that the response of meat quality to Moringa supplementation may depend on genetic factors, dietary level, and experimental conditions.

Although no significant effects were observed on pH and cooking loss in the present study, Akip et al. (2024) reported improved meat quality in broilers supplemented with *Moringa oleifera* leaf powder, including higher initial pH and reduced cooking loss. These improvements were attributed to the presence of alkaline minerals such as calcium, magnesium, and potassium, as well as antioxidant compounds including vitamin E, selenium, phenolics, and flavonoids. These bioactive compounds may stabilize muscle cell membranes, reduce protein denaturation, and enhance water-holding capacity, thereby decreasing cooking loss. Similarly, Jiang et al. (2023) reported that *Moringa oleifera* supplementation improved water-holding capacity and reduced cooking loss, although the differences were not statistically significant. They suggested that flavonoids, polyphenols, and polysaccharides in Moringa could reduce lipid peroxidation and maintain muscle cell membrane integrity, thereby improving tenderness and water retention. The absence of such effects in the present study may be due to differences in Moringa form (spray-dried extract vs. leaf powder), supplementation level, or environmental conditions during rearing.

Regarding meat color, no significant differences in lightness (L*) were observed among treatments in the present study. This finding agrees with Sebola et al. (2018), who also reported no variation in L* values across dietary treatments in some chicken strains. However, the present study found that broilers supplemented with 1.0% Moringa extract showed higher redness (a*) and yellowness (b*) compared with control groups. This result is consistent with previous reports indicating that *Moringa oleifera* supplementation can enhance meat color characteristics. Sebola et al. (2018) reported that higher inclusion levels of Moringa leaf meal increased b* values due to carotene and xanthophyll pigments present in Moringa leaves. Similarly, Jiang et al. (2023) observed increasing trends in a* and b* values following Moringa supplementation. These pigments may accumulate in muscle tissues and improve color intensity, particularly redness and yellowness.

In addition, no significant differences in TBARS values during storage were observed in this study, indicating that spray-dried Moringa extract did not significantly affect lipid oxidation during refrigerated storage. Although Moringa leaves are known to contain antioxidant compounds such as phenolics and

flavonoids, the levels used in this study may have been insufficient to produce measurable effects. Jiang et al. (2023) suggested that antioxidant compounds in Moringa can reduce oxidative stress and improve meat preservation by preventing lipid peroxidation; however, these effects may be more pronounced under stress conditions or at higher supplementation levels.

Overall, the findings of this study indicate that supplementation with spray-dried Moringa leaf extract at levels up to 1.0% had limited effects on most meat quality parameters but improved meat color characteristics, particularly redness and yellowness. These results are partially consistent with previous studies, which reported variable effects of Moringa supplementation depending on form, inclusion level, and experimental conditions. Therefore, further studies using higher inclusion levels, different processing methods, or stress conditions are recommended to better evaluate the potential of *Moringa oleifera* leaf extract to improve broiler meat quality.

Table 6
Meat quality of broilers fed spray-dried *Moringa oleifera* leaf extract diet on 28 d of age

Traits	**Spray-dried Moringa leaf extract (%)**					**SEM**[2]	***p*-value**
	0	**Placebo**[1]	**0.25**	**0.5**	**1.0**		
Moisture (%)	63.60	64.50	64.25	62.82	62.51	0.92	0.4923
Drip loss (%)	21.29	20.13	21.05	20.53	19.18	1.03	0.6309
Cooking loss (%)	19.84	18.36	19.27	19.72	21.33	0.94	0.3123
pH	6.12	6.22	6.18	6.13	6.11	0.03	0.1347
Color							
L*	67.16	66.15	65.15	67.01	66.28	0.58	0.1561
a*	1.80^{a}	1.79^{a}	2.10^{ab}	2.10^{ab}	2.54^{b}	0.15	0.0197
b*	14.94^{a}	15.47^{ab}	15.20^{ab}	15.87^{b}	16.95^{c}	0.30	0.0027
Shear force (g)	3105.10	2615.05	2823.36	3116.62	2652.24	283.34	0.5930
TBARS (g MDA/kg meat)							
d-0	0.96	1.00	1.29	1.01	1.04	0.25	0.8886
d-3	0.96	1.15	1.47	1.45	1.74	0.49	0.8187
d-6	0.90	1.26	1.53	1.21	1.62	0.61	0.9235
d-9	1.12	1.42	1.63	1.70	2.10	0.72	0.9007

[1] Placebo is a basal diet supplemented with 1% of maltodextrin and whey protein

[2] SEM stands for standard error of the mean

Conclusion

Based on the results of this study, supplementation of spray-dried Moringa leaf extract at levels of 0.25, 0.5, and 1.0% in broiler diets did not affect feed intake, growth performance, feed conversion ratio, or carcass characteristics. Although Moringa leaf extract contains bioactive compounds with antioxidant properties, the supplementation levels used in this experiment may have been insufficient to induce significant physiological responses, particularly under normal rearing conditions without environmental stress or immune challenges. Compared with previous studies using Moringa leaf meal, which reported both positive and negative effects depending on the form and inclusion level, the present findings suggest that spray-dried Moringa leaf extract at low inclusion levels does not markedly influence productive performance or carcass traits. Nevertheless, the biological mechanisms of active compounds in Moringa extract related to growth performance, meat quality, and oxidative stress status in broilers remain unclear and warrant further investigation.

In conclusion, spray-dried Moringa leaf extract at the tested levels can be safely used as a dietary supplement for broilers without adverse effects on production performance or carcass characteristics. However, its potential to enhance growth performance or improve carcass traits was not clearly demonstrated. Therefore, further studies are recommended to determine optimal inclusion levels, investigate physiological mechanisms, and evaluate the effectiveness of Moringa extract under stress conditions for a more comprehensive assessment.

Declarations

Competing interests

The researchers declare that there is no conflict of interest.

Funding

This work was supported by Faculty of Agriculture, Ubon ratchathani University. The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Author contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Warisara Kamsaenrat, Paritchaya Pimvong, Thanyachanok Lompong, Areerat Lunpha, Ekasit Onsa-ard, and Surachai Suwanlee. The first draft of the manuscript was written by Surachai Suwanlee and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Acknowledgments

The authors would like to express their sincere gratitude to Mr. In Sala-ngam for his assistance and for providing the facilities for conducting this experiment. The authors also gratefully acknowledge Ms. Rojjana Noptana, Ph.D. student at the Local Food Industry Research and Development Center, Ubon Ratchathani University, for her valuable advice and assistance in analyzing total phenolic compounds and antioxidant activity in the spray-dried *Moringa oleifera* leaf extract powder. Their support greatly contributed to the successful completion of this research.

Data availability

The datasets of the current study are available from the corresponding author on reasonable request.

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