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Evaluating mulberry (*Morus alba* L.) leaf powder as a sustainable dietary supplement for improving growth performance, carcass traits, and meat quality in broiler chickens

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Abstract Dietary supplementation with mulberry leaf powder (MLP) was significantly influenced some broiler performance and meat quality parameters. However, feed intake, feed conversion ratio (FCR), and mortality rates were unchanged. Inclusion of 4% MLP reduced final body weight and cumulative average daily gain compared to the control and 2% MLP groups, and increased FCR during both the starter and grower-finisher phases. Hot carcass weight, carcass yield, retail cuts, and visceral organ weights were similar across all treatments, except for a linear increase in relative head weight at the 4% level. At 4% MLP, breast meat yellowness (b*) increased at both 1 h and 24 h postmortem, while cooking loss and shear force values decreased. In thigh meat, 24 h postmortem lightness (L*) decreased at 2% MLP, redness (*a) peaked at 2% but declined at 4%, and yellowness increased at both 2% and 4% MLP. Crude protein content increased with MLP levels in both muscles. Fat composition of breast meat was lower in 2% MLP and in thigh meat at 4% MLP. Moisture content in thigh meat was significantly reduced with MLP inclusion. It suggested that moderate MLP inclusion affected meat color and composition without adverse carcass effects, whereas high addition (4%) may impair performance.

Keywords: Mulberry leaf powder, Broiler, Growth performance, Carcass characteristics, Meat quality, Sustainability

Introduction

Mulberry (*Morus alba* L.) leaves have attracted increasing attention as a feed ingredient for poultry because they provide nutrients and bioactive compounds that may improve animal performance and meat quality (Ding *et al*., 2021; So-In and Sunthamala, 2022; Wang *et al*., 2022a). Mulberry leaves contain

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crude protein, vitamins, minerals, flavonoids, polyphenols, chlorogenic acid, rutin, quercetin, and 1-deoxynojirimycin (DNJ), which are associated with antioxidant activity, lipid metabolism, and nutrient utilization (Aziz-Aliabadi *et al*., 2023; Ding *et al*., 2021; Wang *et al*., 2022b). These characteristics have led to the evaluation of mulberry leaf powder (MLP) as a natural feed additive in broiler production (Ding *et al*., 2021).

Previous studies have shown that dietary MLP influences broiler growth performance, although the responses have not been consistent. Ding *et al*. (2021) reported that fermented mulberry leaf powder (FMLP) improved growth performance and reduced feed conversion ratio in broilers, whereas other studies found that the effects depended on the dietary inclusion level and production conditions (So-In and Sunthamala, 2022). Most studies have reported little or no effect of MLP on carcass yield or the proportion of major carcass cuts (Ding *et al*., 2021). The effects of MLP on meat quality are also inconsistent. Dietary MLP has been reported to improve meat quality traits, increase the abundance of beneficial *Lactobacillus*, and reduce serum cholesterol concentration in broilers (Aziz-Aliabadi *et al*., 2025). Ding *et al*. (2021) found that FMLP reduced shear force in breast and thigh meat but had little effect on muscle pH or drip loss. Aziz-Aliabadi *et al*. (2025) reported that dietary MLP increased breast muscle pH at 24 h postmortem and reduced lightness, whereas drip loss, cooking loss, shear force, redness, and yellowness still unchanged. These findings indicate that the response of meat quality traits to MLP differs among studies.

A recent systematic review and meta-analysis by Geng *et al*. (2024) achieved similar conclusions. Across available studies, MLP consistently increased the crude protein content of chicken meat and reduced drip loss; however, its effects on growth performance, tenderness, meat color, and carcass characteristics were variable (Geng *et al*., 2024). Differences in the level of inclusion, mulberry processing, and experimental conditions were claimed by Geng *et al*. (2024), who had contradictory results as reasons for their inconsistent responses to mulberry levels. Moreover, mulberry leaf powder has emerged as a promising functional feedstuff in broiler nutrition. Its effects on growth performance, carcass characteristics, and meat quality in broilers have been controversial with results varying from negative or neutral to beneficial. These inconsistent results could be attributed to the variations in inclusion levels, feed formulation, seasonal, locational, and experimental conditions, which make it difficult to identify the optimal supplementation level (Geng *et al*., 2024).

Thus, the study aimed to find out the optimum level of supplementation after evaluating the effect of mulberry leaf powder from 0-4% in broiler ration relative to growth performance, carcass characteristics, and meat quality.

Materials and methods

Ethical approval

The Animal Care and Use Committee of Maejo University reviewed and approved the use of live birds during this experiment (Approval No. MACUC 007A/2564).

Preparation of mulberry leaf powder and experimental diets

Mulberry leaves were harvested fresh from Mahidol University Amnatcharoen Campus. They were sun-dried until initial moisture content was reduced and then dried in a forced air hot oven to constant weight (60 °C, 48 h). The dried leaves were subsequently milled into a fine powder using a laboratory hammer mill and stored in airtight containers at room temperature until diet formulation. A commercial basal diet was purchased from local markets and formulated to meet the nutrient requirements of broilers during the starter, grower, and finisher phases. The experimental diets were prepared by supplementing the basal diet with mulberry leaf powder (MLP) at the expense of the basal diet ingredients. Three dietary treatments were established: Treatment 1 (T1), a control basal diet containing 0% MLP; Treatment 2 (T2), the basal diet supplemented with 2% MLP; and Treatment 3 (T3), the basal diet supplemented with 4% MLP. All diets were provided in mash form. The result of chemical composition of the experimental diets and MLP is shown in Table 1.

Table 1. Chemical composition of experimental diets and mulberry leaf powder

Items	Chemical composition (%DM)					Gross Energy (kcal/kg)
	Moisture	Crude protein	Ether extract	Ash	Crude Fiber	
Feed 1 (1 - 21 Day)	8.23	21.89	4.52	1.65	4.52	4,089.87
Feed 2 (21- 42 Day)	7.54	17.92	3.94	2.96	5.67	3,831.20
Mulberry leaf powder	7.19	19.38	1.92	3.19	10.20	3,966.15

Birds, housing, and experimental design

A total of 120 mixed-sex, 4-day-old Ross 308 broiler chicks were obtained from a commercial hatchery. Upon arrival, all birds were fully vaccinated according to the standard regional vaccination schedule. These birds were randomly distributed into three treatments in a completely randomized design (CRD) with four replicates of ten birds per treatment pen (experimental unit).

The broiler chicks were placed in 12 pens, each measuring 1.5×1.5 m^2. A 60 watts incandescent light bulb was put in each pen to provide supplemental heat during the brooding phase. Each pen had a tube feeder and a bell waterer to allow birds ad libitum access to feed and water, respectively.

The experimental period was 42 days. The ambient temperature and relative humidity in the poultry house were recorded twice daily (at 07:30 and 17:00 h) to determine the daily mean temperature and relative humidity, and feed was provided to the birds twice a day (at 07:30 and 17:00 h).

Growth performance and mortality

Growth performance parameters such as body weight (BW), feed intake (FI), average daily gain (ADG), and feed conversion ratio (FCR) were calculated. The daily FI was calculated by weighing the daily feed offered and orts, and then the FI per day was added to obtain the cumulative FI. The BW were obtained weekly. The FCR was determined by dividing FI by the BW gain. Mortality was observed and recorded daily. At the end of the 42-day trial, the cumulative mortality rate was calculated as follows:

Mortality rate (%) = (Number of dead birds / Initial number of birds placed) × 100.

Carcass characteristics and organ weights

At the end of the 42-day feeding trial, the birds were weighed to determine live weight and subjected to a 12-h feed withdrawal period (water was provided continuously). Following the withdrawal period, birds were humanely slaughtered via cervical dislocation and exsanguinated. Following defeathering and evisceration, the chilled carcasses were weighed to determine carcass yield. The carcasses were then partitioned into primal cuts (breast, thigh, drumstick, and wing), which were individually weighed. The edible internal organs (liver, heart, and gizzard) and abdominal fat pad were also excised and weighed. All yields and percentages were calculated relative to the pre-slaughter live weight or eviscerated carcass weight, as appropriate, using the following equations:

Carcass yield (%) = (Carcass weight / Live weight) × 100

Cut yield (%) = (Individual cut weight / Carcass weight) × 100

Internal organ yield (%) = (Organ weight / Carcass weight) × 100

Meat quality assessment

Meat quality was also determined in the breast (*Pectoralis major*) and thigh muscles of the birds used for carcass evaluation. For pH measurement, a

penetration glass electrode coupled with a portable digital pH meter (HI99163, Hanna Instruments, Woonsocket, RI) was used to measure the pH of each sample at 1 and 24 h post-mortem.

Meat color was recorded from the freshly cut surface of breast and thigh muscles 1 and 24 h post-mortem, with lightness (L*), redness (a*) and yellowness (b*) values measured using a Chroma Meter (CR-400, Konica Minolta Sensing, Tokyo, Japan) calibrated against a standard white tile before use (AMSA, 2012; King *et al*., 2023). Water-holding capacity (WHC) was determined by measuring the drip loss and cooking loss of breast and thigh meat samples using the recommended reference procedures of Honikel (1998).

Meat samples were cooked to an internal temperature of 75°C using a waterbath and thermocouple to ensure the cooking temperature. Cooked meat samples were sheared with a Warner-Bratzler shear blade on a texture analyzer (TA.*XT* Plus, Stable Micro Systems, Surrey, UK) to determine the Warner-Bratzler Shear Force (WBSF). In strict adherence to the American Meat Science Association (AMSA, 2016) research guidelines, the analysis was carried out by the texture analyzer. Cooked meat cubes ($1\times1\times1$ cm^3) were compressed twice in a Texture Profile Analysis (TPA) with a 50 mm cylindrical aluminum probe using above machine following Bourne. The force-time deformation curves obtained were used to derive the following textural properties: hardness, springiness, cohesiveness, and chewiness (Bourne, 1978).

The standard method of the Association of Official Analytical Chemists (AOAC, 2012) was used to perform proximate analysis for moisture, total ash, crude fiber and ether extract. The crude protein content was determined by the Dumas combustion method on a DUMATHERM® analyzer (Gerhardt, Königswinter, Germany) and a nitrogen conversion factor of 6.25 was used. The gross energy was measured using an isoperibol bomb calorimeter (IKA C 6000, IKA-Werke, Staufen, Germany).

Statistical analysis

All data were analysed as Completely Randomized Design (CRD) using the Statistical Tool for Agricultural Research (STAR) software, version 2.0.1 (Gulles *et al*., 2014). All the parameters were analyzed by variance analysis (ANOVA). Treatment means were separated in case of significant treatment effect ($P<0.05$) by Duncan's New Multiple Range Test (DMRT).

Results

Environmental conditions of the experimental house

The environmental parameters recorded within the experimental house throughout the 42-day period is shown in Figure 1. The relative humidity fluctuated between 56.0 and 69.0%, maintaining a stable daily average between 60.0 and 65.0%. The ambient house temperature ranged from 20.5 to 29.0°C; after an initial minor decrease to 20.5°C on Day 4, temperatures stabilized between 25.0 and 28.0°C for the remainder of the study.

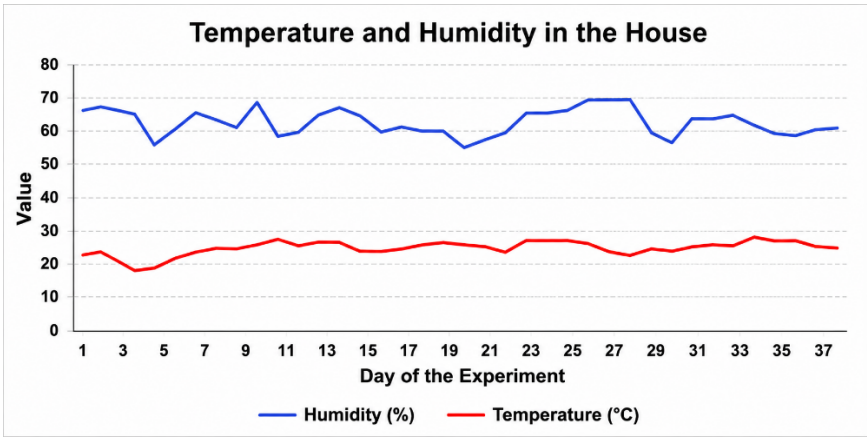


Figure 1. Ambient temperature (°C) and relative humidity (%) recorded within the experimental house throughout the 42-day period

Growth performance

The effects of dietary mulberry leaf powder (MLP) supplementation on broiler growth performance are presented in Table 2. In the starter phase (days 1 to 21), dietary MLP supplementation had no effect on initial body weight, final body weight, feed intake, or average daily gain (ADG) ($P>0.05$). However, feed conversion ratio (FCR) differed among treatments ($P=0.001$). Broilers fed 4% MLP had the highest FCR (1.34), followed by those fed 2% MLP (1.27) and the control diet (1.22). No mortality was observed during this phase. In grower-finisher phase (d 21 to 42), broilers fed 4% MLP had a lower final body weight than those in the control and 2% MLP groups ($P=0.007$). The feed conversion ratio was also higher in the 4% MLP group than in the control group ($P=0.03$). Feed intake, ADG, and mortality were not affected by dietary treatment ($P>0.05$). Overall period (d 1 to 42), broilers receiving 4% MLP had lower final body weight ($P=0.007$) and overall ADG ($P=0.008$) than birds fed the control or 2% MLP diets. In contrast, cumulative feed intake, overall FCR, and mortality did not differ among treatments ($P>0.05$).

Carcass and non-carcass characteristics

The carcass yield, retail cut percentages, and internal organ weights are presented in Table 3. Dietary MLP supplementation did not affect final body weight at slaughter, hot carcass weight, or carcass yield (P>0.05). Among the retail cuts, only the relative weight of the head differed among treatments, increasing with higher dietary MLP inclusion (P=0.01). The proportions of all other retail cuts (neck, drumette, mid-joint wing, wing tip, breast, fillet, thigh, drumstick, and rib), abdominal fat, and internal organs (heart, liver, spleen, gizzard, and intestine) were similar across treatments (P>0.05).

Table 2. Effects of mulberry leaf powder on growth performance of broilers

Items	Mulberry leaf powder (%)			SEM	P-value
	0	2	4		
1 - 21 days					
Initial weight (g)	45.17	45.40	43.87	0.77	0.72
Final weight (g)	1,185.27	1,181.52	1,118.20	14.67	0.10
Feed intake (g)	144.65	149.85	149.50	1.61	0.37
Average daily gain (g/d)	34.93	34.64	32.35	0.61	0.17
Feed conversion ratio	1.22^{c}	1.27^{b}	1.34^{a}	0.02	0.001
Mortality rate (%)	0	0	0	-	-
21 - 42 days					
Initial weight (g)	1185.27	1181.52	1118.20	14.67	0.10
Final weight (g)	2,364.80^{a}	2,330.76^{a}	2,231.55^{b}	20.94	0.007
Feed intake (g)	309.11	318.26	320.66	3.36	0.36
Average daily gain (g/d)	85.04	85.96	83.96	0.92	0.71
Feed conversion ratio	1.21^{b}	1.25^{ab}	1.30^{a}	0.02	0.03
Mortality rate (%)	0.62	0.62	0.00	0.07	0.62
1 - 42 days					
Initial Wight (g)	45.17	45.40	43.87	0.77	0.72
Final weight (g)	2,364.80^{a}	2,330.76^{a}	2,231.55^{b}	20.94	0.007
Feed intake (g)	119.41	123.19	123.73	1.24	0.33
Average daily gain (g/d)	61.04^{a}	60.14^{a}	57.57^{b}	0.28	0.008
Feed conversion ratio	2.03	2.05	2.08	0.55	0.72
Mortality rate (%)	0.62	0.62	0.00	0.02	0.62

^{abc} Different letters in the same row are significantly different (P<0.05)

Meat quality and texture profiles

The effects of dietary MLP supplementation on meat quality traits and texture profile analysis (TPA) are presented in Tables 4 and 5. Dietary MLP supplementation did not affect pH measured at 1 or 24 h postmortem, drip loss, or shear energy (P>0.05) in breast meat. However, breast meat yellowness increased in the 4% MLP group at both 1 h (P=0.02) and 24 h (P=0.005)

postmortem. Cooking loss (P=0.03) and shear force (P = 0.04) were lower in the 4% MLP group than in the other treatments. None of the TPA parameters, including hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness, and resilience, differed significantly among the treatments (P>0.05). In thigh meat, dietary MLP supplementation did not affect pH, drip loss, cooking loss, shear force, or any TPA parameters (P>0.05). At 24 h postmortem, lightness was lower in the 2% MLP group (P=0.01). Redness was highest in the 2% MLP group and lowest in the 4% MLP group (P=0.01). Additionally, yellowness was higher in both the 2% and 4% MLP groups than in the control group (P = 0.001).

Table 3. Effects of mulberry leaf powder on carcass and non carcass characteristics

Items	Mulberry leaf powder (%)			SEM	P-value
	0	2	4		
Final body weight (g)	2,545.95	2,556.90	2,461.65	19.65	0.08
Carcass weight (g)	2,313.00	2,360.05	2,264.75	18.86	0.11
Carcass percentage (%)	90.81	92.34	91.93	0.48	0.44
Retail cut percentages (%)					
Head	2.17[b]	2.27[ab]	2.45[a]	0.045	0.01
Neck	4.43	4.71	4.82	0.121	0.43
Drumette	3.98	4.14	4.18	0.057	0.34
Mid joint wing	2.89	3.00	2.94	0.022	0.16
Wing tip	0.91	0.94	0.95	0.008	0.07
Breast	23.25	21.32	21.60	0.596	0.39
Fillet	4.58	4.29	5.05	0.166	0.17
Thigh	14.40	14.30	13.97	0.199	0.69
Drumstick	10.65	10.73	10.05	0.173	0.23
Rib	15.95	16.18	16.32	0.218	0.81
Shank + feet	3.78	4.01	3.91	0.056	0.26
Visceral fat	0.66	0.48	0.61	0.059	0.44
bottom	1.16	1.33	1.08	0.078	0.46
Internal organs (%)					
Heart	0.60	0.65	0.62	0.012	0.30
Liver	2.28	2.43	2.50	0.042	0.08
Spleen	0.13	0.12	0.14	0.007	0.60
Gizzard	1.11	1.46	1.26	0.096	0.36
Intestine	5.27	5.48	5.55	0.057	0.10
Others					
Fur	3.39	2.67	2.33	0.323	0.43
Blood	3.05	3.10	4.28	0.649	0.72

[ab] Different letters in the same row are significantly different (P<0.05)

Chemical composition of meat

The proximate compositions of the breast and thigh meats are presented in Table 6. The moisture and ash contents of breast meat did not differ significantly among treatments (P=0.491 and 0.663, respectively). However, the crude protein (CP) content varied significantly (P<0.001), with birds fed 4% MLP having the highest CP content, while those receiving 0% or 2% MLP had lower values. Ether extract (EE) was also significantly affected (P=0.046).

Table 4. Effects of mulberry leaf powder on meat quality

Items	Mulberry leaf powder (%)			SEM	P-value
	0	2	4		
Breast meat					
pH					
pH 1-h p.m.	6.26	6.24	6.29	0.05	0.90
pH 24-h p.m.	5.68	5.63	5.68	0.02	0.52
Color, 1-h p.m.					
L*	48.62	48.17	47.91	0.20	0.36
a*	5.89	5.97	6.67	0.21	0.27
b*	14.02^{b}	14.39^{b}	16.11^{a}	0.36	0.02
Color, 24-h p.m.					
L*	53.09	49.07	51.80	0.97	0.23
a*	7.79	6.46	7.80	0.27	0.05
b*	15.79^{b}	16.38^{b}	18.74^{a}	0.46	0.005
Drip loss (%)	5.51	6.11	5.37	0.20	0.30
Cooking loss (%)	29.50^{a}	28.81^{a}	26.51^{b}	0.53	0.03
Shear force (N)	11.93^{a}	10.68^{ab}	9.42^{b}	0.44	0.04
Shear Energy (N.mm)	104.05	93.73	87.70	3.44	0.14
Thigh meat					
pH					
pH 1-h p.m.	6.05	6.10	6.05	0.01	0.28
pH 24-h p.m.	6.28	6.34	6.32	0.02	0.36
Color, 1-h p.m.					
L*	54.41	52.02	51.63	0.79	0.32
a*	11.94	13.88	12.03	0.57	0.32
b*	16.30	16.97	17.76	0.30	0.12
Color, 24-h p.m.					
L*	52.88^{a}	50.88^{b}	54.19^{a}	0.52	0.01
a*	11.87^{ab}	13.04^{a}	10.50^{b}	0.39	0.01
b*	14.74^{b}	16.34^{a}	16.71^{a}	0.29	0.001
Drip loss (%)	5.41	5.92	5.11	0.18	0.20
Cooking loss (%)	27.00	27.05	25.50	0.48	0.36
Shear force (N)	13.44	14.36	14.35	0.30	0.39
Shear Energy (N.mm)	141.14	123.00	130.21	3.26	0.05

^{ab} Different letters in the same row are significantly different (P<0.05)

In thigh meat, dietary MLP supplementation significantly affected the moisture, CP, and EE content (P<0.05), whereas the ash content was unchanged (P>0.05). Birds fed 0% MLP had the highest thigh moisture, while 2% and 4%

MLP reduced moisture compared to the control (P<0.001). Thigh CP content increased with higher MLP levels, reaching the highest value in the 4% MLP group (P<0.001). Fat content decreased as dietary MLP increased (P=0.033), with the lowest intramuscular fat in the 4% MLP group.

Table 5. Effects of mulberry leaf powder on texture profiles of meat

Items	Mulberry leaf powder (%)			SEM	P-value
	0	2	4		
Breast meat					
Hardness (g)	415.73	633.91	590.53	46.89	0.12
Adhesiveness (g.sec)	-15.86	-21.18	-20.77	2.06	0.54
Springiness	0.0925	0.1037	0.1080	0.00	0.08
Cohesiveness	0.7725	0.7817	0.7575	0.01	0.70
Gumminess	316.13	489.07	455.21	36.83	0.12
Chewiness	31.96	53.51	54.25	5.16	0.12
Resilience	0.3147	0.3320	0.3060	0.01	0.14
Thigh meat					
Hardness (g)	306.57	388.46	358.23	29.90	0.57
Adhesiveness (g.sec)	-17.17	-24.87	-16.01	2.96	0.45
Springiness	0.1027	0.1065	0.1037	0.00	0.93
Cohesiveness	0.7737	0.7987	0.7575	0.01	0.33
Gumminess	234.95	304.51	284.89	21.68	0.44
Chewiness	26.06	36.17	31.48	3.32	0.50
Resilience	0.3345	0.3560	0.3740	0.01	0.08

Table 6. Chemical composition of meat

Items	Mulberry leaf powder (%)			SEM	P-value
	0	2	4		
Breast meat					
Moisture (%)	65.35	62.74	64.06	1.38	0.49
Crude protein (%DM)	84.86^{b}	84.97^{b}	87.18^{a}	0.27	<0.001
Ether extract (%)	3.45^{a}	2.78^{b}	3.02^{ab}	0.23	0.046
Ash (%)	1.84	1.86	1.89	0.16	0.66
Thigh meat					
Moisture (%)	74.88^{a}	66.09^{b}	65.53^{b}	1.56	<0.001
Crude protein (%DM)	74.45^{c}	77.25^{b}	80.77^{a}	0.57	<0.001
Ether extract (%)	4.53^{a}	4.20^{ab}	3.65^{b}	0.23	0.032
Ash (%)	1.49	1.37	1.54	0.06	0.15

^{abc} Different letters in the same row are significantly different (P<0.05)

Discussion

Influence of mulberry leaf powder on growth performance

In the recent study, dietary supplementation of broilers with mulberry leaf powder affected the growth performance of broilers in a dose-dependent manner. Broilers fed 2% MLP had final body weight and average daily gain similar to

that of control birds, whereas the 4% MLP group showed a reduction in final body weight and average daily gain and a higher FCR than the control group.

A higher level of dietary MLP (4%) reduced the growth performance of broilers. This can be attributed to the nutritional composition of the mulberry leaves. Mulberry leaf powder was reported to be higher in terms of crude fiber and antinutritional factor (e.g., tannins). Antinutritional factors may interfere with the utilization of dietary nutrients by inhibiting enzyme activity and reducing the availability of nutrients for absorption. In addition, the fiber content of mulberry leaves can be high, which may increase the passage rate of digesta and lower the nutrient digestibility of the diet, resulting in poor FCR and growth performance (So-In and Sunthamala, 2022; Aziz-Aliabadi *et al*., 2025). Likewise, Irmayani *et al*. (2024) reported that low to moderate level of substitution of conventional feed ingredients with MLP could prevent an increase in crude fiber content and maintain the nutrient level of the diet.

The results of the previous study showed the different responses to dietary mulberry products, which might be related to the different inclusion levels, processing methods, diet formulations, and genotypes of broiler chickens. Aziz-Aliabadi *et al*. (2023) found that 2% MLP supplementation resulted in superior daily weight gain and FCR in broilers, whereas Xing *et al*. (2024) noted that mulberry leaf extract supplementation led to better body weight and feed efficiency in broilers. During the rainy season, the supplementation of MLP (0–1.5%) in the chicken diet improved feed intake and weight gain (Khunmanee *et al*., 2024). Ding *et al*. (2021) showed that feeding broilers 3% FMLP resulted in optimal growth and feed efficiency. During the experimental period, ADG was 18% higher than that of the control group, and the feed/gain ratio was 11% lower. On the other hand, Qin *et al*. (2023) observed that lipid metabolism improved, but growth performance did not. Geng *et al*. (2024) summarized the current evidence and found that the effect of dietary mulberry leaves on poultry performance among different studies is inconclusive, and the optimal inclusion level varies depending on various management conditions and diet formulations.

Several mechanisms could explain the improvements observed in broilers at moderate inclusion levels. As a source of flavonoids and bioactive components, mulberry leaves may promote intestinal growth and development by improving the villus height to crypt depth ratio and increasing digestive enzyme activity to enhance nutrient digestibility (Ding *et al*., 2021; Liu *et al*., 2024; So-In and Sunthamala, 2022). Furthermore, antioxidants in mulberry leaves may trigger cytoprotective responses (p38-MAPK/Nrf2 signaling) and mitigate oxidative stress to support intestinal health (So-In and Sunthamala, 2022; Xing *et al*., 2024; Liu *et al*., 2024). Other studies have indicated that processing affects outcomes. For example, Ding *et al*. (2021) found that

fermented MLP improved ADG and feed conversion better than that of nonfermented MLP, suggesting that fermentation reduced the adverse effects of fiber and antinutritive factors while preserving bioactive phytochemicals.

Impact on carcass characteristics, meat quality, and textural attributes

The live body weight of broilers fed 4% MLP was lower, but there were no differences among treatments in terms of hot carcass yield, retail cut percentages, and relative weights of internal organs. The results obtained in the present study show that at the levels of dietary MLP evaluated, the effects on carcass composition and the relative development of the main commercial cuts and visceral organs were not altered. The current findings are consistent with those of Aziz-Aliabadi *et al*. (2023), who reported that supplementation with 0 – 2% MLP did not affect carcass yield or the relative proportions of the breast, thigh, liver, spleen, thymus, or abdominal fat in broilers at 42 days of age. Similarly, Ding *et al*. (2021) found that feeding 3% fermented MLP for 56 days did not alter dressing percentage, eviscerated yield, or thigh yield, although breast muscle yield increased by 8%. In the same study, broilers fed 3% unfermented MLP had a 13% lower abdominal fat percentage than those receiving fermented MLP, indicating that processing may influence the effects of mulberry leaves on carcass fat deposition without substantially affecting overall carcass yield. Supplementing Pradu-HangDam chicken diets with 0–1.5% MLP during the rainy season improved carcass and breast weights. However, similar effects were not observed during the cold season (Khunmanee *et al*., 2024).

The meat quality and composition of broiler chickens showed selective effects when produced using dietary MLP, particularly with respect to meat color, meat tenderness, and nutrient composition. However, postmortem pH and water-holding capacity were only slightly affected. These findings indicate that MLP mainly affects muscle properties and does not significantly affect glycolysis in postmortem. The present study did not show any significant differences in muscle pH at 1 and 24 h postmortem, which was similar to the results of Ding *et al*. (2021), who found no significant differences in pH in either breast or thigh muscle after fermented mulberry leaf powder (FMLP) use. Likewise, no difference in drip loss was observed in the present study, suggesting that the water-holding capacity of broiler meat did not change when supplemented with MLP in this experimental set-up. Aziz-Aliabadi *et al*. (2025) also concluded that there was no difference in the drip loss between supplementation with 1% and 2% MLP. In contrast, Geng *et al*. (2024) found the same decrease in drip loss in chickens with supplementation at varying levels. Xing *et al*. (2024) also found that the drip loss rate linearly decreased with

increasing concentrations of dietary MLP water extract (MLE) from 0 to 600 mg/kg. Such differences are possibly due to the variations between the different studies in the type of mulberry used, the amount used, the processing method, the diet formulation, the genotype of the broilers used, or the environmental conditions. It is noteworthy that the meta-analysis combined data from several experiments with different mulberry products and production systems, while the current study evaluated one source of mulberry leaves under controlled conditions.

Breast and thigh meat responded to MLP supplementation differently regarding color. Breast meat became yellower when broilers were fed 4% MLP without affecting L* and a* values of meat. In contrast, thigh meat became darker and redder in response to 2% MLP supplementation and yellower following supplementation with both concentrations of MLP. In line with our findings, a reduction in the brightness of breast meat and stable yellowness and redness were reported with increased dietary MLP inclusion (Aziz-Aliabadi *et al*. 2025). Other authors also reported that breast meat brightness increased and thigh meat yellowness decreased following dietary FMLP addition (Ding *et al*. 2021). These discrepancies suggest that the effects of supplementing broiler diets with mulberry on meat color characteristics could be dependent on the form of the additive, the amount of the additive added to diet, and the meat type. Breast and thigh muscles can respond to antioxidant and pigment supplementation differently, depending on their differences in composition, especially in fiber type, myoglobin concentration, lipid content, and oxidative metabolism. The increased meat yellowness observed in the current study could have resulted from the deposition or preservation of carotenoids and polyphenolic compounds. This possibility was not evaluated in our study.

At 4%, dietary MLP improved tenderness of breast meat by decreasing cooking loss and shear force. No effects weres seen on the thigh meat or TPA properties. The decrease in shear force was in accordance with the findings of Ding *et al*. (2021), who found that the shear force was reduced in both breast and thigh muscles of broilers fed 6% FMLP. On the other hand, Aziz-Aliabadi *et al*. (2025) did not observe any change in shear force with MLP, and Geng *et al*. (2024) reported that moderate and high supplementation levels did not significantly influence tenderness. Together, these results suggest that the effect of MLP on meat tenderness is inconsistent and may depend on the concentration of the mulberry leaves in the diet, the processing process of the mulberry leaves, and/or the interaction between the two. Although no difference in drip loss was observed, it is possible that the cooking loss was reduced because of better moisture retention during thermal processing, which would result in lower shear force.

Chemical composition of meat

Supplementing broiler diets with MLP in a recent study affected macronutrients in meat. In the breast, crude protein rose and fat was altered, whereas water and ash contents remained unchanged. However, higher levels of MLP in diets caused an increase in protein and a decrease in water and fat contents in the thigh, which were more noticeable (Table 6). These results are aligned with the study of Geng *et al*. (2024), who reported that mulberry supplementation increased the protein content of chicken meat. Although the review did not show a clear effect of MLP on fat in the breast and thigh, this study revealed that MLP supplementation decreased the amount of fat in the thigh muscle. On the contrary, Ding *et al*. (2021) found no significant differences in the proportions of moisture, ether extract, and crude protein in the muscle of broilers among the different groups. MLP contains several active compounds, such as flavonoids, polyphenols, and 1-deoxynojirimycin (DNJ). These compounds regulate fat metabolism, improve nutrient utilization, and promote protein synthesis (Mehmood *et al*., 2025), potentially explaining the higher protein and lower fat content in thigh muscle through enhanced amino acid utilization and reduced fat accumulation (Liu *et al*., 2023).

One of the limitations of this study is that the specific metabolic or molecular mechanisms underlying the effects of MLP on broiler growth performance and meat quality were not investigated. Furthermore, the study was conducted under controlled environmental conditions with one source and processing of MLP which may affect the generalizability of the results, as different mulberry varieties, processing methods, broiler genotypes and production systems may be used. This study is suggested to be extended by molecular analysis of the samples and by testing a variety of sources of MLPs and testing conditions, which would help gain more insight and applicability.

It could be summarized that dietary MLP influenced broiler performance depending on the level of MLP. Ross 308 broilers can be fed diets containing 2% MLP without detriment to growth or meat quality. Adding 4% MLP to the diet is beneficial for some meat quality characteristics but negatively affects growth.

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Conflicts of interest

The authors declare no conflict of interest.

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