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Mulberry (Morus Alba) Leaf Powder Supplementation in Low-Protein Concentrate Diets: Impacts on Production Performance, Heat Stress Resistance, and Carcass Quality of Broiler Chickens in Tropical Climates

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ABSTRACT

Heat stress and the rising cost of protein feed ingredients are major challenges in broiler production in tropical regions, creating a need for alternative feed additives that improve productivity and thermal resilience. This study evaluated the effects of mulberry (Morus alba) leaf powder (MLP) supplementation in low-protein concentrate diets on growth performance, heat stress responses, and carcass quality of broiler chickens. A total of 240 day-old Ross 308 broilers were assigned to four dietary treatments: P0 (0% MLP), P1 (1% MLP), P2 (3% MLP), and P3 (5% MLP), with four replications in a completely randomized design for 35 days. MLP supplementation significantly (P<0.05) improved body weight gain and feed conversion ratio, particularly at 3–5% inclusion levels. Serum corticosterone and heat shock protein 70 levels decreased, indicating enhanced heat stress resistance. Carcass percentage increased from 70.89% to 76.40%, while abdominal fat, serum cholesterol, and LDL levels decreased. Meat quality also improved through lower drip loss and higher water-holding capacity. These findings indicate that MLP can be included up to 5% in low-protein concentrate diets to improve production performance, heat stress tolerance, and carcass quality in broilers under tropical conditions, providing a cost-effective and sustainable alternative to conventional protein sources.

Keywords: *Mulberry Leaf Powder, Broiler, Heat Stress, Production Performance, Carcass Quality, Tropical Conditions*

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INTRODUCTION

Broiler chicken production in tropical regions faces two major interrelated challenges: increasing feed costs and heat stress. Conventional feed ingredients such as corn and soybean meal have experienced substantial price increases, with feed constituting 60-70% of total production costs. Simultaneously, high ambient temperatures in tropical climates cause chronic heat stress, reducing feed intake, growth performance, and meat quality while increasing mortality and morbidity (Oloruntola *et al*., 2024). The recommended ambient temperature for poultry is between 16 and 25°C, yet broiler chickens in low-tech systems are frequently exposed to temperatures exceeding 30°C during the finisher phase.

Heat stress disrupts acid-base balance, causing panting and respiratory alkalosis, and alters blood metabolites and hormones. Prolonged heat exposure induces endocrinological changes that increase lipogenesis, decrease lipolysis, and increase amino acid catabolism, stimulating lipid accumulation. The production of heat shock proteins and elevated lipid peroxidation are additional indicators of oxidative stress under heat exposure, as confirmed in broilers fed phytogenic leaf-powder supplements under tropical high ambient temperatures (Oloruntola *et al*., 2024).

Mulberry (Morus alba L.) leaves have emerged as a promising feed supplement for poultry due to their favorable nutritional profile and bioactive properties. Mulberry leaves are rich in protein (15-35%), minerals (calcium: 2.42-4.71%; phosphorus: 0.23-0.97%), and energy, with comparatively low anti-nutritional factors relative to other plant materials. Fermentation of mulberry leaf powder further reduces crude fiber and anti-nutritional content while increasing peptide and amino acid availability, improving growth performance, breast muscle yield, and meat quality in broilers (Ding *et al*., 2021).

Beyond its nutritional value, mulberry leaves contain bioactive compounds including flavonoids, polyphenols, and other antioxidants that provide anti-inflammatory and immunomodulatory effects. These compounds can activate digestive enzymes, improve nutrient absorption, and enhance the immune system. Supplementation of mulberry and green tea leaf powder has been shown to improve growth performance, carcass characteristics, immune response, and intestinal morphology of broiler chickens (Aziz-Aliabadi & Noruzi, 2023), while also improving meat quality traits and beneficial ileal bacteria populations (Aziz-Aliabadi *et al*., 2025).

Mulberry leaf powder used in this study was characterized by a high crude protein content (18-23% DM), moderate crude fiber (6.4-6.9%), bioactive flavonoids and polyphenols, favorable mineral content, and low anti-nutritional factors. Comparable leaf-based supplements under high stocking density have similarly been shown to improve growth performance, blood parameters, and antioxidant status in broilers (So-In & Sunthamala, 2022), supporting the general premise that leaf-powder additives can substitute part of conventional protein sources without adverse effects, provided fiber content remains within tolerable limits for monogastric digestion.

Heat stress triggers several physiological responses in broiler chickens that can be ameliorated by phytogenic supplements, including oxidative stress (elevated reactive oxygen species and malondialdehyde), inflammation (elevated acute phase proteins and corticosterone),

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heat shock protein induction (HSP70 upregulation), and metabolic disruption (altered lipid metabolism and protein catabolism). Leaf-powder phytogenics rich in flavonoids and polyphenols have been reported to modulate HSP70 expression, enhance serum antioxidant enzymes, and stabilize metabolic hormones in heat-stressed broilers under tropical ambient temperatures (Oloruntola *et al*., 2024). Reviews of phytogenic feed additives further confirm that polyphenols and flavonoids are central bioactive classes underlying thermotolerance improvements in broilers (Oni *et al*., 2024).

Similarly, leaf-based additives such as Brachiaria decumbens leaf meal have been reported to improve growth performance and normalize blood biochemistry and stress biomarkers of broilers reared under tropical conditions (Chung *et al*., 2024), while artichoke leaf powder has shown benefits for hematological and biochemical profiles, hepatic and antioxidant enzyme activities, and gut microbiota (Nasser *et al*., 2025), reinforcing the broader evidence base for leaf-powder phytogenics as heat-stress mitigators in tropical poultry systems. This study aimed to evaluate the effects of mulberry leaf powder supplementation in low-protein concentrate diets on: (1) production performance (body weight gain, feed intake, feed conversion ratio); (2) physiological responses to heat stress (corticosterone, HSP70, oxidative stress markers); (3) carcass quality (carcass percentage, abdominal fat, meat quality); and (4) hematological and biochemical parameters. It was hypothesized that MLP supplementation would improve production performance by compensating for protein deficiency, enhance heat stress resistance through antioxidant and anti-inflammatory properties, improve carcass quality, and could be included up to 5% without negative effects.

METHODS

The study was conducted at the Poultry Research Farm over a 35-day period (days 1-35) during the dry season under tropical conditions, with average ambient temperature of 28-34°C and relative humidity of 70-85%. A total of 240 day-old Ross 308 broiler chicks (mixed sex) were randomly assigned to four dietary treatments with four replications each (15 birds per replicate) in a completely randomized design (CRD): P0 (control, low-protein basal diet + 0% MLP), P1 (+1% MLP), P2 (+3% MLP), and P3 (+5% MLP). Birds were housed in floor pens with wood shavings litter and provided ad libitum feed and water. Standard vaccination and medication protocols were followed throughout the study.

1. Mulberry Leaf Powder Preparation

Fresh mulberry leaves were harvested from local plantations, washed, sun-dried for 2-3 days, and ground into fine powder. Nutritional composition was analyzed using standard procedures, as summarized in Table 1.

The nutritional composition of mulberry leaf powder (MLP) was determined using standard laboratory analytical procedures. The analyzed parameters included dry matter, crude protein, crude fiber, crude fat, ash, calcium, phosphorus, flavonoids, polyphenols, tannins, and gross energy. The laboratory analysis results are presented in Table 1. The MLP contained 91.2 ± 0.5% dry matter, 28.21–30.46% crude protein, 6.4–6.9% crude fiber, 3.2–4.1% crude fat, 12.3–15.7% ash, 2.42–4.71%

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calcium, 0.23–0.97% phosphorus, 12.4–15.8 mg/g flavonoids, 18.2–22.6 mg/g polyphenols, 0.8–1.2 mg/g tannins, and 3,850–4,200 kcal/kg gross energy.

On day 35, blood samples were collected from two birds per replicate for laboratory analysis. Serum corticosterone and HSP70 concentrations were determined using ELISA, MDA was analyzed using the thiobarbituric acid method, SOD activity was determined using a spectrophotometric method, and GPx activity was determined using ELISA. Serum biochemical parameters, including total cholesterol, HDL cholesterol, LDL cholesterol, triglycerides, total protein, and glucose, were also analyzed. The results of these laboratory analyses are presented in Tables 5 and 8, respectively.

Table 1. Nutritional Composition of Mulberry Leaf Powder

Parameter	Content
Dry Matter (%)	91.2 ± 0.5
Crude Protein (%)	28.21 – 30.46
Crude Fiber (%)	6.4 – 6.9
Crude Fat (%)	3.2 – 4.1
Ash (%)	12.3 – 15.7
Calcium (%)	2.42 – 4.71
Phosphorus (%)	0.23 – 0.97
Flavonoids (mg/g)	12.4 – 15.8
Polyphenols (mg/g)	18.2 – 22.6
Tannins (mg/g)	0.8 – 1.2
Gross Energy (kcal/kg)	3,850 – 4,200

2. Diet Formulation

The basal diet was formulated to be low in crude protein (approximately 18% CP) compared to standard broiler requirements, to evaluate the protein-supplementation effect of MLP. Diets were formulated to be isocaloric and isoenergetic across all treatments, as shown in Table 2 and Table 3.

Table 2. Diet Composition by Treatment (%)

Ingredient	P0	P1	P2	P3
Corn	58.0	57.5	56.5	55.5
Soybean Meal	22.0	21.5	21.0	20.0
Rice Bran	8.0	8.0	7.5	7.5
Fish Meal	5.0	5.0	5.0	5.0
Mineral-Vitamin Premix	4.0	4.0	4.0	4.0

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Ingredient	P0	P1	P2	P3
Vegetable Oil	3.0	3.0	3.0	3.0
Mulberry Leaf Powder	0.0	1.0	3.0	5.0
Total	100.0	100.0	100.0	100.0

Table 3. Calculated Nutrient Composition of Experimental Diets

Nutrient	P0	P1	P2	P3
Crude Protein (%)	18.2	18.5	19.1	19.7
Crude Fiber (%)	4.2	4.3	4.6	4.9
ME (kcal/kg)	3,100	3,095	3,088	3,080
Calcium (%)	0.92	0.93	0.95	0.97
Phosphorus (%)	0.45	0.45	0.46	0.47
Methionine (%)	0.45	0.45	0.46	0.47
Lysine (%)	0.98	0.99	1.00	1.01

3. Data Collection

Body weight was measured weekly on days 0, 7, 14, 21, 28, and 35. Feed intake was recorded daily per replicate, feed conversion ratio was calculated as feed intake divided by body weight gain, and mortality was recorded daily. On day 35, blood samples were collected from two birds per replicate via brachial vein for analysis of corticosterone and heat shock protein 70 (HSP70) by ELISA, malondialdehyde (MDA) by the thiobarbituric acid method, superoxide dismutase (SOD) by spectrophotometric method, and glutathione peroxidase (GPx) by ELISA. On day 35, two birds per replicate (8 birds per treatment) were randomly selected for carcass evaluation, including slaughter weight, carcass weight, carcass percentage, abdominal fat percentage, and meat quality parameters (pH at 45 min and 24 h post-mortem, drip loss, water-holding capacity, and meat color L, a, b values). Serum samples were analyzed for total cholesterol, HDL cholesterol, LDL cholesterol, triglycerides, total protein, and glucose. Data were analyzed using analysis of variance (ANOVA) with a completely randomized design model. Differences between treatment means were determined using Tukey's Honestly Significant Difference (HSD) test at $P < 0.05$. All statistical analyses were performed using SAS version 9.4.

RESULTS

1. Production Performance

The inclusion of mulberry leaf powder in low-protein diets significantly improved production performance ($P<0.05$). The groups receiving 3-5% MLP showed higher body weight gain

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and improved feed conversion ratio compared to the control group during the grower and whole phases, as shown in Table 4 and Figure 1.

Table 4. Growth Performance of Broiler Chickens by Treatment

Parameter	P0 (0%)	P1 (1%)	P2 (3%)	P3 (5%)	LSD (0.05)
Initial weight (g)	42.5 ± 1.2	42.8 ± 1.1	42.3 ± 1.3	42.6 ± 1.2	NS
Final weight (g)	1,842 ± 85 b	1,920 ± 92 ab	2,015 ± 98 a	2,120 ± 105 a	112
Body weight gain (g)	1,799.5 ± 84 b	1,877.2 ± 91 ab	1,972.7 ± 97 a	2,077.4 ± 104 a	111
Daily weight gain (g/d)	51.41 ± 2.4 b	53.63 ± 2.6 ab	56.36 ± 2.8 a	59.35 ± 3.0 a	3.2
Feed intake (g)	3,645 ± 182	3,680 ± 190	3,716 ± 195	3,740 ± 198	NS
FCR	2.03 ± 0.08 a	1.96 ± 0.07 ab	1.88 ± 0.06 b	1.80 ± 0.06 c	0.09
Mortality (%)	5.0 ± 2.1	3.3 ± 1.4	3.3 ± 1.4	1.7 ± 0.8	NS

Values are means ± standard deviation. Within rows, means followed by different letters are significantly different at $P < 0.05$. NS = not significant.

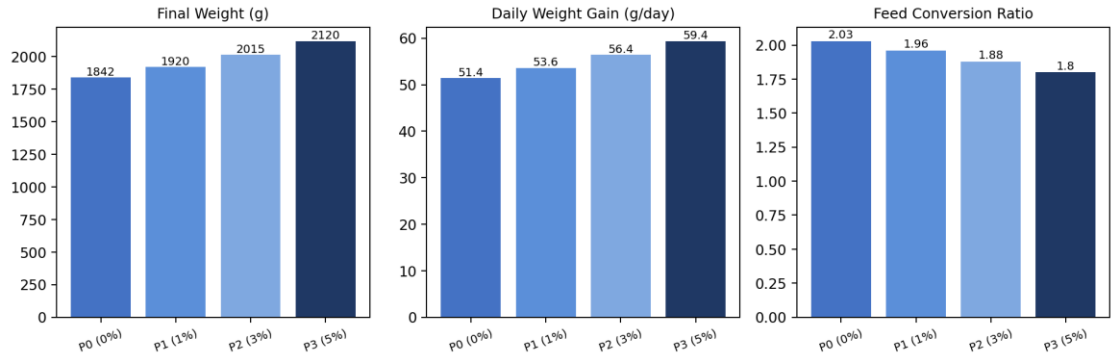


Figure 1. Growth performance parameters by treatment

2. Physiological and Stress Parameters

Mulberry leaf powder supplementation significantly reduced stress indicators in broiler chickens exposed to tropical heat stress. The groups receiving higher MLP levels showed lower corticosterone, HSP70, and MDA levels, and higher antioxidant enzyme activity, as shown in Table 5 and Figure 2.

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Table 5. Stress and Oxidative Stress Parameters by Treatment

Parameter	P0 (0%)	P1 (1%)	P2 (3%)	P3 (5%)	LSD (0.05)
Corticosterone (ng/mL)	8.42 ± 0.85 a	7.18 ± 0.72 ab	6.24 ± 0.65 b	5.48 ± 0.58 c	0.95
HSP70 (ng/mL)	2.86 ± 0.32 a	2.34 ± 0.28 ab	1.92 ± 0.22 b	1.56 ± 0.18 c	0.38
MDA (nmol/mL)	2.84 ± 0.35 a	2.42 ± 0.28 ab	1.96 ± 0.22 b	1.58 ± 0.18 c	0.40
SOD (U/mL)	3,245 ± 285 b	3,680 ± 310 ab	4,120 ± 345 a	4,450 ± 380 a	460
GPx (U/mL)	285 ± 32 b	320 ± 35 ab	365 ± 40 a	395 ± 42 a	52

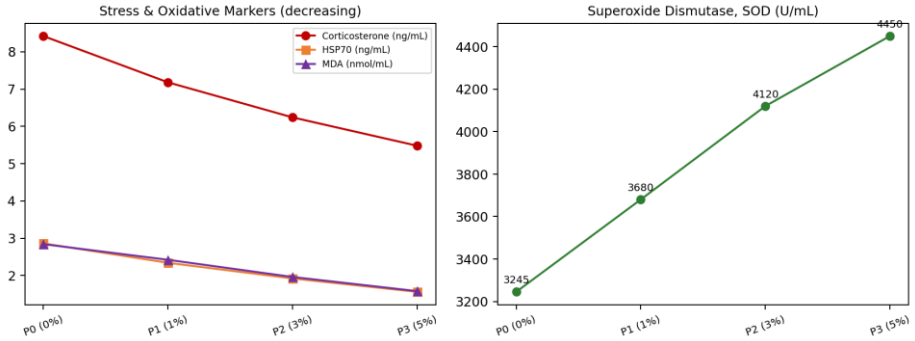


Figure 2. Stress and oxidative stress markers by treatment

3. Carcass Quality

Mulberry leaf powder supplementation significantly improved carcass quality parameters. Carcass percentage increased with increasing MLP inclusion, while abdominal fat decreased, as shown in Table 6 and Figure 3.

Table 6. Carcass Quality Parameters by Treatment

Parameter	P0 (0%)	P1 (1%)	P2 (3%)	P3 (5%)	LSD (0.05)
Slaughter Weight (g)	1,842 ± 85 b	1,920 ± 92 ab	2,015 ± 98 a	2,120 ± 105 a	112
Carcass Weight (g)	1,306 ± 62 c	1,431 ± 69 bc	1,529 ± 74 ab	1,620 ± 80 a	98
Carcass Percentage (%)	70.89 ± 1.8 c	74.51 ± 1.9 b	74.71 ± 2.0 b	76.40 ± 2.1 a	2.8
Abdominal Fat (%)	2.85 ± 0.32 a	2.35 ± 0.28 b	2.02 ± 0.24 c	1.78 ± 0.20 c	0.38
Breast Meat (%)	28.4 ± 2.1 b	30.2 ± 2.3 ab	32.1 ± 2.5 a	33.8 ± 2.8 a	3.5
Thigh Meat (%)	22.1 ± 1.8	22.8 ± 1.9	23.2 ± 2.0	23.8 ± 2.1	NS

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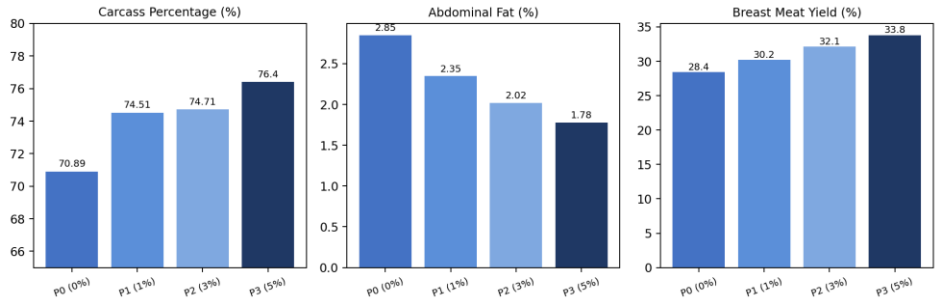


Figure 3. Carcass quality parameters by treatment

4. Meat Quality Parameters

Meat quality parameters showed improvement with MLP supplementation (Table 7), consistent with findings from recent studies on leaf-powder phytogenics and meat quality traits (Aziz-Aliabadi *et al.*, 2025).

Table 7. Meat Quality Parameters by Treatment

Parameter	P0 (0%)	P1 (1%)	P2 (3%)	P3 (5%)	LSD (0.05)
pH 45 min	6.42 ± 0.12	6.38 ± 0.11	6.35 ± 0.10	6.32 ± 0.10	NS
pH 24 h	5.82 ± 0.08 b	5.78 ± 0.07 b	5.72 ± 0.06 ab	5.68 ± 0.05 a	0.09
Drip Loss (%)	3.85 ± 0.42 a	3.12 ± 0.38 ab	2.65 ± 0.32 b	2.24 ± 0.28 c	0.52
Water-Holding Capacity (%)	62.4 ± 3.5 b	66.8 ± 3.8 ab	70.5 ± 4.0 a	74.2 ± 4.2 a	5.6
Meat Color L*	58.2 ± 3.2	57.8 ± 3.1	57.2 ± 3.0	56.8 ± 2.9	NS
Meat Color a*	4.82 ± 0.42	4.95 ± 0.45	5.12 ± 0.48	5.28 ± 0.50	NS
Meat Color b*	9.45 ± 0.82	9.32 ± 0.78	9.18 ± 0.75	9.02 ± 0.72	NS

5. Serum Biochemical Parameters

MLP supplementation significantly affected serum biochemical parameters, with beneficial effects on lipid profiles and protein status (Table 8).

Table 8. Serum Biochemical Parameters by Treatment

Parameter	P0 (0%)	P1 (1%)	P2 (3%)	P3 (5%)	LSD (0.05)
Total Cholesterol (mg/dL)	158 ± 14 a	142 ± 12 ab	128 ± 11 b	115 ± 10 c	18
HDL (mg/dL)	42 ± 4 b	48 ± 5 ab	54 ± 6 a	58 ± 6 a	8
LDL (mg/dL)	82 ± 8 a	72 ± 7 ab	62 ± 6 b	52 ± 5 c	9

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Parameter	P0 (0%)	P1 (1%)	P2 (3%)	P3 (5%)	LSD (0.05)
Triglycerides (mg/dL)	145 ± 14 a	132 ± 12 ab	118 ± 11 b	108 ± 10 b	16
Total Protein (g/dL)	6.2 ± 0.5 b	6.8 ± 0.6 ab	7.4 ± 0.7 a	7.8 ± 0.8 a	0.9
Glucose (mg/dL)	212 ± 18 a	198 ± 16 ab	185 ± 15 b	175 ± 14 b	22

DISCUSSION

1. Production Performance Improvement

The significant improvement in body weight gain and feed conversion ratio (FCR) observed in MLP-supplemented groups can be explained by the combined nutritional and physiological effects of mulberry leaf powder. In the present study, the initial body weights were comparable among treatments, indicating that the subsequent differences in final body weight and body weight gain were not attributable to differences in starting body weight. In addition, feed intake did not differ significantly among treatments, whereas body weight gain and FCR differed significantly. Therefore, the improved production performance was more likely associated with improved utilization of consumed nutrients rather than increased feed consumption. Feed conversion ratio was calculated as feed intake divided by body weight gain; thus, the lower FCR observed in P2 and P3 indicates that birds receiving 3% and 5% MLP converted a similar amount of feed into body tissue more efficiently. The FCR decreased from 2.03 in P0 to 1.88 in P2 and 1.80 in P3, while body weight gain increased from 1,799.5 g to 1,972.7 g and 2,077.4 g, respectively.

The first mechanism is related to the nutritional contribution of MLP. The mulberry leaf powder used in this study contained 28.21–30.46% crude protein, while the calculated crude protein concentration of the experimental diets increased progressively from 18.2% in P0 to 19.7% in P3. This additional protein provides amino acids required for protein synthesis, muscle development, and tissue deposition. Consequently, greater availability of dietary amino acids may have promoted lean tissue accretion and contributed to the higher body weight gain observed in the 3% and 5% MLP groups. The increase in serum total protein from 6.2 g/dL in P0 to 7.4 and 7.8 g/dL in P2 and P3, respectively, further supports the possibility of improved protein availability and utilization in MLP-supplemented birds.

A second mechanism involves the bioactive compounds present in mulberry leaves. The MLP used in this study contained flavonoids (12.4–15.8 mg/g) and polyphenols (18.2–22.6 mg/g), which have antioxidant and physiological activities. These compounds may support intestinal function and nutrient utilization by reducing oxidative damage and maintaining the functional integrity of intestinal tissues. Previous research on fermented mulberry leaf powder has reported improvements in nutrient digestibility and intestinal morphology, including villus-related characteristics, which can facilitate nutrient absorption in broilers (Ding et al., 2021). Thus, although intestinal digestibility and morphology were not directly measured in the present study, improved nutrient absorption provides a plausible mechanism for the greater body weight gain and lower FCR observed with MLP supplementation.

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A third mechanism is related to heat-stress mitigation. The birds were raised under tropical conditions with ambient temperatures of 28–34°C and relative humidity of 70–85%, conditions that can impose considerable thermal stress on broilers. Heat stress increases metabolic and oxidative challenges, which can divert nutrients and energy away from productive processes toward maintenance and stress responses. The antioxidant properties of MLP may reduce oxidative stress and help preserve normal physiological function. This interpretation is supported by the results in Table 5, where MLP supplementation reduced corticosterone, HSP70, and MDA concentrations while increasing SOD and GPx activities. These changes indicate a lower physiological and oxidative stress burden in supplemented birds and may have contributed indirectly to the maintenance of growth and feed efficiency under tropical conditions.

Taken together, the results suggest that the improvement in production performance was not caused by greater feed intake, because feed intake was statistically similar among treatments. Rather, the response appears to have resulted from improved nutrient availability and utilization, supported by the additional protein and bioactive compounds supplied by MLP, together with reduced oxidative and physiological stress. These mechanisms provide a plausible explanation for why the 3% and 5% MLP treatments produced greater body weight gain and better FCR than the control treatment. However, because nutrient digestibility, intestinal morphology, and muscle protein synthesis were not directly measured in this study, these proposed mechanisms should be considered biologically plausible interpretations rather than directly demonstrated mechanisms.

2. Heat Stress Resistance Enhancement

The reduction in stress indicators with MLP supplementation demonstrates its effectiveness in mitigating heat stress in tropical climates. The significant decreases in corticosterone, HSP70, and MDA levels indicate reduced activation of the hypothalamic-pituitary-adrenal (HPA) axis, reduced cellular stress requiring less chaperone protein production, and reduced oxidative damage through lipid peroxidation, respectively, while increased SOD and GPx indicate enhanced antioxidant enzyme activity. These findings align with research on other leaf-powder phytogenics in heat-stressed broilers, where mistletoe leaf powder supplementation modulated HSP70 expression, boosted antioxidant enzymes, and improved metabolic hormone and gut microbiota balance under tropical high ambient temperatures (Oloruntola *et al*., 2024). This antioxidant-mediated protection parallels evidence that mulberry branch extracts activate the Nrf2 and cytochrome P450 signalling pathways to enhance antioxidant enzyme activity in the breast muscle of yellow-feather broilers (Shi *et al*., 2024), and that mulberry-leaf extracts and flavonoids alleviate hepatic oxidative stress and lipid-metabolism disorders in laying hens (Chen et al., 2023; Zhang *et al*., 2024).

Broader reviews of phytogenic feed additives confirm that polyphenols and flavonoids are central bioactive compounds underlying improved thermotolerance in broiler chickens, alongside growth-promoting and immune-modulating actions (Oni *et al*., 2024). Comparable leaf-meal supplements, such as Brachiaria decumbens leaf meal, have likewise been shown to normalize growth performance, blood biochemistry, and stress biomarkers of broilers reared under tropical

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conditions (Chung *et al*., 2024), while artichoke leaf powder improved hematological, hepatic, and antioxidant enzyme profiles in broiler chickens (Nasser *et al*., 2025), reinforcing the plausibility of the antioxidant and anti-inflammatory mechanisms proposed for MLP in the present study. Immunomodulatory contributions of mulberry-derived polysaccharides have also been reported in Newcastle disease virus-vaccinated chicks, in which supplementation enhanced the respiratory mucosal barrier immune response (Chen *et al*., 2021), while reviews of fermented leaf-based feed ingredients report parallel improvements in broiler gastrointestinal microecology, immune response, and physiological condition (Sugiharto & Ranjitkar, 2019; Sugiharto, 2021).

3. Carcass Quality Improvement

The significant increase in carcass percentage and reduction in abdominal fat with MLP supplementation has important implications for meat production quality. The improvement in carcass percentage (from 70.89% to 76.40%) is within the ideal range reported for broiler chickens. Improved protein deposition supported by the high protein content of MLP, reduced lipid accumulation associated with bioactive flavonoids, and better feed conversion together explain the observed gains in carcass weight and reduction in abdominal fat, consistent with reports that fermented mulberry leaf powder increased breast muscle yield and reduced abdominal fat ratio in broilers (Ding *et al*., 2021). Reductions in serum and tissue cholesterol following mulberry leaf supplementation have similarly been reported in laying hens (Kamruzzaman *et al*., 2018; Siddiqui *et al*., 2022; Muthoni *et al*., 2020), supporting a consistent lipid-modulating effect of mulberry-derived bioactives across poultry production types.

The improvement in meat quality parameters, including reduced drip loss and improved water-holding capacity, is consistent with findings reported for green tea and mulberry leaf powder supplementation, which improved meat quality traits and beneficial ileal bacteria populations in broilers (Aziz-Aliabadi *et al*., 2025). The increased pH at 24 h and reduced drip loss indicate better water-binding capacity and potentially improved meat texture and consumer acceptability. Comparable production and meat-quality benefits of mulberry leaf inclusion have been reported in growing and laying quail, including improved productive performance in growing quail (Perdomo *et al*., 2019), positive effects on laying performance from white mulberry pulp supplementation (Sengul et al., 2021), and improved productive traits, economic indices, and immunity in Japanese quail (Shehata *et al*., 2021), although carcass and meat-quality traits of Japanese quail have been shown to respond negatively above moderate inclusion levels, underscoring the importance of dose optimisation for this feedstuff across species (Ustundag & Ozdogan, 2023).

4. Serum Biochemical Parameter Improvements

The reduction in serum cholesterol, LDL, and triglycerides with MLP supplementation is a significant finding with implications for meat quality and consumer health perception. These effects are likely mediated by flavonoid inhibition of intestinal cholesterol absorption, antioxidant protection of LDL particles from oxidation, and modulation of hepatic lipid metabolism enzymes,

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mechanisms broadly consistent with the antioxidant and metabolic benefits reported for leaf-powder phytogenics in tropical broiler systems (Nasser *et al*., 2025; Oloruntola *et al*., 2024). The increase in total protein levels with MLP supplementation reflects improved protein status and nitrogen utilization, consistent with the higher protein content of MLP-supplemented diets. These lipid- and protein-related benefits must nonetheless be balanced against the crude fibre content of leaf-based ingredients, which reviews of dietary fibre in poultry nutrition indicate can influence nutrient utilisation, gut health, and performance depending on inclusion level and fibre source (Jha & Mishra, 2021; Tejeda & Kim, 2021).

5. Optimal Inclusion Level and Practical Implications

The results of this study suggest that 3-5% MLP inclusion is optimal for broiler chickens in tropical conditions. Higher inclusion levels increase crude fiber content, which can reduce nutrient digestibility in poultry due to their limited capacity to digest cellulose and hemicellulose; the 5% MLP diet in this study had 4.9% crude fiber, within acceptable limits but warranting monitoring at higher inclusion rates. Fermentation of mulberry leaf powder before inclusion has been shown to further reduce anti-nutritional factors and fiber content while improving digestibility and meat quality outcomes (Ding *et al*., 2021), suggesting a promising direction for further optimizing MLP use at higher inclusion levels. A similar threshold pattern has been reported in layer diets, where moderate mulberry leaf extract or flavonoid inclusion enhanced egg quality, lipid metabolism, and antioxidant indices in laying hens (Zhang *et al*., 2022; Lin *et al*., 2017), improved eggshell quality and liver lipid metabolism in aged breeder hens (Huang *et al*., 2022a, 2022b), and supported reproductive performance in broiler breeder hens whose offspring subsequently showed enhanced skeletal muscle development (Huang *et al*., 2024).

CONCLUSIONS

This study demonstrates that mulberry leaf powder (MLP) supplementation in low-protein concentrate diets can improve production performance, heat stress resistance, and carcass quality of broiler chickens under tropical conditions. Supplementation at 3–5% MLP significantly improved body weight gain and feed conversion ratio, with the most favorable production performance observed at 5% inclusion. MLP supplementation also enhanced heat stress resistance, as reflected by reductions in corticosterone, HSP70, and MDA levels and increases in SOD and GPx activities.

Regarding carcass quality, MLP supplementation increased carcass percentage from 70.89% to 76.40% and reduced abdominal fat from 2.85% to 1.78%, while also improving meat quality through reduced drip loss and increased water-holding capacity. In addition, MLP supplementation improved serum biochemical parameters by reducing total cholesterol, LDL, and triglycerides and increasing total protein levels. These findings indicate that MLP supplementation, particularly at 5%, is a promising dietary strategy to support growth performance, resistance to heat stress, favorable carcass and meat quality, and improved physiological status of broiler chickens raised in tropical climates.

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