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Effect of feeding sun-dried azolla (*Azolla pinnata*) on carcass characteristics, gut health and meat quality of broiler chicks

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Abstract

The present study was conducted to evaluate the effect of sun-dried *Azolla pinnata* on carcass characteristics of broiler chickens. A total of 120-day-old broiler chicks were randomly allocated into four treatment groups with three replicates of 10 birds each. The treatments included T₁ (control), T₂ (5% azolla), T₃ (10% azolla) and T₄ (15% azolla) replacing standard ration on a dry matter basis. Results revealed that carcass evaluation showed significantly higher eviscerated yield in T₂ (68.45±0.25) and T₃ (67.60±0.19) groups. Carcass cuts such as neck, wings and thigh were improved with azolla inclusion, while breast yield remained unaffected. Giblet analysis indicated improved gizzard development in T₂. Gastrointestinal pH was significantly influenced in gizzard, jejunum and ileum, suggesting improved digestive efficiency. Meat pH was significantly lower in T₂ and T₃, indicating better meat quality. It can be concluded that inclusion of sun-dried azolla at 5-10% level enhances carcass traits and gut health without adverse effects, making it a cost-effective and sustainable feed ingredient in broiler production.

Keywords: Azolla, broiler, carcass traits, giblets, gastrointestinal pH, meat quality

Introduction

The poultry industry plays a vital role in meeting the increasing global demand for high-quality animal protein due to its rapid growth rate, efficient feed conversion and relatively low production cost. Broiler meat, in particular, is widely accepted because of its high nutritional value, tenderness and affordability. However, the rising cost of conventional feed ingredients such as soybean meal and maize has posed a significant challenge to sustainable poultry production. This has necessitated the exploration of alternative, cost-effective and nutritionally rich feed resources that can partially replace conventional feed ingredients without compromising productivity or meat quality.

In recent years, the use of unconventional feed resources, especially aquatic plants, has gained considerable attention. Among these, *Azolla pinnata*, a floating fern belonging to the family Azollaceae, has emerged as a promising feed supplement due to its high protein content, essential amino acids, vitamins, minerals and bioactive compounds. It also contains symbiotic cyanobacteria (*Anabaena azollae*), which contribute to its high nitrogen-fixing capacity and nutritional value. Due to these characteristics, Azolla has been widely studied as a sustainable and eco-friendly feed ingredient in livestock and poultry nutrition (Mishra *et al.*, 2016) [10].

Sun-drying of Azolla is an effective method to enhance its shelf life and facilitate its incorporation into poultry diets. The drying process reduces moisture content while preserving most of its nutrients, making it easier to handle, store and mix with conventional feed. Previous studies have reported that inclusion of sun-dried Azolla in broiler diets can improve growth performance, feed efficiency and carcass traits when used at optimal levels (Kumar *et al.*, 2021; Samad *et al.*, 2020) [8, 18]. Abdelatty *et al.* (2021) [1] also reported that Azolla supplementation enhances muscle development and carcass yield due to its high digestibility

and protein quality.

Carcass characteristics are important indicators of the economic value of broiler production, as they directly reflect the quantity and quality of edible meat. Parameters such as dressed weight, eviscerated weight and distribution of carcass cuts provide valuable insights into the efficiency of nutrient utilization and muscle deposition. Several researchers have reported improvements in carcass yield with *Azolla* supplementation, particularly at moderate inclusion levels (Ara *et al.*, 2015; Rathod *et al.*, 2013) [3, 7]. In addition to carcass traits, gut health plays a crucial role in determining the overall performance and productivity of broiler chickens. A healthy gastrointestinal tract ensures efficient digestion, nutrient absorption and microbial balance. Dietary interventions, including the use of natural feed additives like *Azolla*, can influence gut morphology, enzyme activity and microbial populations. Studies have shown that *Azolla* supplementation can improve gut health by enhancing digestive efficiency and maintaining a favorable intestinal environment (Shamna *et al.*, 2013; Olugbemi *et al.*, 2010) [19, 13]. Meat quality is another critical aspect influencing consumer acceptance and market value. Among various quality parameters, meat pH is considered a key indicator as it affects color, tenderness, water-holding capacity and shelf life. Dietary factors play a significant role in influencing postmortem muscle metabolism and pH decline. Natural feed ingredients rich in antioxidants, such as *Azolla*, may help improve meat quality by reducing oxidative stress and enhancing muscle energy metabolism (Sujatha *et al.*, 2013; Thavasi *et al.*, 2020) [21, 22]. Despite the recognized nutritional potential of *Azolla*, there is still limited information on the comprehensive effects of sun-dried *Azolla pinnata* on carcass characteristics, gut health and meat quality in broiler chickens, particularly under practical feeding conditions. Therefore, the present study was undertaken to evaluate the effect of feeding sun-dried *Azolla pinnata* at different inclusion levels on carcass traits, gastrointestinal parameters and meat quality of broiler chicks.

Materials and methods

Experimental Site

The present study was conducted at the Poultry Unit, Department of Poultry Science, College of Veterinary and Animal Science, Rajasthan University of Veterinary and Animal Sciences (RAJUVAS), Bikaner, with laboratory analyses performed at SKRAU, Bikaner.

Experimental Design

A total of 120 unsexed, day-old commercial broiler chicks of the same hatch were randomly allotted to four treatment groups under a Completely Randomized Design for a period of 28 days (February 13 to March 12, 2025). Each treatment consisted of 30 birds with three replicates of 10 birds each. The treatments included T₁ (control; standard broiler ration), T₂ (5% replacement of standard ration with sun-dried *Azolla pinnata* on a dry matter basis), T₃ (10% replacement) and T₄ (15% replacement). Birds were reared under a deep litter system with sawdust bedding and provided pre-starter (0-7 days), starter (8-21 days) and finisher (22-28 days) diets. Feed and water were offered *ad libitum* throughout the study

period. All the necessary routine management practices and the recommended vaccinations were strictly observed throughout the period of 28 days which the study lasted.

Carcass and Organs Weight Determination

At the end of the experiment total 36 birds were selected at random starved for about for 12 hours before slaughter. All the birds selected for slaughter were weighed individually. Birds were slaughtered by halal method. Thereafter, flaying was done and the internal organs such as the heart, liver, gizzard, lungs, pancreas, proventriculus and intestines were collected and weighed individually to measure various carcass parameters (Dressed weight percentage, eviscerated weight percentage, weight percentage of various carcass cuts, pH of various segments of gastrointestinal tract and pH of meat).

Proximate Composition

Proximate composition of the test ingredients was analyzed using the method of AOAC.

Statistical Analysis

Experimental data were subjected to analysis of variance "one-way ANOVA" as described by Snedecor and Chochran (2004). The significance of mean differences was tested by Duncan's New Multiple Range Test (Duncan's Range Test) as modified by Kramer.

Results and Discussion

Dressed weight percentage and eviscerated weight percentage

The present study was conducted to evaluate the effect of different levels of *Azolla* inclusion on carcass characteristics, organ weights and gastrointestinal parameters in broiler birds. The results obtained clearly indicate that *Azolla* supplementation influenced several production traits depending on the level of inclusion. The data regarding the dressed weight (%) and eviscerated weight (%) of broiler birds for the *Azolla* treatment are illustrated in Table 1. The carcass characteristics revealed that eviscerated weight (%) was significantly influenced ($p < 0.05$) by dietary treatments. The highest value was observed in T₂ ($68.45 \pm 0.25\%$), followed by T₃ ($67.60 \pm 0.19\%$) and T₄ ($67.07 \pm 0.51\%$), whereas the lowest value was recorded in T₁ ($66.24 \pm 0.25\%$). The improvement in eviscerated weight in T₂ indicates better nutrient utilization and muscle deposition at 5% *Azolla* inclusion. These findings are in agreement with the reports of Mishra *et al.* (2016) [10] and Kumar *et al.* (2021) [8], who observed improved carcass yield in broilers fed *Azolla* at moderate inclusion levels. Similarly, Abdelatty *et al.* (2021) [1] reported enhanced carcass traits due to the high protein content and digestibility of *Azolla*. However, dressed weight (%) did not differ significantly among treatments ($P > 0.05$), although higher numerical values were recorded in T₃ ($74.16 \pm 0.16\%$), T₂ ($74.12 \pm 1.11\%$) and T₄ ($74.06 \pm 0.56\%$) compared to T₁ ($72.69 \pm 0.12\%$). This observation is consistent with the findings of Samad *et al.* (2020) [18] and Rathod *et al.* (2013) [17], who also reported non-significant differences in dressed weight despite improvements in other carcass traits.

Table 1: Average dressed weight (%) and eviscerated weight (%) in different treatment groups

Carcass Characteristic (Live weight percentage)	Group			
	T ₁	T ₂	T ₃	T ₄
Dressed Weight%	72.69 ± 0.12	74.12 ± 1.11	74.16 ± 0.16	74.06 ± 0.56
Eviscerated Weight%	66.24 ^a ± 0.25	68.45 ^b ± 0.25	67.60 ^{ab} ± 0.19	67.07 ^{ab} ± 0.51

Mean with different superscripts in row differ significantly ($p < 0.05$)

Weight percentage of different carcass cuts

The data regarding the weight (%) of different carcass cuts of broiler birds for the Azolla treatment is illustrated in Table 2. The distribution of carcass cuts showed that neck weight (%) was significantly higher in T₂ ($4.68 \pm 0.13\%$) compared to T₁ ($3.20 \pm 0.11\%$), with T₃ ($4.36 \pm 0.39\%$) and T₄ ($3.78 \pm 0.18\%$) showing intermediate values. This improvement in minor cuts may be attributed to better protein utilization, as also reported by Kumar *et al.* (2021). Wing percentage was highest in T₃ ($6.07 \pm 0.21\%$) followed by T₄ ($5.82 \pm 0.17\%$), T₂ ($5.73 \pm 0.17\%$) and T₁ ($5.29 \pm 0.27\%$). This trend supports the findings of Rathod *et al.* (2013) and Samad *et al.* (2020) [18], who observed enhanced development of specific carcass parts with increasing Azolla levels. Breast percentage did not differ significantly among treatments, ranging from $24.26 \pm 0.40\%$ (T₄) to $25.06 \pm 0.56\%$ (T₃), indicating that Azolla inclusion did not compromise the most valuable cut. Similar observations were reported by Abdelatty *et al.* (2021) [1]. Back percentage also remained unaffected, ranging from $11.03 \pm 0.55\%$ to $11.87 \pm 0.15\%$. Thigh percentage increased with higher inclusion levels, reaching $11.73 \pm 0.30\%$ in T₄ compared to $10.87 \pm 0.22\%$ in T₁, which is in line with findings by Kumar *et al.* (2018) [6] and Joysowal *et al.* (2018) [4], who reported improved leg muscle development. Conversely, drumstick percentage decreased significantly in T₃ ($9.68 \pm 0.55\%$) and T₄ ($9.61 \pm 0.39\%$) compared to T₁ ($11.07 \pm 0.26\%$) and T₂ ($10.84 \pm 0.89\%$), suggesting a shift in nutrient partitioning, as also noted by Paudel *et al.* (2015) [15].

Table 2: Average weight (%) of different carcass cuts in different treatment groups

Carcass cuts (%)	Group			
	T ₁	T ₂	T ₃	T ₄
Neck	3.20 ^a ± 0.11	4.68 ^c ± 0.13	4.36 ^{bc} ± 0.39	3.78 ^{ab} ± 0.18
Wings	5.29 ^a ± 0.27	5.73 ^{ab} ± 0.17	6.07 ^c ± 0.21	5.82 ^c ± 0.17
Breast	24.51 ± 0.46	24.41 ± 0.41	25.06 ± 0.56	24.26 ± 0.40
Back	11.30 ± 0.25	11.46 ± 0.15	11.03 ± 0.55	11.87 ± 0.15
Thigh	10.87 ^a ± 0.22	11.32 ^{ab} ± 0.19	11.39 ^{ab} ± 0.32	11.73 ^b ± 0.30
Drumstick	11.07 ^b ± 0.26	10.84 ^b ± 0.89	9.68 ^a ± 0.55	9.61 ^a ± 0.39

Mean with different superscripts in row differ significantly ($p < 0.05$)

Weight (%) of Giblets

The data regarding the weight (%) of giblets including heart, liver and gizzard of broiler birds for the azolla treatment is illustrated in Table 3. The giblet characteristics indicated that liver weight (%) did not differ significantly among treatments, with values ranging from $1.79 \pm 0.12\%$ (T₄) to $2.03 \pm 0.07\%$ (T₃). This suggests that Azolla inclusion did not adversely affect liver function, which agrees with the findings of Ara *et al.* (2015). Heart weight (%) was significantly lower in T₂ ($0.46 \pm 0.01\%$) compared to T₁ ($0.56 \pm 0.02\%$), while T₃ ($0.52 \pm 0.03\%$) and T₄ ($0.53 \pm 0.02\%$) showed intermediate values. This reduction may indicate improved metabolic efficiency, as suggested by Rathod *et al.* (2013) and Sharma *et al.* (2020). Gizzard weight (%) was significantly higher in T₂ ($1.92 \pm 0.06\%$), followed by T₃ ($1.75 \pm 0.12\%$), T₁ ($1.68 \pm 0.06\%$) and T₄ ($1.63 \pm 0.04\%$). The increased gizzard weight may be attributed to the fibrous nature of Azolla, which stimulates

muscular activity, as reported by Parthasarathy *et al.* (2002) [14] and Naghshi *et al.* (2014) [12]. Total giblet weight did not differ significantly among treatments, which is consistent with Kumar *et al.* (2018) [6] and Samad *et al.* (2020) [18].

Table 3: Average weight (%) of giblets in different treatment groups

Giblets Weight	Group			
	T ₁	T ₂	T ₃	T ₄
Liver	1.98 ± 0.06	1.92 ± 0.07	2.03 ± 0.07	1.79 ± 0.12
Heart	0.56 ^b ± 0.02	0.46 ^a ± 0.01	0.52 ^{ab} ± 0.03	0.53 ^{ab} ± 0.02
Gizzard	1.68 ^a ± 0.06	1.92 ^b ± 0.06	1.75 ^{ab} ± 0.12	1.63 ^a ± 0.04
Total Giblet	4.22 ± 0.06	4.30 ± 0.09	4.29 ± 0.17	3.95 ± 0.14

Mean with different superscripts in row differ significantly ($p < 0.05$)

Weight (%) of overall visceral inedible

The data regarding the weight (%) of overall visceral inedible including the intestine, lungs, proventriculus, pancreas, kidney, spleen and crop of broiler birds for the Azolla treatment is illustrated in Table 4. The analysis of visceral organs revealed that intestinal weight (%) was lowest in T₂ ($3.54 \pm 0.09\%$) and highest in T₄ ($4.55 \pm 0.11\%$), indicating improved digestive efficiency at moderate inclusion levels and increased gut mass at higher levels. Similar findings were reported by Abdelatty *et al.* (2021) [1] and Shamna *et al.* (2013) [19]. Pancreas weight (%) was highest in T₃ ($0.42 \pm 0.01\%$), followed by T₂ ($0.40 \pm 0.05\%$), suggesting increased digestive enzyme activity, which aligns with Rathod *et al.* (2013) [17]. Proventriculus weight (%) was also higher in T₃ ($0.44 \pm 0.03\%$) and T₄ ($0.43 \pm 0.03\%$) compared to T₁ ($0.34 \pm 0.02\%$), supporting enhanced digestive function as reported by Parthasarathy *et al.* (2002) [14]. Kidney weight (%) was lowest in T₂ ($0.35 \pm 0.02\%$), indicating reduced metabolic load, which agrees with Kumar *et al.* (2018) [6]. The weights of lungs, spleen and crop did not differ significantly among treatments, confirming the safety of Azolla inclusion, as also observed by Joysowal *et al.* (2018) [4] and Samad *et al.* (2020) [18].

Table 4: Average weight (%) of overall visceral inedible in different treatment groups

Visceral Inedible	Group			
	T ₁	T ₂	T ₃	T ₄
Intestines	4.14 ^b ± 0.13	3.54 ^a ± 0.09	4.14 ^b ± 0.14	4.55 ^c ± 0.11
Lungs	0.49 ± 0.03	0.44 ± 0.02	0.50 ± 0.02	0.50 ± 0.03
Pancreas	0.34 ^a ± 0.02	0.40 ^{ab} ± 0.05	0.42 ^c ± 0.01	0.37 ^{ab} ± 0.02
Proventriculus	0.34 ^a ± 0.02	0.38 ^{ab} ± 0.02	0.44 ^b ± 0.03	0.43 ^b ± 0.03
Kidney	0.49 ^b ± 0.03	0.35 ^a ± 0.02	0.41 ^a ± 0.06	0.51 ^b ± 0.04
Spleen	0.30 ± 0.07	0.25 ± 0.02	0.28 ± 0.02	0.30 ± 0.02
Crop	0.34 ± 0.02	0.31 ± 0.03	0.37 ± 0.03	0.32 ± 0.01

Mean with different superscripts in row differ significantly ($p < 0.05$)

Weight (%) of overall external offal

The data regarding the weight (%) of overall external offal including the head, shanks, feathers and blood of broiler birds for the azolla treatment is illustrated in Table 5. The external offal characteristics showed that feather weight (%) was significantly higher in T₂ ($14.54 \pm 0.23\%$) compared to T₁ ($13.62 \pm 0.36\%$), T₃ ($13.43 \pm 0.18\%$) and T₄ ($13.58 \pm 0.25\%$).

This may be due to improved protein and micronutrient utilization, as reported by Abdelatty *et al.* (2021) [1] and Sharma *et al.* (2020). Blood weight (%) was highest in T₁ ($4.02 \pm 0.12\%$) and significantly reduced in T₂ ($2.77 \pm 0.31\%$), T₃ ($2.81 \pm 0.08\%$) and T₄ ($2.50 \pm 0.17\%$), which may indicate improved metabolic efficiency, as suggested by Rathod *et al.* (2013). Shank weight (%) was significantly higher in T₄ ($6.21 \pm 0.29\%$) and T₃ ($6.05 \pm 0.17\%$) compared to T₂ ($4.87 \pm 0.54\%$), indicating better skeletal development due to the mineral-rich nature of Azolla. Similar results were reported by Ara *et al.* (2015). Head weight and total external offal did not differ significantly among treatments, which is consistent with Mishra *et al.* (2016) [10].

Table 5: Average weight (%) of overall external offal in different treatment groups

Overall External Offal	Group			
	T ₁	T ₂	T ₃	T ₄
Feather	$13.62^a \pm 0.36$	$14.54^b \pm 0.23$	$13.43^a \pm 0.18$	$13.58^a \pm 0.25$
Blood	$4.02^b \pm 0.12$	$2.77^a \pm 0.31$	$2.81^a \pm 0.08$	$2.50^a \pm 0.17$
Shanks	$5.44^{ab} \pm 0.14$	$4.87^a \pm 0.54$	$6.05^b \pm 0.17$	$6.21^b \pm 0.29$
Head	4.23 ± 0.13	3.70 ± 0.39	3.56 ± 0.09	3.64 ± 0.24
Total	27.32 ± 0.13	25.88 ± 1.11	25.85 ± 0.15	25.93 ± 0.56

Mean with different superscripts in row differ significantly ($p < 0.05$)

pH of Various Segments of Gastrointestinal Tract

The data regarding pH of various segments of gastrointestinal tract recorded in this experiment has been presented in Table 6. The pH of different segments of the gastrointestinal tract indicated that crop pH (4.06-4.14) and proventriculus pH (3.51-3.82) were not significantly affected by treatments, which is in agreement with Ahmed *et al.* (2023) [2] and Muzammil *et al.* (2018) [11]. However, gizzard pH was significantly higher in T₂ ($3.53 \pm 0.11\%$) and T₃ ($3.49 \pm 0.09\%$) compared to T₄ ($3.19 \pm 0.08\%$), possibly due to the buffering effect of Azolla, as suggested by Qin *et al.* (2020) [16]. Jejunum pH was highest in T₃ ($6.29 \pm 0.17\%$), while ileum pH was highest in T₂ ($6.99 \pm 0.12\%$), indicating improved microbial activity and nutrient absorption. Similar observations were reported by Olugbemi *et al.* (2010) [13]. Caecum pH did not differ significantly among treatments, which agrees with Parthasarathy *et al.* (2002) [14]. In azolla inclusion particularly at 5 to 10% influenced pH in specific gut segments like the gizzard, jejunum and ileum which may contribute to improved digestion and gut health. These effects support the inclusion of azolla as a feed in broiler nutrition with potential implications for enhancing nutrient utilization and promoting gut microbial balance.

Table 6: Mean values of pH of various segments of gastrointestinal tract in different treatment groups

Segment	Groups			
	T ₁	T ₂	T ₃	T ₄
Crop	4.06 ± 0.09	4.14 ± 0.08	4.11 ± 0.10	4.09 ± 0.09
Proventriculus	3.82 ± 0.11	3.51 ± 0.09	3.75 ± 0.15	3.79 ± 0.11
Gizzard	$3.26^{ab} \pm 0.07$	$3.53^c \pm 0.11$	$3.49^{bc} \pm 0.09$	$3.19^a \pm 0.08$
Duodenum	5.80 ± 0.09	5.91 ± 0.09	5.87 ± 0.05	5.71 ± 0.78
Jejunum	$5.85^a \pm 0.83$	$6.07^{ab} \pm 0.05$	$6.29^b \pm 0.17$	$5.76^a \pm 0.10$
Ileum	$6.58^a \pm 0.13$	$6.99^c \pm 0.12$	$6.89^{bc} \pm 0.07$	$6.64^{ab} \pm 0.12$
Caecum	7.13 ± 0.15	7.32 ± 0.14	7.15 ± 0.92	7.17 ± 0.11

Means having different superscript in a row differ significantly ($p < 0.05$)

pH of meat

The data regarding pH of meat recorded in this experiment has been presented in Table 7. The meat pH showed significant variation among treatments, with the lowest values recorded in T₂ ($5.49 \pm 0.90\%$) and T₃ ($5.56 \pm 0.10\%$), while higher values were observed in T₁ ($6.27 \pm 0.03\%$) and T₄ ($6.49 \pm 0.08\%$). The lower pH in T₂ and T₃ indicates better postmortem glycolysis and improved meat quality, which is in agreement with Thavasi *et al.* (2020) [22]. Higher pH values in T₁ and T₄ may be associated with slower glycogen depletion, as reported by Mir *et al.* (2017) [9] and Kannan *et al.* (2001) [5]. Additionally, the antioxidant properties of Azolla may contribute to improved muscle metabolism, as suggested by Sujatha *et al.* (2013) [21].

Table 7: Mean values of pH of meat in different treatment groups

pH of meat	Groups			
	T ₁	T ₂	T ₃	T ₄
pH of meat	$6.27^b \pm 0.03$	$5.49^a \pm 0.90$	$5.56^a \pm 0.10$	$6.49^b \pm 0.08$

Means having different superscript in a row differ significantly ($p < 0.05$)

Overall, the findings of the present study clearly demonstrate that Azolla inclusion at 5% (T₂) is optimal for improving carcass traits, organ development, gut health and meat quality in broiler chickens. Higher inclusion levels showed variable effects, indicating that moderate supplementation is more beneficial for achieving efficient production performance.

Conclusion

The inclusion of sun-dried *Azolla pinnata* at 5-10% level in broiler diets significantly improves growth performance, carcass characteristics, digestive efficiency and meat quality without adverse effects on organ development. The 5% inclusion level was found to be optimal for maximizing productivity and profitability. Azolla can be recommended as a sustainable, cost-effective alternative feed ingredient in broiler production systems.

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