



Effects of Organic Acids on Growth Performance, Livability, Carcass Traits, Leg Bone Qualities, and Economic Profitability in Broiler Chickens Fed Low-Protein Vegetable-Based Diets

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ABSTRACT

A variety of feed additives are widely used in the modern poultry industry for improving productivity and feed conversion efficiency. This study evaluated the effects of dietary organic acids, either butyric acid alone or in combination with acetic acid, supplemented low-protein (crude protein) vegetable diets on growth performance, livability, carcass traits, leg bone qualities, and cost-benefit of broiler production. A total of 216 unsexed one-day-old Ross-308 broiler chickens were randomly assigned to four treatments, each comprising six replicates of nine chickens. The treatments included D1_c (basal diet without OA), D1 (0.6% butyric acid), D2_c (basal diet without OA), and D2 (0.3% of butyric and acetic acid). The findings showed that the OA supplementation significantly increased live body weight (LBW) and feed intake (FI), while decreasing feed conversion ratio (FCR), both at 21 and 42 days, when compared to respective controls. Basal diets had no significant effect on LBW, FI, or FCR at either age. However, a significant interaction between basal diets and OA ($A \times B$) was observed for FI and FCR at 21 days. Livability did not differ significantly among treatment groups. Carcass evaluation revealed that broiler chickens in the D2 group showed significantly increased dressing yield, drumstick, breast and giblet percentages, followed by D1, compared with control groups. However, neither basal diets nor $A \times B$ interaction had any significant effect on dressing yield or individual carcass parts. In terms of bone qualities, the D2 group demonstrated a significant increase in tibial bone length, width, and ash content compared with the control groups. Although basal diets significantly increased tibial phosphorus content in the D1_c group, neither basal diets nor the $A \times B$ interaction significantly affected the overall bone traits. Economically, total production cost per kg live body weight reduced and profit increased significantly in the D2 group, followed by D1, compared with controls. Basal diets and $A \times B$ interaction did not significantly influence production cost or profitability. In conclusion, supplementation with 0.30% butyric and acetic acid in low-protein vegetable-based diets enhances growth performance, carcass traits, bone qualities, and profitability without affecting livability in broiler chickens.

Keywords: Broiler chicken, Carcass, Growth, Leg bone quality, Low-protein diet, Organic acid

INTRODUCTION

The poultry industry plays an essential role in satisfying the protein requirements of the population in Bangladesh through the production of meat and eggs and contributes significantly to the national economy (Hamid et al., 2017). Since poultry meat contributes around 37% of Bangladesh's total meat output (Begum et al., 2011), it has become a major source of animal protein for humans, owing to its favorable health profile, cost-effectiveness, and high production efficiency (Choi et al., 2023). However, intensive poultry farming is linked to environmental challenges, including nitrogen (N) pollution from dietary protein excretion, which causes eutrophication, soil acidification, and ammonia emissions (Belloir et al., 2017). In this context, low-protein diets (LPD) have gained increasing attention in broiler chicken nutrition because of the potential role in reducing nitrogen excretion and mitigating environmental pollution (Macelline et al., 2020). It has been reported that reducing crude protein (CP) levels in broiler chicken diets by 1% can decrease nitrogen excretion by approximately 13% (Belloir et al., 2017). Rising feed costs of high-protein ingredients, together with growing environmental concerns, have further encouraged the adoption of LPD strategies in broiler chicken production systems (Ravangard et al., 2017). Since plant-derived protein sources constitute the primary supply of amino acids in poultry diets, vegetable-based LPD formulations are particularly relevant in commercial practice (Beski et al., 2015).

At the same time, the modern poultry industry demands high productivity and efficient feed conversion, which are often supported through the strategic use of particular feed additives (Khan and Iqbal, 2016). In the past, antibiotics have been utilized at both therapeutic and subtherapeutic levels to improve feed conversion efficiency and growth performance in the production of food animals (Salim et al., 2018). However, following restrictions on antibiotic growth promoters (AGPs) and increasing concerns over antimicrobial resistance, research has increasingly focused on natural feed additives that promote gut health and sustain broiler chicken performance without compromising food safety (Ramigani et al., 2017; Haque et al., 2020). Consequently, identifying effective non-antibiotic alternatives has become an urgent priority for sustainable poultry production (Dai et al., 2021).

Nutritional strategies involving dietary crude protein, energy, and amino acid modulation, combined with bioactive feed additives such as prebiotics, vitamins, probiotics, organic acids, enzymes, and plant polyphenols, have shown promise in improving growth performance, meat quality, and body composition in broiler chickens (Choi et al., 2023). Among these alternatives, organic acids (OA) are the carboxylic acids that are organic and have a common structure (R–COOH) and have been utilized extensively in poultry feed for over thirty years as preservatives and growth-promoting ingredients (Polycarpo et al., 2017). Short-chain fatty acids, including formic, acetic, propionic, and butyric acids, are commonly used in poultry diets due to the favorable physicochemical properties (Dibner and Richards, 2005). The European Union has certified OA as a non-antibiotic feed additive, and its use is widely acknowledged to be safe (Zeeshan et al., 2022). Inclusion of OA in feed or water has been associated with improved gut health, enhanced nutrient digestibility, strengthened immunity, and better growth performance, along with reduced incidence of intestinal disorders (Yadav and Jha, 2019).

Organic acids, including butyric and valeric acids, showed broad-spectrum antibacterial activity against both Gram-positive and Gram-negative bacteria, whereas formic and acetic acids mainly inhibit Gram-negative bacteria by disrupting bacterial cell walls (Liu et al., 2021; Rathnayake et al., 2021). Organic acids can enhance the natural immune response in poultry, which may contribute to maintaining high livability across treatments (Houshmand et al., 2012; Abbas et al., 2013). Moreover, by making nutrients more soluble and accessible in the digestive system, promoting easier digestion and absorption, boosting immunological responses, and suppressing pathogenic bacterial proliferation, organic acids improve growth performance (Mustafa et al., 2021; Manvatkar et al., 2022; Okey et al., 2023). According to a recent study, supplementation of broiler chickens with acetic (0.5% and 1%), formic (0.5% and 1%), and citric (2% and 3%) acid showed a significant improvement in the count of *Lactobacillus* while also demonstrating a significant decrease in *Proteus* spp. and *E. coli* in the total bacterial count (Elnaggar and El-kelawy, 2024).

Despite extensive study on organic acids and low-protein diets individually, systematic evaluations of the combined use of OA in low-protein vegetable-based diets remain limited, particularly evident under practical production conditions in developing countries such as Bangladesh. Therefore, the present study was designed to investigate the effects of organic acid supplementation in low-protein vegetable-based diets on growth performance, livability, carcass traits, leg bone quality, and economic profitability in broiler chickens.

MATERIALS AND METHODS

Ethical approval

The Animal Ethics Committee of the Directorate of Research and Extension (R&E), Chattogram Veterinary and Animal Sciences University (CVASU), Khulshi-4225, Chattogram, Bangladesh, examined and approved the experimental protocol (CVASU/Dir[R&E]EC/2021/241[4]).

Experimental broiler chickens

A total of 216 unsexed day-old broiler chickens (Ross 308 strain) with an average body weight of 44.37 g were procured from a reliable hatchery in Chattogram, Bangladesh. Strict selection criteria were applied prior to purchase to ensure that the broiler chickens were uniform in size and free of apparent defects, including abnormalities in wing and leg structure, and their general level of alertness.

Study location and experimental design

The study was conducted at the Poultry Research and Training Centre (PRTC) of Chattogram Veterinary and Animal Sciences University (CVASU), Khulshi-4225, Chattogram, Bangladesh. The research units are located at 22°21'46" N latitude and 91°48'16" E longitude. The average annual humidity in Chittagong was 79% (Weather and Climate, 2025). A 2 × 2 factorial experiment involving two dietary treatments was designed to evaluate the productivity of broiler chickens. With a completely randomized design (CRD), the broiler chickens were divided into four dietary treatment groups. Each treatment consisted of six replicates of nine broiler chickens each.

Housing and management

During the trial period, broiler chickens were housed in battery cages with a floor space of 622.45 sq. cm per broiler chicken. The cages were divided into 24 pens of equal size, and each pen (91.44 cm × 60.96 cm) was allotted nine broiler chickens. During the first week, the chickens were maintained at a brooding temperature of 33°C. After that, the temperature was gradually reduced by 2°C each week until it reached 24°C for the rest of the trial. The broiler chickens were exposed to continuous lighting for 23 hours per day, followed by one hour of darkness (Aviagen, 2015). Throughout the experimental period, all broiler chickens had free access to both feed and water. All broiler chickens were vaccinated against Newcastle Disease (ND) on days 4 and 21 (Nobilis® ND Clone 30, MSD Animal Health, Netherlands) via eye drop. Infectious Bursal Disease (IBD) vaccine was administered to broiler chickens on days 10 and 17 (Nobilis® Gumboro 228E, MSD Animal Health, Netherlands) in drinking water. All vaccines used in this study were live vaccines, and administered following the guidelines provided by the vaccine manufacturer.

Experimental design

All broiler chickens were provided with both starter and finisher diets in mash form throughout the experiment. Diets were iso-caloric with reduced protein levels, which varied between the starter (day 1 to 28) and finisher (day 29 to 42) phases. The crude protein (CP) content of both diets was slightly lower than the levels recommended by the National Research Council (NRC, 1994) for broiler chickens. The broiler chickens in the D1_c group were fed a corn-wheat-soybean meal-mustard oil cake-based basal diet containing 20.5% CP during the starter phase and 18.5% CP during the finisher phase without supplementation of OA, whereas the D1 group received the same diet with an addition of 0.6% butyric acid. Similarly, the D2_c group of broiler chickens was given a corn-rice polish-soybean meal-mustard oil cake-based basal diet containing 19.5% CP during the starter phase and 17.5% CP during the finisher phase without supplementation of OA, whereas the D2 group received the same diet supplemented with a blend of butyric (0.3%) and acetic (0.3%) acids. The ingredient and nutrient compositions are presented in Tables 1 and 2.

Table 1. Ingredient and nutrient composition of the starter diet for broiler chickens (day 1-28)

Ingredients (%)	Treatment groups ¹			
	D1 _c	D1	D2 _c	D2
Corn	56.25	56.25	57.20	57.20
Wheat	3.22	3.22	0.00	0.00
Rice polish	0.00	0.00	3.50	3.50
Vegetable oil	2.45	2.45	2.60	2.60
Mustard oil cake	1.00	1.00	1.50	1.50
Soybean meal	32.60	32.53	29.60	29.60
Limestone	1.40	1.40	1.40	1.40
DCP	1.42	1.42	1.42	1.42
Lysine	0.11	0.11	0.13	0.13
Methionine	0.11	0.11	0.11	0.13
Threonine	0.12	0.12	0.12	0.12
Choline chloride	0.06	0.06	0.06	0.06
Vita-min-premix	0.25	0.25	0.25	0.25
Salt (NaCl)	0.25	0.25	0.50	0.50
Sodium carbonate	0.20	0.20	0.32	0.20
Butyric acid	0.00	0.60	0.00	0.30
Acetic acid	0.00	0.00	0.00	0.30
Silica (SiO ₂)	0.53	0.00	1.26	0.76
Enzyme	0.04	0.04	0.04	0.04
Marker (TiO ₂)	0.03	0.03	0.03	0.03
Calculated value (%)				
ME (Kcal/kg)	2,926.00	2,925.00	2,925.00	2,926.00
CP	20.50	20.50	19.50	19.50
CF	4.76	4.76	4.63	4.63
EE	5.54	5.54	5.54	5.58
Ca	0.86	0.86	0.86	0.86
P	0.42	0.42	0.43	0.43
Chemical value (%)				
CP	20.30	20.30	19.01	19.01
CF	4.81	4.81	4.15	4.15
EE	5.12	5.12	5.04	5.04
Ca	1.01	1.01	1.05	1.05
P	0.49	0.48	0.50	0.50

¹The control groups, including D1_c and D2_c, were fed basal diets without organic acids, whereas the experimental groups, D1 and D2, received diets supplemented with 0.60% butyric acid and a blend of 0.30% butyric and 0.30% acetic acid, respectively. DCP: Dicalcium phosphate, SiO₂: Silicon dioxide, ME: Metabolizable energy, CP: Crude protein, CF: Crude fiber, EE: Ether extract, Ca: Calcium, P: Phosphorus; Source: NRC, 1994.

Table 2. Ingredient and nutrient composition of finisher diet for broiler chickens (day 29-42)

Ingredients (%)	Treatment groups ¹			
	D1 _c	D1	D2 _c	D2
Corn	58.25	58.25	58.25	58.25
Wheat	4.22	4.22	0.00	0.00
Rice polish	0.00	0.00	5.00	5.00
Vegetable oil	4.00	4.00	4.35	4.35
Mustard oil cake	1.00	1.00	1.00	1.00
Soybean meal	27.34	27.34	25.00	25.00
Limestone	1.44	1.44	1.49	1.49
DCP	1.42	1.42	1.40	1.40
Lysine	0.11	0.11	0.11	0.11
Methionine	0.11	0.11	0.11	0.11
Threonine	0.12	0.12	0.12	0.12
Choline chloride	0.06	0.06	0.06	0.06
Vita-min-premix	0.25	0.25	0.35	0.35
Salt (NaCl)	0.50	0.50	0.50	0.40
Sodium carbonate	0.17	0.27	0.60	0.50
Butyric acid	0.00	0.60	0.00	0.30
Acetic acid	0.00	0.00	0.00	0.30
Enzyme	0.04	0.04	0.04	0.04
Silica (SiO ₂)	1.00	0.28	1.63	1.23
Marker (TiO ₂)	0.00	0.00	0.00	0.00
Calculated value (%)				
ME (Kcal/kg)	3,034.00	3,034.00	3,035.00	3,045.00
CP	18.50	18.50	17.50	17.50
CF	4.60	4.59	4.53	4.53
EE	5.62	5.62	5.67	5.67
Ca	0.86	0.86	0.88	0.88
P	0.43	0.43	0.44	0.44
Chemical value (%)				
CP	17.59	17.59	16.65	16.65
CF	4.10	4.10	4.68	4.68
EE	5.32	5.32	5.84	5.84
Ca	0.98	0.98	0.96	0.96
P	0.54	0.54	0.52	0.52

¹The control groups, including D1_c and D2_c, were fed basal diets without organic acids, whereas the experimental groups, D1 and D2, received diets supplemented with 0.60% butyric acid and a blend of 0.30% butyric and 0.30% acetic acid, respectively. DCP: Dicalcium phosphate, SiO₂: Silicon dioxide, ME: Metabolizable energy, CP: Crude protein, CF: Crude fiber, EE: Ether extract, Ca: Calcium, P: Phosphorus; Source: [NRC, 1994](#).

Growth performance parameters

Weekly data collections were made throughout the trial period. The FI and LBW of broiler chickens were recorded each week to determine FCR. The FI of each replicate was determined by subtracting the leftover feed from the feed provided at the end of the week. The Formula 1 was used to calculate the FCR weekly.

$$\text{Feed conversion ratio (FCR)} = \frac{\text{Total feed intake (g)}}{\text{Total live body weight (g)}} \quad (\text{Formula 1})$$

Livability

The broiler chickens were carefully observed, and dead chickens were removed immediately. The mortality of broiler chickens was recorded daily for each replicate throughout the 42-day experimental period. The livability percentage at the end of the trial (day 42) was calculated using Formula 2.

$$\text{Livability percentage (\%)} = \frac{\text{Number of chickens alive at the end}}{\text{Number of chickens at the start}} \times 100 \quad (\text{Formula 2})$$

Carcass and relative organ weights

On day 42, six broiler chickens from each treatment were selected randomly based on average weight. Then, a fasting period of about 10 hours was maintained before the broiler chickens were humanely slaughtered using the halal method. A pre-slaughter fasting period of 8 to 12 hours reduces the risk of contamination and ensures optimal carcass

yield (Schneider and Gewehr, 2023). Carcass traits, including dressed yield and the weights of the breast, thigh, drumstick, shank, and gible (heart, liver, and gizzard), were recorded using a digital weighing scale with a minimum sensitivity of 20 g. The dressing percentage of chickens was calculated according to Formula 3 described by Wu et al. (2020).

$$\text{Dressing percentage (\%)} = \frac{\text{Carcass weight (g)}}{\text{Live body weight (g)}} \times 100 \quad (\text{Formula 3})$$

Leg bone traits

In order to prepare samples for bone trait evaluation, the tibial bones (right) of broiler chickens were removed on day 42 of the trial, gently boiled in deionized water for 10 minutes to remove adherent soft tissues, and then defatted with a solvent (diethyl ether). Morphometric measurements were made using a digital slide caliper (CD-6 ASX 0-6"/150 mm, Mitutoyo, Japan) to determine bone length (proximal to distal end) and bone width (widest point across the proximal epiphysis). Fresh bone weight was determined using an analytical balance. The bones were then dried at 105°C for 24 hours and ashed at 600°C for 6 hours to determine ash percentage (Diaz-Alonso et al., 2019). The mineralized ash was further analysed using an inductively coupled plasma spectrophotometry (ICP-MS) machine (SUPEC 7000 ICP-MS, Zhejiang, China) to quantify the key minerals associated with skeletal development, particularly calcium (Ca) and phosphorus (P). Every laboratory test was performed in accordance with standard protocols (AOAC, 2019).

Cost-benefit analysis

Economic analysis of broiler chicken production was performed at 42 days of age. Live body weight and livability were used to estimate the total live body weight per treatment. Total production costs included feed, broiler chickens, and other variable costs such as housing, labor, and vaccination, expressed per kilogram of live weight. Total return was calculated by multiplying the live body weight (BW) by the fixed market price of live broiler chickens. Profit per kilogram of live broiler chickens was calculated according to the methods of Tareen et al. (2017) by subtracting the total production cost from the total return.

Data analysis

All data were analyzed using the Generalized Linear Model (GLM) procedure in Minitab statistical software (Minitab, 2000). A two-way analysis of variance (ANOVA) was performed based on a completely randomized design (CRD), and differences among dietary treatment means were determined using Duncan's Multiple Range Test (DMRT). Statistical significance was considered at $p \leq 0.05$.

RESULTS

The results for feed intake (FI), live body weight (LBW), and feed conversion ratio (FCR) are shown in Table 3. At 21 days, the FI for control groups was 802.83 g (D1_c) and 782.15 g (D2_c), while 798.34 g and 816.63 g, respectively, for D1 (0.6% butyric acid) and D2 (the 0.30% butyric and acetic acid) groups. For D1_c, D1, D2_c, and D2, the FI at 42 days was 2989.10 g, 3127.20 g, 3029.70 g, and 3186.00 g, respectively. When comparing with control groups, OA supplementation significantly increased FI ($p \leq 0.05$) in the D2 group, followed by D1, at both 21 and 42 days of age (Table 3). The LBW for broiler chickens fed the basal diets (D1_c and D2_c) was 488.06 g and 493.47 g, respectively, whereas the higher LBW was observed in D1 (531.99 g) and D2 (529.41 g) groups at 21 days of age. The 0.6% butyric acid-supplemented group (D1) had the significantly highest body weight when compared to the other treatment groups ($p \leq 0.05$). At 42 days of age, the LBW for D1_c, D1, D2_c, and D2 groups was 1612.10 g, 1730.70 g, 1600.80 g, and 1750.00 g (D2), respectively. The LBW was significantly increased ($p \leq 0.05$) by dietary supplementation with 0.30% butyric and acetic acid (D2) as compared to the other treatment groups. The FCR was significantly lower (1.60) in the OA-supplemented group (both D1 and D2) when compared to the control groups D1_c (1.80) and D2_c (1.70) at 21 days of age. D1_c, D1, D2_c, and D2 were found to be 1.91, 1.86, 1.95, and 1.87 at 42 days of age. At 42 days of age, 1.91, 1.86, 1.95, and 1.87 were observed for D1_c, D1, D2_c, and D2. Supplementation of OA significantly reduced FCR (1.86) in the D1 group, followed by D2 (1.87), D1_c (1.91), and D2_c (1.95) groups ($p \leq 0.05$). The FI, LBW, and FCR were not significantly impacted by the basal diets at either 21 or 42 days of age ($p > 0.05$). Organic acids and basal diet had a significant combined effect ($A \times B$) on FI and FCR at 21 days of age ($p \leq 0.05$); however, this interaction was not significant at 42 days of age ($p > 0.05$). In contrast, no significant $A \times B$ interaction for LBW was observed at both 21 and 42 days of age ($p > 0.05$).

The effect of low-protein diets supplemented with organic acids on the livability of broiler chickens (Ross-308) was displayed in Figure 1. The D1_c group showed the highest livability percentage (83.33), followed by the D2_c, D2, and D1

groups (83.00, 81.00, and 79.20, respectively) at 42 days of age. However, the basal diets, organic acids, or A × B interaction had no significant effect on the livability of broiler chickens ($p > 0.05$).

The effect of low-protein vegetable-based diets supplemented with organic acids on carcass traits of broiler chickens (Ross-308) was presented in Table 4. At 42 days of age, the dressing yields for D1_c, D1, D2_c, and D2 were 72.38%, 74.57%, 73.66%, and 74.90%, respectively. The OA supplementation significantly increased dressing yield, drumstick, breast, and giblet percentages in the D2 and D1 groups compared to the corresponding control groups ($p \leq 0.05$). The findings showed that dressing yield, drumstick, thigh, breast, giblet, and shank percentages were not significantly impacted by basal diets or the A × B interaction ($p > 0.05$).

Table 5 presents the effect of low-protein vegetable-based diets supplemented with organic acids on leg bone traits of broiler chickens (Ross-308) at 42 days of age. For D1_c, D1, D2_c, and D2, the corresponding bone lengths were 61.00, 63.00, 61.30, and 63.50 mm; the bone ash values were 0.55, 0.60, 0.53, and 0.63 g, respectively, while the bone width was measured at 12.45, 13.61, 12.93, and 13.25 mm. In comparison to the other treatment groups, the results showed that supplementing with OA significantly enhanced bone length, width, and ash content in 0.30% butyric and acetic acid (D2) group ($p \leq 0.05$). However, dietary OA supplementation had no significant effect on bone weight and tibial calcium content ($p > 0.05$). None of the evaluated bone characteristics were significantly impacted by the A × B interaction ($p > 0.05$). Organic acids supplementation had no significant effect on tibial Ca and P contents ($p > 0.05$). The findings also showed that bone ash, calcium, weight, width, and length were not significantly affected by basal diets ($p > 0.05$). However, basal diets significantly increased the tibial phosphorus percentage in the D1_c group compared to all other treatment groups in the present study ($p \leq 0.05$).

The effect of low-protein vegetable-based diets supplemented with organic acids on the cost-benefit of broiler chicken (Ross-308) production is presented in Table 6. For D1_c, D1, D2_c, and D2 groups, the total production cost (USD/kg LBW) was 0.99, 0.96, 1.01, and 0.95 for D1_c, D1, D2_c, and D2, respectively, and the profit (USD/kg LBW) was 0.030, 0.063, 0.016, and 0.071 at the end of the trial. When compared to other treatment groups, the total production cost per kg of live body weight was significantly decreased in the D2 group ($p \leq 0.05$). The findings showed that live body weight, total production cost, and profit were not significantly impacted by either basal diets or the A × B interaction ($p > 0.05$). The basal diet, organic acid supplementation, and their combination had no significant effects on livability, feed cost, chick cost, or other costs ($p \geq 0.05$).

Table 3. Growth performance of broiler chickens fed low-protein vegetable-based diets supplemented with organic acids in the period of 42 days

Parameters ²	Age (day)	Treatment groups ¹				SEM	Level of significance		
		D1 _c	D1	D2 _c	D2		Basal diets (A)	Organic acids (B)	A×B
FI (g)	21	802.83 ^a	798.34 ^a	782.15 ^b	816.63 ^a	2.33	0.80	0.01	0.01
	42	2,989.10 ^b	3,127.20 ^a	3,029.70 ^b	3,186.00 ^a	18.7	0.11	0.01	0.81
LBW (g)	21	488.06 ^b	531.99 ^a	493.47 ^b	529.41 ^a	1.48	0.64	0.01	0.20
	42	1,612.10 ^b	1,730.70 ^a	1,600.80 ^b	1,750.00 ^a	9.45	0.84	0.01	0.43
FCR (g/g)	21	1.80 ^a	1.60 ^b	1.70 ^a	1.60 ^{bc}	0.01	0.44	0.01	0.01
	42	1.91 ^a	1.86 ^b	1.95 ^a	1.87 ^b	0.01	0.36	0.05	0.63

¹The control groups, including D1_c and D2_c, were fed basal diets without organic acids, whereas the experimental groups, D1 and D2, received diets supplemented with 0.60% butyric acid and a blend of 0.30% butyric and 0.30% acetic acid, respectively. ²FI: Feed intake, LBW: Live body weight, FCR: Feed conversion ratio. ^{a, b, c} Different superscript letters within a row differ significantly ($p \leq 0.05$); SEM: Standard error of the mean.

Table 4. Carcass traits and relative organ weights (as the percentages of live body weight) of broiler chickens fed low-protein vegetable-based diets supplemented with organic acids in the period of 42 days

Parameters	Treatment groups ¹				SEM	Level of significance		
	D1 _c	D1	D2 _c	D2		Basal diets (A)	Organic acids (B)	A×B
Dressing yield	72.38 ^b	74.57 ^a	73.66 ^b	74.90 ^a	0.26	0.19	0.03	0.42
Drumstick	7.91 ^b	9.95 ^a	7.78 ^b	10.98 ^a	0.12	0.14	0.05	0.08
Thigh	9.71 ^a	11.17 ^a	7.50 ^a	10.10 ^a	0.46	0.15	0.09	0.57
Breast	19.58 ^b	21.26 ^a	19.36 ^b	22.47 ^a	0.43	0.59	0.05	0.44
Giblet	4.83 ^b	5.12 ^a	4.20 ^b	5.23 ^a	0.06	0.09	0.05	0.06
Shank	3.02 ^a	2.49 ^a	3.55 ^a	3.12 ^a	0.13	0.09	0.14	0.86

¹The control groups, including D1_c and D2_c, were fed basal diets without organic acids, whereas the experimental groups, D1 and D2, received diets supplemented with 0.60% butyric acid and a blend of 0.30% butyric and 0.30% acetic acid, respectively. ^{a, b} Different superscript letters within a row differ significantly ($p \leq 0.05$); SEM: Standard error of the mean.

Table 5. Leg bone qualities of broiler chickens fed low-protein vegetable-based diets supplemented with organic acids in the period of 42 days

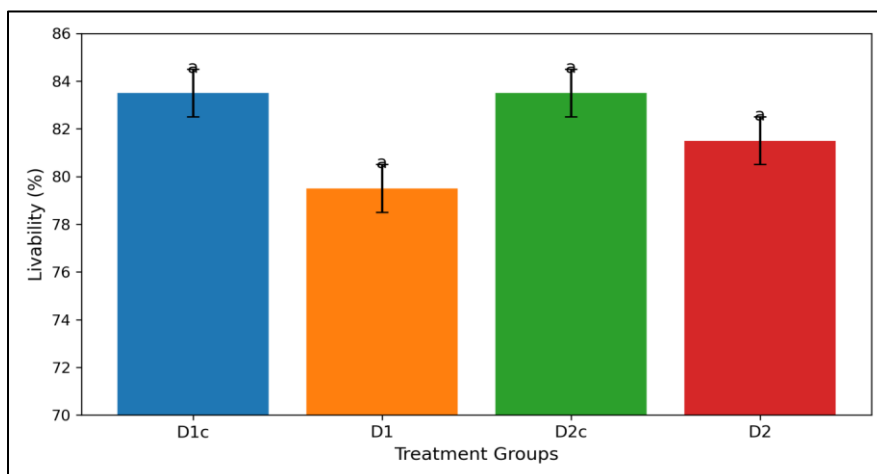
Parameters ²	Treatment groups ¹				SEM	Level of significance		
	D1 _c	D1	D2 _c	D2		Basal diets (A)	Organic acids (B)	A×B
Bone length (mm)	61.00 ^b	63.00 ^a	61.30 ^b	63.50 ^a	0.290	0.53	0.02	0.87
Bone weight (g/kg BW)	2.98 ^a	3.01 ^a	2.86 ^a	3.03 ^a	0.030	0.39	0.13	0.24
Bone width (mm)	12.45 ^b	13.61 ^a	12.93 ^b	13.25 ^a	0.084	0.76	0.01	0.07
Bone ash (g)	0.55 ^b	0.60 ^a	0.53 ^b	0.63 ^a	0.011	0.90	0.03	0.32
Ca (%)	8.75 ^a	8.05 ^a	7.15 ^a	7.85 ^a	0.198	1.00	0.09	0.15
P (%)	4.08 ^a	3.50 ^{ab}	2.88 ^b	3.29 ^{ab}	0.092	0.02	0.31	0.06

¹The control groups, including D1_c and D2_c, were fed basal diets without organic acids, whereas the experimental groups, D1 and D2, received diets supplemented with 0.60% butyric acid and a blend of 0.30% butyric and 0.30% acetic acid, respectively. ²Ca: Calcium, P: Phosphorus, BW: Body weight, ^{a, b} Different superscript letters within a row differ significantly ($p \leq 0.05$); SEM: Standard error of the mean.

Table 6. Cost-benefit analysis of broiler chickens fed low-protein vegetable-based diets supplemented with organic acids in the period of 42 days

Parameters ²	Treatment groups ¹					Level of significance		
	D1 _c	D1	D2 _c	D2		Basal diets (A)	Organic acids (B)	A×B
Live body weight (g/broiler chicken)	1,612.10 ^b	1,730.70 ^a	1,600.00 ^b	1,750.00 ^a		NS	**	NS
Livability (%)	83.33 ^a	79.2 ^a	83.00 ^a	81.00 ^a		NS	NS	NS
Feed cost (USD/kg LBW)	0.54 ^a	0.53 ^a	0.56 ^a	0.54 ^a		NS	NS	NS
DOC cost (USD/Chicken)	0.38 ^a	0.38 ^a	0.38 ^a	0.38 ^a		NS	NS	NS
Other cost (USD/kg LBW)	0.21 ^a	0.20 ^a	0.21 ^a	0.20 ^a		NS	NS	NS
Market price (USD/kg LBW)	1.02 ^a	1.02 ^a	1.02 ^a	1.02 ^a		NS	NS	NS
Total production cost (USD/kg LBW)	0.99 ^a	0.96 ^b	1.01 ^a	0.95 ^b		NS	*	NS
Profit (USD/kg LBW)	0.030 ^b	0.063 ^a	0.016 ^{bc}	0.071 ^a		NS	**	NS

¹The control groups, including D1_c and D2_c, were fed basal diets without organic acids, whereas the experimental groups, D1 and D2, received diets supplemented with 0.60% butyric acid and a blend of 0.30% butyric and 0.30% acetic acid, respectively. ²Live body weight (g/Chicken): Average weight of a broiler chicken at the end of the rearing period; Livability (%): Percentage of chickens that survive until the end of the study; Feed cost (USD/kg live body weight): Cost required to produce 1 kg body weight; DOC cost (USD/Chicken): Cost of a one-day-old broiler chicken; Other cost (USD/kg LBW): Additional production cost per kg of live body weight, including vaccines, medicines, labor, transport, electricity, and water; Market price (USD/kg LBW): Selling price of one kilogram of live body weight of broiler chickens; Total production cost (USD/kg LBW): Overall cost to produce one kilogram of live body weight of broiler chickens, including feed, broiler chicken, and other expenses; Profit (USD/kg LBW): Money earned per kilogram of live broiler chicken, calculated as the difference between market price and total production cost, including feed, labor, medicine, and other expenses; DOC: Day old chickens, LBW: Live body weight. SEM (Standard error of the mean) values are not presented in this table; significance is based on statistical analysis of the raw data. ^{a, b, c} Different superscript letters within a row differ significantly ($p \leq 0.05$); NS: Non-significant ($p > 0.05$); **: $p < 0.01$; *: $p < 0.05$.

**Figure 1.** Livability of broiler chickens fed low-protein vegetable-based diets supplemented with organic acids for 42 days. The control groups, including D1_c and D2_c, were fed basal diets without organic acids, whereas the experimental groups, D1 and D2, received diets supplemented with 0.60% butyric acid and a blend of 0.30% butyric and 0.30% acetic acid, respectively. Bars with the same letter (a) are not significantly different ($p > 0.05$).

DISCUSSION

In the present study, dietary supplementation with OA significantly increased FI and LBW, and decreased FCR. These findings are consistent with those of [Imran et al. \(2018\)](#), who reported that supplementation with butyric acid at 0.25, 0.35, and 0.45 g/kg of feed increased body weight gain and decreased feed conversion efficiency in Hubbard Classic broiler chickens. Similarly, [Younis et al. \(2024\)](#) demonstrated that 0.5% propionic acid supplementation significantly improved LBW, average daily gain, feed intake, and FCR in Ross 308 broiler chickens. In addition, Hubbard Classic broiler chickens fed with acetic acid at a concentration of 10, 20, and 30 g/kg of feed from 8 to 42 days of age improved both FCR and BWG compared with the control group ([Rehman et al., 2016](#)). The ability of organic acids to control the microbiota in the gastrointestinal tract, enhance gut microstructure, stimulate the immune system, release different digestive enzymes, and increase nutrient digestibility and absorption is thought to be responsible for their growth-promoting effects ([Nguyen et al., 2018](#); [Yang et al., 2018](#); [Ma et al., 2021](#)).

The livability percentage of broiler chickens was not significantly affected by the basal diets, organic acids, or A × B interaction at the end of the experiment. In contrast, [Abou-Ashour et al. \(2021\)](#) reported that Arbor Acres broiler chickens fed a diet supplemented with a mixture of 1% citric and 0.5% acetic acids significantly improved livability percentage (96.67%), compared with 86.67% in the control group. Similarly, Ross 308 broiler chickens receiving a dietary mixture of OA at a concentration of 0.3% to 0.9% showed reduced mortality rates, decreasing from 2.58% in the control group to 0.00–0.59% in the experimental groups ([Brzoska et al., 2013](#)). By enhancing gut eubiosis, controlling intestinal pH, and encouraging symbiotic bacteria while reducing pathogenic colonization, butyric acid improves the immunity of Hubbard Classic broiler chickens and makes them more livable ([Sikandar et al., 2017](#)). These variations among studies could be explained by variations in the type of organic acid, inclusion level, management practices, environmental conditions, or health status of the broiler chickens.

In this investigation, 0.30% of butyric and acetic acids supplementation significantly enhanced the dressing percentage, weight of drumstick, breast, and giblet in Ross 308 broiler chickens at 42 days of age. These results align with the findings of [Deghani-Tafti and Jahanian \(2016\)](#), who reported that dietary 2.5 g/kg of either citric or butyric acid supplementation increased carcass yields in Ross 308 broiler chickens. [Younis et al. \(2024\)](#) reported that 0.5% or 0.75% propionic acid supplementation significantly improved carcass yield in Ross 308 broiler chickens, which further supports the present findings. Furthermore, broiler chickens (Ven Cobb 430Y) fed a blend-coated organic acids at a concentration of 0.3, 0.6, and 1 g/kg of feed exhibited improved eviscerated and carcass yields, as well as increased breast meat, drumstick, and relative organ weights ([Manvatkar et al., 2022](#)). On the contrary, [Sabour et al. \(2019\)](#) observed no significant difference in dressing percentage by having diets in Ross 308 broiler chickens supplemented with 0.1% of citric, lactic, acetic, butyric, formic, and propionic acids.

The present study indicated that dietary butyric and acetic acid supplementation at a concentration of 0.30% significantly increased bone length, bone width, and ash content in broiler chickens. These results are consistent with the findings of [Swiatkiewicz and Arczewska-Wlosek \(2012\)](#), who concluded that OA, or short-chain fatty acids (formic, propionic, and acetic acid) supplementation at a concentration of 1.5, 1.0, and 1.5 g/kg feed, respectively, improved bone quality in Ross 308 broiler chickens. Similarly, supplementation of Cobb 500 broiler chickens with butyric, fumaric, and lactic acids at concentrations of 2% and 3% has been shown to increase serum calcium and phosphorus concentrations ([Adil et al., 2010](#)). However, the findings differ slightly from those of [Yildiz et al. \(2013\)](#), who reported that 17.5% of boric acid supplementation did not significantly affect most bone characteristics, such as bone weight and length, although bone phosphorus content was improved in Ross 308 broiler chickens.

It is evident from the results that broiler chickens fed OA-supplemented diets achieved higher profit with reduced production costs. Contrarily, broiler chickens fed basal diets exhibited lower profit and increased production costs. Similar findings have been reported by several researchers investigating dietary supplementation to enhance productivity and profitability in poultry farming. [Abou-Ashour et al. \(2021\)](#) reported that dietary supplementation with a mixture of acetic and citric acids at a concentration of 0.5% and 1%, respectively, in broiler chickens (Arbor Acres) resulted in greater relative economic efficiency compared to the control groups. Likewise, Hubbard Classic broiler chickens fed a diet supplemented with 0.5% of citric acid had the lowest production costs, followed by those fed antibiotics, the negative control (without additions), and the combination of them ([Chowdhury et al., 2009](#)). Economic outcomes are influenced by live weight, carcass yield, feed costs, and market prices, all of which fluctuate in commercial settings, necessitating continuous economic assessment ([Zhai et al., 2013](#)).

CONCLUSION

The results of this study demonstrated that adding organic acids to low-protein vegetable diets significantly increased the feed conversion ratio as well as the profit per kilogram of live body weight, dressing yield, drumstick, breast, and giblet percentages, bone length, bone width, and bone ash content of broiler chickens. It is recommended that future studies examine the effects of various organic acid inclusion levels and combinations, as well as their long-term effects on gut health and nutrient digestibility. Additionally, investigations should be conducted under commercial farming conditions with larger flock sizes.

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Competing interests

The authors have declared that there are no competing financial interests or personal affiliations related to the study described in this manuscript.

Author's contributions

This study was carried out in collaboration among all authors. Authors Sharmin Zaman, Mohammad Abul Hossain, and Nasima Akter designed the study, conducted the laboratory analysis, performed the statistical analysis, and wrote the protocol. Authors Shoriful Islam, Sabuj Kanti Nath, and Dilruba Akter Mir contributed to sample collection and initial draft writing of the manuscript. Authors Nasrin Akter, Syidul Islam, Mosammat Mahamuda Khatun, Fowzia Bahar, and Md. Sahidul Islam managed the literature searches, interpretation of the results, and critical review. All authors read and approved the final version of the manuscript before publication in the present journal.

Ethical considerations

According to the journal's standards, the authors certify that all ethical issues, such as plagiarism, publication permissions, research misconduct, and duplicate submission or publication, have been carefully considered. The authors declared that they have not used AI tools for conducting the study, preparing data, or statistical analysis.

Availability of data and materials

The data supporting this study are available from the corresponding author upon reasonable request.

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