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Effects of Citric Acid Powder Supplementation on Feed Intake and Feed Conversion Ratio in Broiler Chickens

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ABSTRACT

The experiment was conducted to determine the effects of different levels of citric acid powder on feed intake and feed conversion ratio (FCR) in Ross 308 broiler chicks. A total of 48 broiler chicks, with an average initial body weight of 42 ± 4.2 grams, were used in a completely randomized design (CRD). The birds were divided into four groups, with three replicates per group. The control (G1) was fed a basal diet without citric acid supplementation. Group 2 (G2) (basal diet + 0.25% citric acid), Group 3 (G3) (basal diet + 0.50% citric acid), and Group 4 (G4) (basal diet + 0.75% citric acid) were provided with drinking water, and birds were given feed and water ad libitum. The trial lasted for 35 days. During the experimental period, feed intake and feed conversion ratio (FCR) were recorded and analysed. Data analysis was conducted using Statistica 9. The results demonstrated that the various levels of citric acid had different impacts on improving both feed intake and FCR. Among the treatments, G4 exhibited the most favorable effects on the measured parameters, increasing ($P<0.01$) the average total dry matter intake (12,265.87) relative to the control (11,929.68) and, though not statistically, numerically reducing the feed conversion ratio (1.33) compared with the control (1.37). Based on these findings, Citric acid supplementation at 0.75% may serve as a natural alternative to synthetic antibiotic growth promoters in broilers .These findings may support poultry production in Afghanistan and similar regions.

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INTRODUCTION

In the contemporary world, the need for high-quality, healthy, and affordable protein sources is a significant challenge facing human societies, especially in developing countries. Among these, broiler chicken farming, as one of the essential and fast-growing sources of animal protein, plays a significant role in food security. Due to its high nutritional value, fast digestibility, short growth period, and low production costs, chicken meat has consistently been among the top choices for consumers (Islam et al., 2008). However, this industry faces

challenges such as increased feed intake, disease outbreaks, bacterial resistance, and restrictions on antibiotic use (Njeumi et al., 2007).

In recent years, due to international restrictions on the use of antibiotics as growth promoters, extensive scientific efforts have been made to develop natural, healthy alternatives for poultry nutrition. One of these alternatives is organic acids, notably citric acid. Citric acid is naturally found in citrus fruits and is used in the poultry feed industry as an additive with antibacterial properties, pH regulation, and digestive performance enhancement (Afsharmanesh & Pourreza, 2005; Fattah et al., 2008).

The physiological functions of citric acid in the digestion of birds include reducing pH, inhibiting the growth of harmful bacteria, improving the solubility of minerals (such as phosphorus and calcium), and increasing the activity of digestive enzymes (Boling et al., 2000). These effects improve nutrient absorption and increase feed efficiency in birds. As a result, birds fed with citric acid generally show higher feed intake, better feed conversion ratios, and greater resistance to diseases (Hassan et al., 2016). One study demonstrated that adding citric acid to the diet of broiler chicks significantly improved growth, increased feed intake, and reduced the feed conversion ratio. The same study also reported a reduction in intestinal pH and an increase in the absorption of phosphorus and calcium (Islam et al., 2008).

Another study found that citric acid in poultry feed increased phytate solubility, improved mineral availability, and reduced phosphorus excretion in bird feces. These results suggest that citric acid can be effective not only in promoting growth but also in reducing environmental pollution (Boling et al., 2000). In an experimental study conducted in Iran, adding 0.5% citric acid to broiler feed resulted in a significant increase in daily weight gain and improved FCR. Furthermore, the reduction of pathogenic bacterial growth in the intestine was another important finding of this study (Afsharmanesh and Pourreza, 2005).

A review also confirmed that citric acid, compared with other organic acids such as fumaric acid and lactic acid, had the most tremendous impact on improving the nutritional performance of poultry. In this study, birds that were fed higher levels of citric acid exhibited faster growth, higher feed intake, and better carcass quality (Fattah et al., 2008). Additionally, the effects of citric acid in reducing poultry mortality were confirmed, stating that this compound can enhance gut microbial balance, boost bird immunity, and reduce the risk of gastrointestinal diseases (Njeumi et al., 2007).

In a more recent study, the use of different levels of citric acid (0.25%, 0.50%, and 0.75%) in the drinking water of broiler chicks was investigated. Their findings showed that the highest level (0.75%) was the most effective in improving growth, feed intake, carcass quality, and reducing mortality (Hassan et al., 2016). Based on the aforementioned studies, it can be concluded that citric acid is one of the most effective natural additives in poultry nutrition. By improving the digestive environment, enhancing nutrient absorption, reducing pathogenic factors, and improving overall bird performance, citric acid can serve as a suitable alternative to chemical growth promoters in modern poultry farms.

Various international studies have reported the positive effects of citric acid on improving feed intake and feed conversion ratio in broiler chickens (Adil et al., 2010; Chowdhury et al., 2009; Elbaz et al., 2021). However, in Afghanistan, field research in this area is limited, and there is insufficient information for scientific and practical recommendations. Considering the climatic conditions, farm management capabilities, and the need to enhance productivity in the country's poultry industry, conducting scientific research in this field appears necessary. The present study aimed to;

- To evaluate the effects of varying levels of citric acid powder in drinking water on feed intake and feed conversion ratio in broiler chicks.
- To provide reliable data to support evidence-based decision-making for the sustainable development of poultry production systems in Afghanistan.

METHODS AND MATERIALS

The materials employed in the present study consisted of experimental animals, nutritionally formulated diets, and calibrated measuring equipment. This study was conducted to evaluate the effects of the experimental treatments on the selected response variables under controlled conditions. The experimental design was completely randomized, and all procedures were performed in accordance with standard scientific and ethical guidelines (ARRIVE, 2010).

Area of the Study

This study was conducted at the research farm of the Faculty of Agriculture, Kabul University, over 35 days. The farm was equipped with a natural ventilation system, adequate lighting, and provided the birds with free access to feed and water.

Figure 1 presents the internal view of the poultry house, whereas Figure 2 provides the external view of the facility.

Figure 1. *External View of the Research Site*

Figure 2. *Interior View of the Poultry House*

Experimental Design

The study employed a completely randomized design (CRD). A total of 48 one-day-old broiler chicks of the Ross 308 strain, with similar average initial body weights, were randomly assigned to four experimental groups. Each group consisted of three replicates, with each replicate containing four broiler chicks. Table 1 shows the different levels of citric acid (%)

that were applied to the birds. Table 1 presents the different inclusion levels of citric acid applied as a dietary supplement.

Table 1. *Different Levels of Citric Acid (%)*

No.	Group (G)	Citric Acid Level (%) in Drinking Water
1	G_1 (Control)	0
2	G_2	0.25
3	G_3	0.50
4	G_4	0.75

*Citric acid was prepared as a water-soluble powder and provided to the birds daily with fresh drinking water

During the experimental period, the following parameters were recorded weekly and analyzed at the end of the trial:

- Feed intake (g/day/bird)
- Feed conversion ratio (FCR = Feed Intake / Weight Gain)

Data Collection procedure

All groups were maintained under identical conditions regarding temperature, lighting, ventilation, and access to feed and water. A standard diet was provided in accordance with the National Research Council (NRC) requirements for the starter and grower phases. The diet composition included corn, soybean meal, wheat bran, and mineral and vitamin supplements) NRC, 1994).

Feed consumption in each cage was measured by subtracting the amount of feed remaining from the amount offered. Body weight gain was measured by weighing the birds weekly. At the end of the trial, two birds from each replicate were randomly selected and slaughtered; the weights of their carcass components were then measured.

Data Analysis

The data obtained were analyzed using Statistica 9. Analysis of variance (ANOVA) was performed to determine differences among the groups. When significant differences were detected, mean comparisons were conducted using the Least Significant Difference (LSD) method. The significance level of $P < 0.05$ was considered statistically significant (Statistix 9, 2008).

FINDING

The study showed apparent differences in both feed intake and feed conversion ratio among the experimental groups. Feed intake reflects the total amount of feed consumed by the birds during the trial period, while the feed conversion ratio (FCR) represents the efficiency with which the birds convert feed into body weight gain. A lower FCR indicates better feed utilization efficiency.

Feed Intake

The effects of the citric acid on the total average feed intake are presented in Table 2. The results indicated that feed consumption in the citric acid groups was significantly higher than in the control group ($P < 0.05$). According to the data, statistically significant differences were

observed between all supplemented groups and the control. Groups 4, 3, and 2 consumed 12,265.87 g, 12,207.49 g, and 12,142.44 g of feed, respectively. Overall, feed intake was consistently higher in the citric acid-supplemented groups compared with the control.

Table 2. *Average Total Dry Matter Intake of Broiler Chicks Based on LSD Test during the experimental period (35 days)*

Group	Average Total Dry Matter Intake (g)
G_4	12265.87^a
G_3	12207.49^a
G_2	12142.44^a
G_1	11929.68^b
P-value	(P<0.01)

Note: a-b *Means within a column with different superscripts are different at P < 0.05*

The data in Table 3 show the effect of citric acid supplementation on the average daily dry matter intake (DMI) of broilers. Group G1 had an average daily DMI of 340.84 ± 4.89 g. The groups supplemented with citric acid exhibited higher intake values, with G2, G3, and G4 recording 346.93 ± 0.87 g, 348.78 ± 0.30 g, and 350.46 ± 1.46 g, respectively. These results indicate a dose-dependent increase in daily feed consumption, with the highest intake observed in G4. This suggests that citric acid supplementation positively affects feed intake, potentially improving growth performance in broilers.

Table 3. *Average Daily Dry Matter Intake by Broiler Chicks (per group) (g)*

Group	Average Daily Dry Matter Intake (g)
G_1	340.84 ± 4.89
G_2	346.93 ± 0.87
G_3	348.78 ± 0.30
G_4	350.46 ± 1.46

Based on the results, Group 4 had the highest feed intake percentage (95.01%) relative to the diet, followed by Group 3 (94.56%) and Group 2 (94.05%). Although the differences among these groups were minor, the control group (Group 1) showed the lowest dry matter intake at 92.40% (Fig. 3).

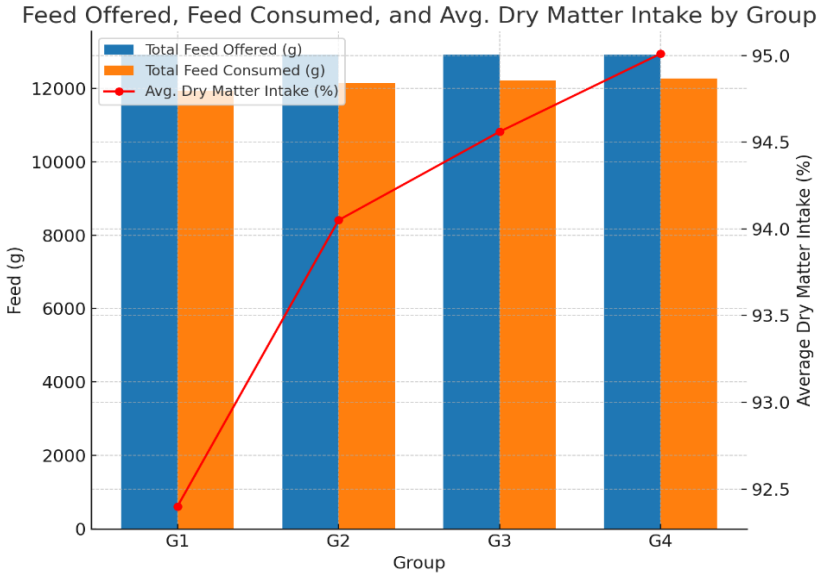

Fig 3. *Average Dry Matter Intake by Broiler Chicks in Different Groups (%)*

The results indicated that dry matter intake by the broiler chicks increased respectively in the Control Group (G_1) from 979.47 g to 3401.62 g, in Group 2 (G_2) from 990.72 g to 3518.26 g, in Group 3 (G_3) from 999.52 g to 3556.11 g, and in Group 4 (G_4) from 975.40 g to 3698.36 g (Table 4). The average total weekly dry matter intake by broiler chicks in Groups 1, 2, 3, and 4 was recorded as 2385.94, 2428.49, 2441.50, and 2453.17 g, respectively (Table 4).

Table 4. *Average Total Daily Dry Matter Intake (g) by Broiler Chicks Under Study*

Time Interval (Days)	G_1 (Control)	G_2	G_3	G_4
0–7	979.47 ± 21.61	990.72 ± 22.21	999.52 ± 20.08	975.40 ± 22.51
8–14	1701.48 ± 47.07	1714.66 ± 46.26	1726.63 ± 47.26	1699.23 ± 46.72
15–21	2549.95 ± 35.02	2623.14 ± 31.77	2626.96 ± 33.15	2592.99 ± 36.16
22–28	3297.40 ± 26.53	3295.69 ± 53.60	3298.30 ± 26.10	3299.92 ± 26.12
29–35	3401.62 ± 28.94	3518.26 ± 24.62	3556.11 ± 2.33	3698.36 ± 11.71
Total	11929.68	12142.44	12207.49	12265.87
Average Weekly Intake	2385.94 ± 31.83	2428.49 ± 35.67	2441.50 ± 29.38	2453.17 ± 28.64

Average Feed Conversion Ratio (FCR)

The results indicate that the average FCR for Group 1 (Control) indicates that 1.37 g of dry matter was consumed for each gram of body weight gain. Similarly, in experimental Group 2 (G2), 1.36 g of dry matter was consumed per gram of weight gain; in Group 3 (G3), 1.35 g; and in Group 4 (G4), 1.33 g of dry matter were consumed for each gram of weight gain by the broiler chicks (Fig 4).

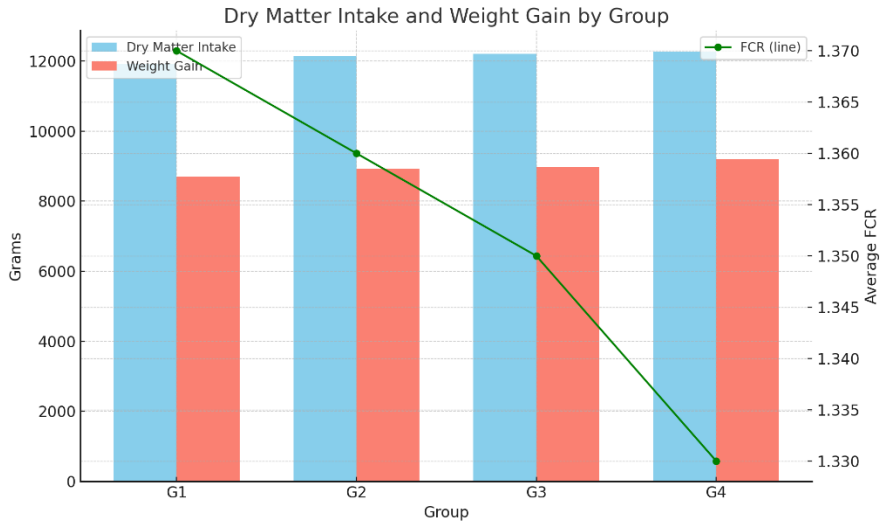

Fig 4. *Average Feed Conversion Ratio (FCR) Based on Total Dry Matter Intake to Total Weight Gain in Broiler Chicks Under Study* A lower FCR indicates greater efficiency in feed utilization and conversion to meat

Based on the findings, the daily FCR in Group 4 was more efficient than in the other groups, with 1.33 units of dry matter consumed per unit of weight gain. Similarly, in Groups 1, 2, and 3, respectively, 1.37, 1.36, and 1.35 units of dry matter were consumed per unit of weight gain. Therefore, feed conversion efficiency was highest in Group 4 (Table 5).

Table 5. *Average Daily Feed Conversion Ratio (FCR) in the Studied Groups*

Group	Average Daily Dry Matter Intake (g)	Average Daily Weight Gain (g)	Average FCR
G_1	994.14	724.74	1.37
G_2	1011.87	744.14	1.36
G_3	1017.29	748.75	1.35
G_4	1022.15	766.75	1.33

Average Feed Conversion Efficiency (FCE)

In this study, feed conversion efficiency (FCE) was calculated for different groups as average daily weight gain divided by average daily dry matter intake. This research indicates that, except for the fourth group, which showed a feed conversion efficiency of 75.01%, the other groups did not demonstrate significant efficiency (Table 6).

Table 6. *Daily Feed Conversion Efficiency (FCE) in the Experimental Groups*

Group	Average Daily Weight Gain (g)	Average Daily Dry Matter Intake (g)	Average Feed Conversion Efficiency (%)
G1	724.74	994.14	72.90
G2	744.14	1011.87	73.54
G3	748.75	1017.29	73.61
G4	766.75	1022.15	75.01

DISCUSSION

Scientific discussion and interpretation of findings allow researchers to contextualize the results within the broader body of existing knowledge, thereby gaining a better understanding of the actual effects of experimental groups. The findings of the current study clearly demonstrated that the use of different levels of citric acid in drinking water, particularly at the 0.75% level, had a positive effect on feed intake and feed conversion ratio in broiler chicks.

Supplementing at different levels of citric acid in the present experiment reveals no significant difference among Groups 2, 3, and 4; however, a statistically significant difference is observed compared with the control group ($P < 0.05$).

The findings of the current research align with the results of Elbaz et al. (2021), who conducted a study (0%, 1%, 2%, and 3%) in broiler chicks. They found that chicks in the control group consumed less feed over the trial period than those in the treatment groups. Brook et al. (2003) investigated the effects of various levels of citric acid and phytate powder on broiler chick performance. They observed that average daily dry matter intake was significantly different in the group that received 3% citric acid powder ($P<0.05$). The results presented in Table 3 of the current study are in complete agreement with those of the aforementioned researchers.

Hariharan et al. (2023) conducted a study on the addition of citric acid powder to the drinking water of broiler chicks and its impact on feed intake. They reported a significant effect of citric acid supplementation on feed intake during the final three weeks of the trial ($P < 0.05$), which aligns with current research. Martínez Amescua et al. (2006) studied the effects of citric acid powder and phytase enzymes on broiler chicks and concluded that both

additives significantly influenced total and daily feed intake ($P < 0.05$). These findings are comparable to those of the present study (Table 5).

Feed intake in the citric acid groups was significantly higher than in the control group. This may be attributed to citric acid's ability to lower the pH of the digestive tract, thereby creating optimal conditions for digestive enzyme activity. Lower pH levels enhance the solubility of minerals and stimulate digestion, thereby increasing appetite and feed intake. This finding is consistent with the results reported by Islam et al. (2008), who observed increased feed consumption following citric acid supplementation.

Feed Conversion Ratio (FCR) is a critical indicator for the economic evaluation of poultry production, and its reduction reflects greater efficiency. The study's results showed that as citric acid levels increased, FCR decreased significantly. These findings are consistent with the findings of Boling et al. (2000) and Hassan et al. (2016), both of which reported a reduction in FCR due to improved mineral availability and enhanced nutrient metabolism.

Since both feed intake and weight gain influence FCR, the simultaneous improvement in these factors in the citric acid groups, particularly G_3 and G_4, is the main reason for the reduction in this indicator. The FCR value obtained in Group T_4(1.33) is also acceptable and competitive compared to international standards.

The average FCR in Group 4 was 1.33, while in Groups 1, 2, and 3 it was measured as 1.37, 1.36, and 1.35, respectively. Chicks in Group 4 achieved greater body weight gain due to higher feed intake than those in the other groups. Based on the results, the best performance was observed in Group 4, with 0.75% citric acid powder.

The reports of Hariharan et al. (2003) indicate that adding 0.3% and 1.5% citric acid powder to the broiler chicks' diet increased feed intake and ultimately led to a more efficient FCR ($P<0.05$). These findings align with the current study.

The findings from Fig. 4 also compare favorably with those of Paul et al. (2019), who showed that feed conversion was more efficient in the supplemented groups than in the control group. Additionally, the findings of Adel et al. (2010), which reported the most favorable FCR in the group supplemented with 0.75% citric acid powder, align with the results presented in Table 5 of the current study.

The findings of Wickramasinghe et al. (2014) showed that the feed conversion ratio (FCR) was not significantly affected by the addition of citric acid powder. This discrepancy may be attributed to differing climatic conditions, which contrasts with the results of the present study. Likewise, Abdul-Fattah et al. (2008) observed a significant impact of citric acid powder on FCR across all ages in the supplemented groups, with a statistically significant difference ($P<0.05$), which supports the findings of the current study.

The findings in Table 5 show that the feed conversion efficiency in the control and supplemented groups was 72.90%, 73.54%, 73.61%, and 75.01%, respectively. Therefore, Group 4 demonstrated greater efficiency compared to the other groups.

Andries et al. (2003) reported that adding citric acid to the broiler chicks' diet improved FCE, which is consistent with the findings of Table 5 in the present study.

Moghaddam et al. (2006) reported significant positive effects of citric acid powder on feed intake in broiler chicks and added that feed conversion efficiency varied significantly ($P<0.05$) among diets. FCE and FCR essentially measure the same performance but are expressed differently, which aligns with the current research's findings.

The results of Noor Mohammadi et al. (2013), who reported positive effects of citric acid supplementation on feed conversion efficiency in broiler chicks, are in agreement with this study (Table 5). Similarly, Awad et al. (2018) demonstrated that varying levels of citric acid significantly affected both feed conversion ratio and feed conversion efficiency, which supports the findings of the present study (Table 6).

The findings of this study provide substantive implications for poultry production and nutritional management. The results demonstrate that dietary supplementation with citric acid affects feed intake and feed conversion efficiency, both of which are fundamental performance parameters in commercial broiler systems. In light of the increasing emphasis on cost-effective, antibiotic-free feed additives, citric acid appears to constitute a viable candidate for improving nutrient utilization and overall production efficiency. These insights may support evidence-based decision-making in dietary formulation and feed management, particularly in contexts where scientific resources and technical guidance remain limited.

Despite the strengths of the current study, several limitations should be considered. The study faced practical constraints, including the lack of standardized housing, limited access to suitable facilities, insufficient laboratory equipment, and a small number of broiler chicks available for the experiment. The study evaluated only a limited range of citric acid levels. Additionally, the short experimental period and limited resources constrained the analysis of advanced parameters, such as gut morphology, microbiota composition, and long-term health effects. These limitations should be taken into account when interpreting the findings and applying them to broader poultry production systems in Afghanistan.

CONCLUSION

The present study provides evidence that dietary supplementation with citric acid improves feed intake and nutrient utilization in broiler chicks. Broilers supplemented with citric acid, particularly at the 0.75% inclusion level, exhibited significantly higher daily, weekly, and cumulative feed intake compared to the control group. This enhancement is likely attributable to improvements in the gastrointestinal environment, increased digestive enzyme activity, and reduced microbial load, collectively stimulating appetite. Although feed conversion ratio (FCR) and feed conversion efficiency (FCE) were not significantly affected during the initial three weeks, supplementation at 0.75% citric acid resulted in the lowest FCR and highest FCE during the latter growth phase, reflecting enhanced feed utilization. Collectively, these findings indicate that citric acid, particularly at higher inclusion levels, is a

promising dietary additive for improving growth performance and feed efficiency in commercial broiler production.

RECOMMENDATION

Based on the findings, it is recommended to include citric acid powder in the diet of broiler chicks, particularly at higher inclusion levels (0.50–0.75%), to enhance total feed intake. Further Investigations are recommended to explore the long-term. Effects, dose rate, interaction, and underlying mechanisms of the citric acid dietary supplementation.

AUTHORS CONTRIBUTIONS

Abul Khaliq Sahes: conceived and designed the study, conducted the experiments, collected and analyzed the data, and prepared the initial draft of the manuscript.
Abdul Ghafoor Moradi and Shamsurahman Shams: contributed to manuscript review and editing.
Bakhtiyar Bashardost and Wakil Ahmad Sarhadi: contributed to the study methodology and critically reviewed the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known financial or personal conflicts of interest that could have influenced the work reported in this manuscript.

DATA AVAILABILITY STATEMENT

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

REFERENCES

Adil, S., Banday, T., Bhat, G. A., Mir, M. S., & Rehman, M. (2010). Effect of dietary supplementation of organic acids on performance, intestinal histomorphology, and serum biochemistry of broiler chicken. *Veterinary Medicine International*, 2010, Article ID 479485. https://doi.org/10.4061/2010/479485.

Afsharmanesh, M., & Pourreza, J. (2005). Effects of calcium, citric acid, ascorbic acid, vitamin D_3 on the efficacy of microbial phytase in broiler starters fed wheat-based diets on performance, bone mineralization and ileal digestibility. *International Journal of Poultry Science, 4*(6), 418–424. https://doi.org/10.3923/ijps.2005.418.424.

Andrys, R., Klecker, D., Zeman, L., & Marecek, E. (2003). The effect of changed pH values of feed in is phosphoric diets on chicken broiler performance. *Czech Journal of Animal Science,* 48, 197–206. Link

Awad, A. L., Tageldin, T. H., & Mohamed Eid, O. A. (2018). Effect of dietary probiotic and citric acid addition on broiler chicks performance during fattening period. *Journal of Sustainable Agricultural Sciences,* 44(3), 123 Link

Boling, S., Douglas, M., Snow, J., Parsons, C., & Baker, D. (2000). Citric acid does not improve phosphorus utilization in laying hens fed a corn-soybean meal diet. *Poultry Science*, 79(9), 1335–1337. https://doi.org/10.1093/ps/79.9.1335.

Broek, G. V. D., Bergh, M. V. D., Ebbinge, B., Selko, B. V., & Tilburg. (2003). Clean drinking water during production by use of organic acids. *World Poultry,* 19, 34–37. Link

Elbaz, A. M., Ibrahim, N. S., Shehata, A. M., Mohamed, N. G., & Abdel-Moneim, A. M. E. (2021). Impact of multi-strain probiotic, citric acid, garlic powder or their combinations on performance, ileal histomorphometry, microbial enumeration and humoral immunity of broiler chickens. *Tropical Animal Health and Production,* 53, 1–10. https://doi.org/10.1007/s11250-020-02552-1.

Fattah, S. A. A., Sanhoury, M. H. E., Mednay, N. M. E., & Azeem, F. A. (2008). Thyroid activity of broiler chicks fed supplemental organic acid. *International Journal of Poultry Science*, 4(6), 418–424. https://doi.org/10.3923/ijps.2008.215.222.

Hariharan, T., & Gangadevi, P. (2023). Synergistic effects of citric acid and microbial phytase on growth performance in broiler chicken. https://doi.org/10.5958/0976-0555.2015.00085.0.

Hassan, R. I., Mosaad, G. M., & Abd Elstar, M. (2016). Effect of feeding citric acid on performance of broiler ducks feed different protein levels. *Journal of Advanced Veterinary Research*, 6(1), 18–26. Link

Kilkenny, C., Browne, W. J., Cuthill, I. C., Emerson, M., & Altman, D. G. (2010). Improving bioscience research reporting: The ARRIVE guidelines for reporting animal research. *PLoS Biology*, 8(6), e1000412. https://doi.org/10.1371/journal.pbio.1000412.

Islam, M., Khandaker, Z., Chowdhury, S., & Islam, K. (2008). Effect of citric acid and acetic acid on the performance of broilers. *Journal of Bangladesh Agricultural University*, 6, 315–320. https://doi.org/10.3329/jbau.v6i2.4828.

Martinez-Amezcua, C., Parsons, C. M., & Baker, D. H. (2006). Effect of microbial phytase and citric acid on phosphorus bioavailability, apparent metabolizable energy, and amino

acid digestibility in distillers dried grains with solubles in chicks. *Poultry Science*, 85(3), 470–475. https://doi.org/10.1093/ps/85.3.470.

Moghadam, A. N., Pourreza, J., & Samie, A. H. (2006). Effect of different levels of citric acid on calcium and phosphorus efficiencies in broiler chicks. *Pakistan Journal of Biological Sciences*, 9(6), 1250–1256. https://doi.org/10.3923/pjbs.2006.1250.1256.

Njeumi, F., Demey, F., & Tankou, C. M. (2007). Evaluation of the effects of organic acids on broiler performance under tropical conditions. *Tropical Animal Health and Production*, 39(2), 109–114. https://doi.org/10.1007/s11250-007-9015-9

Nourmohammadi, R., & Afzali, N. (2013). Effect of citric acid and microbial phytase on small intestinal morphology in broiler chicken. *Italian Journal of Animal Science,* 12, 44–47. https://doi.org/10.4081/ijas.2013.e7.

Pal, R. K., Choudhary, M. K., Sinha, R. K., Nirala, R. K., & Kumar, K. (2019). Effect of butyric acid and citric acid as growth promoters and its effect on growth performance and feed efficiency in broiler chicken. *Journal of AgriSearch, 6(Special),* 104–107. Link

Wickramasinghe, K., Atapattu, N., & Seresinhe, R. (2014). Effects of citric acid on growth performance and nutrient retention of broiler chicken fed diets having two levels of non-phytate phosphorus and rice bran. *Iranian Journal of Applied Animal Science*, 4, 809–815. Link