Original Research

Journal of Advanced Veterinary Research
(2025) Volume 15, Issue 5, 690-695

Utilization of soy sauce waste and citric acid to improve the quail performance and digestive tract profile

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ARTICLE INFO

Recieved: 15 September 2025

Accepted: 11 October 2025

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Keywords:

Quail, Soy sauce waste, Citric acid, Performance, Digestive tract.

ABSTRACT

The study aimed to examine the use of soy sauce waste and citric acid as additives on the morphology, microbiota of the digestive tract in quail after passing the peak egg production phase. As experimental animals used 200 female quail aged 28 weeks. The experimental design used a completely randomized design with 4 treatments and 5 replications, each replication consisting of 10 quails. The treatments are T0: Control treatment (Basal feed without soy sauce waste and citric acid), T1: Basal feed + Soy sauce waste, T2: Basal feed + Citric acid, and T3: Basal feed + Soy sauce waste and citric acid. Data were analyzed by analysis of variance and continued with Duncan's Multiple Range Test. Feed consumption was increased ($P<0.05$) in T2 compare to T1 and T3. Hen daily production was increased ($P<0.05$) in T2 and T3 than T0 and T1. Feed conversion ratio was decreased in T3 compared to T0 and T1. Weight and lenght of small intestine was increased ($P<0.05$) in T0, T1, and T2 compared to T3. Weight and lenght ratio of proventriculus was increased in T1 than T0, T2, and T3. pH of duodenum and jejunum was increased ($P<0.05$) in T0 and T1 than T2 and T3. Ileum pH was increased ($P<0.05$) in T2 and T3 than T0.. In conclusion: The addition of soy sauce waste or citric acid and a combination of both can improve performance and the profile of the digestive tract.

Introduction

Various environmental and management factors substantially influence quail performance, particularly in terms of growth and health. Proper feed management contributes to significant improvements in body weight gain, feed efficiency, and overall growth performance of quails. For instance, Turkish propolis supplementation improved feed efficiency and body weight gain, showcasing the potential benefits of natural feed additives over conventional antibiotics (Denli *et al.*, 2005). Feed management plays a vital role in maintaining reproductive health. Seeking alternative feed ingredients can optimize nutrient digestibility and utilization. Nutritional strategies can alleviate the impacts of environmental stressors, such as heat stress, which significantly reduces feed intake and productivity. Incorporating dietary supplements known for their osmoregulatory properties that can mitigate heat stress effects, improve feed conversion ratios, and boost quail resilience to harsh environmental conditions (Abd El-Ghany and Babazadeh, 2022). strategic feed management, using both conventional and alternative feed ingredients, can enhance the growth, reproductive performance, and economic viability of quail farming. Such practices contribute to sustainable poultry production systems by improving feed conversion efficiency, alleviating environmental stress impacts, and promoting overall bird health and productivity.

Soy sauce waste, a byproduct of soybean fermentation, are rich in nutrients and bioactive compounds that can enhance animal health. Research indicates that incorporating soy sauce waste into animal feed can modify gut microbiota composition, increasing the prevalence of beneficial bacteria and short-chain fatty acids, particularly butyrate, crucial for gut health (Xie *et al.*, 2021). Additionally, soy sauce has demonstrated antimicrobial properties against various pathogenic bacteria, potentially contributing to improved gut health and reduced disease incidence in animals (Adil and Magray, 2012). Citric acid, an organic acid, is extensively utilized as an additive in animal nutrition to enhance the performance and health of various species. In quail performance, citric acid has been acknowledged for its potential benefits, to those observed in other poultry and aquatic animals (Elbaz *et al.*, 2021; Melaku *et al.*, 2021). Citric acid can augment digestive efficiency by lowering the pH of the gastrointestinal tract, thereby creating a more conducive environment for nutrient digestion and absorption. This is accomplished through its ability to maintain gut homeostasis and modulate gut microbiota, potentially reducing pathogenic bacteria (Melaku *et al.*, 2021). Citric acid supports antioxidant defense mechanisms and enhances the immune system. Empirical studies have demonstrated improvements in antioxidant enzyme activities, such as glutathione peroxidase and superoxide dismutase, which can bolster overall health and disease resistance in animals (Melaku *et al.*, 2021; Zhang *et al.*, 2024). The supplementation of citric acid has improved growth performance by enhancing feed conversion ratios and nutrient utilization. This enhancement in feed efficiency and growth metrics can result in increased weight gain and improved overall productivity (Elbaz *et al.*, 2021; Melaku *et al.*, 2021). In regions where quail are subjected to heat stress, a condition known to impair performance by reducing feed intake and growth, citric acid may be a beneficial additive. It holds potential for mitigating the effects of heat stress by supporting gut health and enhancing overall resilience (Alagawany *et al.*, 2017).

The integration of soy sauce waste and citric acid in gastrointestinal health has been investigated to ascertain their potential advantages. A significant aspect of this research is the reduction of citrulline accumulation during soy sauce fermentation, a process facilitated by specific bacterial strains such as *Bacillus amyloliquefaciens*. This reduction is crucial as it decreases the formation of ethyl carbamate, a compound that poses potential health risks when present in elevated levels, thereby potentially enhancing gastrointestinal health (Zhang *et al.*, 2016). Furthermore, soy isoflavones, derived from soy sauce, have demonstrated benefits for gastrointestinal physiological functions. They promote intestinal secretion, mitigate inflammation, protect against morphological damage, and enhance epithelial barrier function. This suggests that soy byproducts, including those from soy sauce waste, can contribute to improved gut health (Al-Nakkash and Kubinski, 2020). This study aimed to investigate the effect of combining say sauce waste and citric acid on growth performance and digestive tract profile of quail.

Materials and methods

This research was conducted at the Poultry Production Laboratory, Faculty of Animal and Agricultural Sciences, Universitas Diponegoro, located in Tembalang, Semarang City, Central Java. The study involved 200 female quails (Coturnix coturnix japonica) aged 25 weeks, with an average body weight of 208.76±19.06 g, and was carried out over 10 weeks. The feed ingredients comprised yellow corn, soybean meal, fine bran, soy sauce waste, and citric acid. The nutrient content of the feed during the treatment period is presented in Table 1. A Completely Randomized Design (CRD) was employed, featuring four treatments and five replications, resulting in a total of 20 experimental units. Each experimental unit consisted of 10 quails in the laying period. The treatments were defined as follows: T0: Basal feed and drinking water without any treatment; T1: Basal feed supplemented with 15% soybean pulp and drinking water without any treatment; T2: Basal feed and drinking water supplemented with 0.5% citric acid; T3: Basal feed supplemented with 15% soybean pulp and drinking water supplemented with 0.5% citric acid.

Experimental diets

The experimental quails were kept in four-tiered wire cages for 10 weeks. Each unit consisted of five pens measuring 65 × 45 × 20 cm, with a capacity of 10 quails per pen. Each cage was equipped with feed and water containers. All the birds were fed the same basal diet during the first week. A gradual mixture of basal and experimental feed was provided in the second week. Only the experimental feed was provided for eight weeks in the third week. The feed was provided ad libitum. For the first 2 weeks, drinking water was administered without any treatment. Starting from the third week, citric acid was added to the drinking water at a concentration of 3% per liter for eight weeks. Feed was given twice a day, every morning and afternoon. At the same time, drinking water was provided ad libitum, with 3 liters per treatment given in the morning and 2 liters per treatment given in the afternoon. Data, including egg weight, egg production, feed, and water intake, were recorded daily throughout the study. Experimental parameters were observed at the end of the treatment period. Examination of digestive and reproductive organs was conducted by slaughtering and dissecting quails, with samples of two birds taken from each experimental unit.

Preparation of soy sauce waste and citric acid

Soy sauce waste were obtained from the Mirama Soy Sauce factory located in Jl. Gg. Gambiran No.80, Kranggan, Semarang Tengah District, Semarang City, Central Java. Soy sauce waste were processed by soaking them in acetic acid for 24 h at a ratio of 2 liters of water, 1 kg of soy sauce waste, and 6 ml of acetic acid. The soaked regs were rinsed with water. Soaking was to reduce the NaCl content in soy sauce waste. Subsequently, the waste were sun-dried until completely dry. The dried soy sauce waste were ground and stored in Ziplock plastic bags. Soy sauce waste were provided for a 14-day maintenance period. When administered, the soy sauce waste were homogenized with the basal feed by adding 15% soy sauce waste. The nutritional contents of the soy sauce waste are presented in Table 2. Citric acid was obtained from PT Multi Kimia Raya Nusantara at Jl. Sidodadi Timur No.20, Karangtempel, Semarang Timur District, Semarang City, Central Java. Citric acid was dissolved in water at a ratio of 5 g citric acid to 1 liter of drinking water. A citric acid solution was prepared by providing water to the quails. Data collection was performed by dissecting 35-week-old quails to observe and examine their reproductive organs. Data were collected at the end of the study period. Observed parameters included morphometry of the digestive tract, pH, and microbes in the digestive tract, as well as morphometry of the reproductive tract and ovaries.

Table 1. Nutritional content of feed for each treatment.

Treatment	WC[1] (%)	Ash[1] (%)	FC[1] (%)	PC[2] (%)	LC[1] (%)	Ca[2] (%)	P[2] (%)	EM[1] (Kkal/kg)
T0	10.69	10.36	6.48	19.32	7.37	3	0.7	3,381.68
T1	9.49	8.59	12.39	19.81	7.79	3.06	0.75	3,342.10
T2	10.69	10.36	6.48	19.32	7.37	3	0.7	3,381.68
T3	9.49	8.59	12.39	19.81	7.79	3.06	0.75	3,342.10

Source: 1) Results of proximate analysis. EM calculation based on the Bolton EM formula (Kcal/Kg) = 40.81 (0.87 (Crude protein + 2.25 Crude fat + BETN) + k).
WC: water content, FC: fiber content, PC: protein content, LC: lipid content, Ca: calcium, P: phosphor, EM: Energy Metabolites

Table 2. Nutritional content of soy sauce waste.

Nutrition	Nutritional content of soy sauce waste
Metabolic energy (ME) (Kkal/Kg)	3,857
Crude protein (%)	31.27
Crude fat (%)	19.9
Crude fiber (%)	29.07
Calcium (Ca) (%)	0.39
Phospor (P) (%)	0.33
Ash (%)	19

Data analysis

The data obtained were analyzed using Analysis of Variance (ANOVA) at a 5% significance level. If a significant effect was found ($P<0.05$), the analysis continued with the Duncan multiple range test to identify differences among treatments.

Results

Performance of quail

The growth performance of quail is shown in Table 3. The feed consumption was increased ($P < 0.05$) in T2 compared to T1 and T3 group. Hen daily production was increased ($P < 0.05$) in T2 and T3 compared to CON and T1 groups. Feed conversion ratio was decreased ($P < 0.05$) in T3 compared to the other groups.

The length of the digestive tract

The average data for digestive organ length after 8 weeks of treatment feeding are presented in Table 4. Based on statistical analysis, the treatments had a significant effect on the length of the small intestine (P < 0.05). The length of the small intestine in the control (T0), with the addition of soybean meal byproduct (T1), and citric acid (T2) showed no differences, but the small intestine length in the treatment combining the addition of soybean meal byproduct and citric acid in the drinking water was significantly shorter (P < 0.05). The treatments of adding soybean meal byproduct and citric acid in the drinking water, either alone or in combination, had no significant effect on other parts of the digestive tract (P < 0.05). The proventriculus, ventriculus (gizzard), cecum, and large intestine showed no differences.

Relative weight of digestive tract

The weight of the digestive organs of quails after the administration of soybean sauce residue in feed and citric acid in drinking water for 8 weeks is shown in Table 5. Statistical analysis indicated a significant effect (P < 0.05) on the small intestine. The relative weight of the small intestine in the control treatment (T0), addition of soybean sauce residue (T1), and citric acid (T2) showed no differences, but the combined treatment (T3) resulted in a significantly (P < 0.05) lower small intestine weight. The addition of soybean sauce residue in feed, citric acid in drinking water, and their combination (T3) had no significant effect on other parts of the digestive tract (ventriculus, proventriculus, cecum, and large intestine).

Weight-length ratio of digestive organs

The weight-length ratio of the digestive tract after treatment with the addition of soy sauce residue in the feed and citric acid in the drinking water, as well as their combination, is presented in Table 6. Based on statistical analysis, the addition of soy sauce residue to the feed and citric acid to the drinking water, as well as their combination, had a significant effect on the weight-length ratio of the proventriculus (P < 0.05). The highest weight-length ratio of the proventriculus was observed in the treatment with the addition of soy sauce residue in the feed (T1), while the control treatment (T0), citric acid addition (T2), and their combination (T3) were not significantly different.

pH of digestive organs.

The acidity (pH) of the digestive tract during the administration of treatments with added soy sauce waste, citric acid, and their combination over 8 weeks is presented in Table 7. Statistical analysis shows that the treatments had a significant effect (P < 0.05) on the acidity of the small intestine (duodenum, jejunum, and ileum). In the duodenum and jejunum, administration of citric acid in drinking water (T2) and the combination of soy sauce waste–citric acid (T3) lowered the pH values, as indicated by lower pH numbers compared to the control treatment (T0) and the addition of soy sauce waste (T1). Meanwhile, in the ileum, treatments T1, T2,

Table 3. Feed consumption, feed conversion ratio, and hen daily production of the quail

Variables	T0	T1	T2	T3	P value
Feed consumption (g/ekor/hari)	2734±114^{ab}	2691±113^{bc}	2838±063^{a}	2600±116^{c}	0001*
Hen daily production (%)	8512±447^{c}	8839±276^{b}	9511±210^{a}	9256±072^{a}	0000*
Feed conversion ratio (FCR)	288±021^{c}	263±011^{b}	257±005^{ab}	243±014^{a}	0000*

^{a,b}Values in the same row with different letters reflect significant different (P < 0.05)

Table 4. Average length (cm) of digestive organs of the quail.

Digestive organ	T0	T1	T2	T3	P value
Proventriculus	2.13±0.34	1.92±0.16	2.09±0.079	1.99±0.068	0.36
Ventriculus	2.68±0.22	2.62±0.35	2.71±0.36	2.62±0.33	0.96
Small intestine	52.23±4.01^{a}	53.45±3.58^{a}	53.40±3.15^{a}	47.12±3.16^{b}	0.034*
Secum	7.59±0.74	7.34±0.42	7.90±0.43	7.71±1.09	0.68
Colon	4.99±0.56	4.26±0.41	4.42±0.45	4.67±0.67	0.19
Pancreas	4.77±0.47	4.43±0.58	4.79±0.39	4.34±0.77	0.50
Heart	4.09±0.59	4.17±0.41	3.96±0.60	3.81±0.38	0.70
Bile	1.25±0.21	1.17±0.19	1.33±0.25	1.27±0.13	0.66

^{a,b}Values in the same row with different letters reflect significant different (P < 0.05)

Table 5. Average relative weight of digestive organs of the quail.

Digestive organ	T0	T1	T2	T3	P value
Proventriculus	0.488±0.048	0.517±0.065	0.459±0.033	0.436±0.031	0.68
Ventriculus	1.936±0.39	2.129±0.32	2.015±0.31	1.713±0.18	0.23
Small intestine	2.576±0.19 ^{a}	2.616±0.22 ^{a}	2.543±0.16 ^{a}	2.221±0.11^{b}	0.009*
Secum	0.606±0.047	0.536±0.058	0.623±0.059	0.581±0.063	0.13
Colon	0.285±0.12	0.224±0.14	0.227±0.045	0.216±0.043	0.70
Pancreas	2.326±0.45	2.288±0.19	2.444±0.43	2.112±0.29	0.54
Heart	0.197±0.039	0.226±0.078	0.237±0.059	0.258±0.089	0.61
Bile	0.180±0.043	0.090±0.015	0.176±0.025	0.146±0.026	0.07

^{a,b}Values in the same row with different letters reflect significant different (P < 0.05)

Table 6. Average weight-to-length ratio of the quail digestive organs.

Digestive organ	T0	T1	T2	T3	P value
Proventriculus	0.43±0.061[b]	0.50±0.025[a]	0.41±0.022[b]	0.40±0.037[b]	0.003*
Ventriculus	1.35±0.24	1.51±0.18	1.39±0.24	1.22±0.11	0.19
Small intestine	0.092±0.009	0.092±0.008	0.089±0.007	0.087±0.006	0.62
Secum	0.15±0.013	0.14±0.022	0.14±0.018	0.14±0.02	0.73
Colon	0.098±0.024	0.089±0.024	0.087±0.01	0.092±0.019	0.78

[a,b]Values in the same row with different letters reflect significant different ($P < 0.05$)

Table 7. Average pH of the digestive organs of the quail.

Parameter	T0	T1	T2	T3	P value
Doudenum	658±0.46 [a]	6.54±0.17 [a]	5.72±0.12 [b]	5.58±0.14 [b]	0,02 *
Jejunum	6.76±0.10 [a]	6.72±0.09 [a]	6.49±0.13 [b]	6.39±0.2 [b]	0,04 *
Ileum	7.41±0.35 [b]	7.43±0.48 [ab]	7.83±0.19 [a]	8.22±0.12 [a]	0,023 *

[a,b]Values in the same row with different letters reflect significant different ($P < 0.05$)

and T3 did not show any differences in pH values. The pH value of T1 was not different from T0, it increased the pH value, which was higher compared to T0, but the T1 treatment did not show any difference with T2, T3, and T0. Furthermore, T1 did not show any differences from the control treatment (T0). The pH value of T0 was lower than those of T2 and T3.

Discussion

Quail performance can be significantly enhanced by including soy sauce waste in their diet, primarily due to the high concentrations of amino acids, proteins, and other bioactive compounds in these waste. The fermentation process involved in soy sauce production generates various metabolites, such as antioxidants and flavor-enhancing peptides, which contribute to the nutritional value of the waste. The elevated levels of amino acids in soy sauce waste are particularly advantageous for quail, as these birds require amino acids for optimal growth and egg production (Wang *et al*., 2007). Furthermore, the presence of umami-active peptides, known for enhancing flavor and palatability in soy sauce, may also improve feed intake and overall avian health when incorporated into quail diets (Zhu *et al*., 2022). Additionally, the fermentation byproducts contain antioxidants, which may protect quails from oxidative stress and enhance their immune responses and vitality (Zhong *et al*., 2018). Furthermore, soy sauce waste may contain beneficial microbial components due to fermentation-derived bacteria and enzymes, which could facilitate digestion and nutrient absorption in quails, ultimately enhancing performance metrics such as growth rate and egg quality (Uchida *et al*., 2005). Citric acid (CA) is a prominent organic acid with a substantial influence on gut microbiota and overall intestinal health. It is extensively employed in animal nutrition due to its advantageous properties, particularly as a non-antibiotic alternative for enhancing gut health and performance. In the context of poultry nutrition, citric acid has been demonstrated to maintain gastrointestinal tract (GIT) homeostasis, improve digestion and absorption, and modulate gut microbiota. This modulation frequently reduces pathogenic bacteria, thereby fostering a more balanced and healthy microbial environment. The reduction in pathogenic bacteria aids in maintaining a stable GIT pH, which is essential for optimal intestinal function and health (Melaku *et al*., 2021).

Dietary fiber and certain supplements can significantly influence the gut dimensions of birds. For instance, research has demonstrated that high-fiber diets can increase gut size in quail, particularly in the colo-rectum and small intestine regions. This enlargement may be a response to increased food intake associated with high-fiber diets, as it necessitates greater digestion and absorption capacity (Savory and Gentle, 1976). In similar contexts, dietary supplementation with probiotics or specific oils, such as chia oil, has been found to enhance growth performance and various physiological parameters in quail. For example, probiotics can improve intestinal health by modifying the gut microbiota, which in turn can lead to better nutrient absorption and possibly increased gut size (Mahrose *et al*., 2019). Similarly, chia oil has been observed to improve growth and antioxidant status, which might indirectly affect gut health (Alagawany *et al*., 2020).

Citric acid, recognized for its preservative and digestive aid properties, may act synergistically with soy sauce waste, a potential source of nutrients and fiber, to facilitate such changes. Citric acid's pH-lowering effect can enhance protease activity, complementing soy waste' fiber-bound nutrients. The main functions of citric acids in animal nutrition include reducing gastric pH, enhancing protein hydrolysis, and improving nutrient digestibility (Suiryanrayna and Ramana, 2015). By lowering the pH in the gastrointestinal tract, organic acids promote the conversion of inactive pepsinogen to active pepsin, which aids in effective protein hydrolysis. Additionally, citric acids possess both bacteriostatic and bactericidal properties, contributing to the control of pathogenic bacteria in the gut (Rathnayake *et al*., 2021).

The mechanism by which the combination of soy sauce waste and citric acid enhances the weight of the digestive tract in quail can be attributed to the bioactive compounds and metabolic processes associated with these substances. Soy sauce dreg, a byproduct of soy sauce production, is enriched with amino acids, peptidase activities, and other nutrients due to its fermentation process. These nutrients can enhance digestive activity and nutrient absorption in the quail's gastrointestinal system. Citric acid, conversely, is a natural preservative and acidity regulator that can improve feed efficiency. It creates an optimal environment in the digestive tract by lowering pH, enhancing the availability and absorption of minerals. This process boosts digestive enzyme activity, leading to increased nutrient intake and absorption, thereby contributing to an increased weight of the digestive tract. Furthermore, introducing citric acid can promote beneficial microbial populations in the gut, aiding digestion and nutrient absorption. This symbiotic relationship within the digestive system might enhance the digestive tract's growth and function, thereby increasing its weight (Frerot and Chen, 2013; Fang *et al*., 2018).

Mechanical and chemical sensing capabilities within the intestine significantly contribute to its absorptive functions. Nutrient sensors, like taste receptors, are distributed throughout the intestinal epithelium. These sensors bind specific nutrients and activate signaling pathways that regulate nutrient processing, such as glucose homeostasis (Sigalet *et al*., 2004). The role of hormones in nutrient absorption is equally critical. For example, glucagon-Like Peptide 2 (GLP-2) has been identified as a pivotal regulatory hormone in nutrient uptake. Research on infants with intestinal dysfunction has demonstrated that postprandial GLP-2 levels correlate with residual small intestinal length and nutrient absorption capacity, indicating its potential utility in managing short bowel conditions (Sigalet *et al*., 2004). Overall, the length of the small intestine is a significant determinant of nutrient absorption, with adaptations occurring at both molecular and functional levels to accommodate changes due to surgery or disease. Advanced insights into intestinal zonation and endocrine regulation enhance the understanding of how nutrient absorption can be optimized despite variations in intestinal length (Ber *et al*., 2021; Gupta *et al*., 2024)

The improvement in the weight-to-length ratio of the digestive tract in quails through the integration of soy sauce waste and citric acid likely involves the influence of fermentation residues and acidifiers on gut microbiota and nutrient absorption. Soy sauce waste, a byproduct of soy sauce production, contain valuable nutrients and bioactive compounds, including fermented proteins and amino acids, which may positively contribute to the digestive health and growth performance of quails by promoting beneficial gut bacteria and enhancing nutrient utilization (Sassi *et al*., 2021). Citric acid may further enhance this process by acting as an acidifier, lowering the pH of the digestive tract, thereby improving enzyme activity and mineral absorption, and reducing pathogenic bacterial load, which could collectively contribute to improved growth metrics in quails.

Statistical analysis indicates that the treatments exerted a significant effect ($P < 0.05$) on the acidity of the small intestine, specifically the duodenum, jejunum, and ileum. The findings suggest that while the incorporation of soy sauce waste into the feed did not enhance the acidity of the digestive tract, the addition of citric acid to the drinking water, either alone or in combination with soy sauce waste, effectively improved the acidity levels in the duodenum and ileum. These results align with previous research. For instance, a study by Xue *et al*. (2023) demonstrated that supplementing feed with up to 2% citric acid increased the acidity of the digestive tract in geese. The observed enhancement of pH in the digestive tract of quails through the combination of soy sauce waste and citric acid is likely attributable to the fermentation and chemical constituents resulting from the fermentation process involved in soy sauce production. The autolysis of mycelia, such as Aspergillus oryzae used in soy sauce production, contributes to the presence of organic acids, including citric acid, which initially increases in concentration during fermentation and plays a role in modifying pH levels (Xu *et al*., 2016).

Soy sauce is abundant in amino acids and beneficial organic acids, such as glutamic acid, which impart its distinctive umami flavor. The presence of these organic compounds and their derivatives may affect the pH of the digestive environment due to their inherent chemical properties. As these amino acids and acids undergo digestion, they can contribute to a more balanced pH, thereby buffering against extreme acidity in the digestive tract (Uchida *et al*., 2005; Cai *et al*., 2024). Citric acid, in particular, is a weak organic acid frequently employed to acidify or balance pH levels in various applications. When introduced concurrently with soy sauce waste, it may interact with the existing microbiota and fermentation residues in the digestive tract, fostering a pH environment that could be more conducive to nutrient absorption and digestive efficiency.

Conclusion

Although specific investigations into the combined effects of soy sauce waste and citric acid on quails are necessary to elucidate precise mechanisms, insights from related nutritional studies suggest that these components may enhance the length of the digestive tract by promoting gut health, optimizing nutrient absorption, or altering gut microbiota. The synergistic effects of organic acids and amino acids may increase the potential for beneficial modifications of pH levels in the digestive tract, potentially fostering a more neutral or less acidic environment. Given that both soy sauce and citric acid are involved in fermentation, their combined application might induce changes in microbial composition, potentially facilitating digestion and nutrient absorption specific to the dietary physiology of quails.

Acknowledgments

The authors acknowledge the financial support and sponsoring for this research by Professor Research Scheme, Universitas Diponegoro (grant number: 222-284/UN7.D2/PP/IV/2025). Thank you to Poultry Production Laboratory, Department of Animal Science, Faculty of Animal and Agricultural Sciences, Universitas Diponegoro, Indonesia.

Conflict of interest

The authors have no conflict of interest to declare.

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