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Growth Performance, Gut Development, and Microbial Balance of Ducks Supplemented with Encapsulated *Centella asiatica* Extract

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ABSTRACT

This study evaluated the effects of encapsulated *Centella asiatica* extract on growth performance, intestinal development, and intestinal microbial in ducks. A total of 240 two-day-old male Tegal ducks with an initial body weight of 42.5 ± 2.3 g were divided into four treatments with six replications. The treatments were T0, basal diet without encapsulated *C. asiatica* extract (ECAE); T1, basal diet + 0.2% ECAE; T2, basal diet + 0.4% ECAE; and T3, basal diet + 0.6% ECAE. The measured variables included intestinal segment weight, length, pH, percentage of live weight, lactic acid bacteria (LAB) and coliform populations, villus height, crypt depth, feed consumption, body weight, feed conversion ratio (FCR), and carcass percentage. Data were analyzed using analysis of variance, followed by Duncan's test at the 5% significance level. The results showed that ECAE significantly increased jejunal length and decreased ileal and cecal pH at 21 days of age (p<0.05). It also increased intestinal length, weight, and the percentage of intestinal segments of live weight at 35 days of age (p<0.05). The LAB population increased significantly in T2 and T3 (p<0.05). Villus height and crypt depth also increased significantly (p<0.05). Body weight gain and final body weight increased significantly in T1, while the FCR decreased (p<0.05). In conclusion, ECAE at all levels (0.2%, 0.4%, and 0.6%) positively affected growth performance, intestinal development, and intestinal microbial in ducks, with the most pronounced improvement in intestinal and microbial parameters observed at 0.6% level and in growth performance parameters (body weight and FCR) at 0.2% level.

Keywords: Centella asiatica; duck meat; encapsulated; lactic acid bacteria; carcass

INTRODUCTION

Ducks have strong potential as an economical source of animal protein to meet public demand for meat. In Indonesia, local duck farming also plays a strategic role in rural development by providing employment opportunities and supporting the local economy. This potential encourages duck farmers to keep improving feed efficiency while maximizing productivity. The use of antibiotic growth promoters (AGPs) is known to enhance poultry growth, but uncontrolled use in livestock farming can leave harmful residues in animal products. Because of these negative effects, AGP use has been banned in both developed and developing countries (Anggriawan *et al*., 2024; Nduku *et al*., 2025). This ban has encouraged research on safe alternative materials (Buonaiuto *et al*., 2025).

Natural feed additives, such as phytobiotics, can be used as alternatives to AGPs while still supporting the production of safe animal products (El-Sabrout *et al*., 2026). The use of phytobiotics from local herbs has been widely explored as a sustainable option in the post-antibiotic era (Sugiharto, 2021). *Centella asiatica*, locally known as pegagan, is recognized as an herbal medicinal plant containing bioactive compounds with antimicrobial, antioxidant, and immunomodulatory properties that may improve growth performance and health (Nemauluma *et al*., 2024; Urban *et al*., 2025; Hein *et al*., 2025). *Centella asiatica* contains bioactive components, such as flavonoids, triterpenoids, centellosides, and antioxidants, that can modulate metabolic pathways, immune responses, and gut microbiota composition (Khursheed *et al*., 2024; Zeng *et al*., 2025).

Supplementation with natural feed additives in ducks has been shown to improve performance and intestinal profiles (Iriyanti *et al*., 2018), as well as increase egg production and quality (Ismoyowati *et al*., 2022). Previous studies on *C. asiatica* showed positive effects on blood profiles and gut bacteria in laying hens (Ajibade *et al*., 2023), while 4% *C. asiatica* leaf meal in broiler diets improved feed utilization, carcass quality, and growth performance (Ajayi *et al*., 2020). Falasifah *et al*. (2018) also stated that supplementation with 5%

cinnamon bark flour and 10% pegagan leaf powder increased the growth rate of quail. Furthermore, Rusli *et al*. (2025) have stated that *C. asiatica* demonstrates significant promise for utilization in poultry farming, primarily due to its capacity as an antibacterial agent.

Direct supplementation with herbal extracts often faces challenges, such as limited bioavailability and susceptibility to degradation in the upper gastrointestinal tract (Duque-Soto *et al*., 2024). Encapsulation is expected to protect bioactive compounds from harsh digestive conditions, improve stability and bioavailability in the gut, support controlled release, and enhance their effectiveness on gut health and growth performance (Grgić *et al*., 2020). Previous studies have shown that encapsulation is an innovation that can improve the bioavailability and stability of herbal additives in host animals. For example, encapsulated cinnamaldehyde improved meat quality and gut health in broilers (Yang *et al*., 2021); encapsulated cardamom waste extract supported digestive tract health in broilers (Alfonia *et al*., 2026); 0.3% encapsulated combination of dahlia extract and *Bacillus subtilis* improved broiler performance, while the best result based on IOFC was found at the 0.2% level (Anjani *et al*., 2025); and encapsulated essential oil up to 1,000 mg/kg basal diet had a positive effect on growth performance and intestinal health in ducks (Bao *et al*., 2023). Although the beneficial effects of the encapsulation nature extract have been documented in broilers, laying hens, and quail, information on its application in encapsulated form in ducks remains scarce, despite ducks being an economically important poultry species with distinct 80-digestive physiology. This gap underscores the novelty of evaluating encapsulated *C. asiatica* extract specifically in duck production. Therefore, this study aimed to investigate the use of encapsulated *C. asiatica* extract on growth performance, intestinal development, and intestinal microbial in Indonesian local ducks.

MATERIALS AND METHODS

Ethical Approval

The research procedures in this study were approved by the Animal Research Ethics Committee, Faculty of Animal Husbandry and Agriculture, Universitas Diponegoro (Approval No. 61-08/A-16/KEP-FPP).

Preparation of *Centella asiatica* Extract

Centella asiatica used in this study was obtained from plantations around Semarang City, Central Java, Indonesia. Fresh, high-quality leaves that were not wilted or rotten were selected, cleaned of dirt, and washed thoroughly with running water. The leaves were dried at 50 °C to reduce moisture content and prevent fungal growth. The dried leaves were ground using a blender at medium speed and sieved through a 0.3 mm mesh to reduce particle size and increase the surface area for extraction. Extraction was performed by soaking the powder in 96% ethanol at a 1:10 (w/v) ratio in a closed, light-protected container for 48 hours with occasional stirring. The extract was separated from the residue using filter paper. The residue was then added to the rotary evaporator to remove the leftover ethanol (Alfonia *et al*., 2026). *C. asiatica* contains 1.46% lipid, 13.81% protein, 15.45% ash, 12.08% moisture (Kumar & Kumar, 2022). It also contains other compounds, including antioxidant activity of 15,360%, total anthocyanin content of 14,369 mg TA/100 g, total flavonoid content of 104,358 mg QE/100 g, and total phenolic content of 24,215 mg GAE/100 g (Kauser-Ul-Alam *et al*., 2025).

The Encapsulation Process

Encapsulation began with the preparation of maltodextrin as a coating agent according to Agusetyaningsih *et al*. (2022). First, maltodextrin was weighed and dissolved in distilled water at a 1:10 ratio. Second, *C. asiatica* extract was weighed and dissolved in distilled water at a 1:5 ratio. Both solutions were mixed and stirred until homogeneous using a magnetic stirrer. The encapsulated material was dried using a freeze dryer. The freeze-drying method works by freezing the material at an extremely low temperature of around -40 °C, followed by pressure reduction to remove water through sublimation (Uwineza & Zhang, 2026).

Experimental Animal and Diet

The experiment was conducted at the Nutrition and Feed Science Laboratory, Faculty of Animal and Agricultural Sciences, Diponegoro University, Semarang. A total of 240 male ducks with an initial

Table 1. Composition and nutritional content of the experimental diet for ducks

Ingredient	Composition (%)
Ground yellow corn	45.0
Rice bran	22.0
Dried leftover rice	7.0
Soybean meal	18.0
Fish meal	7.0
Premix	1.0
Total	100.00
Nutritional content	
Metabolizable energy (kcal/kg) *	2915.06
Crude protein	19.04
Crude fiber	4.03
Crude fat	5.64
Calcium (Ca)	0.55
Total Phosphorus (P)	0.82
Lysine	0.85
Methionine	0.36
Methionine+cystine	0.68

Note: *Metabolizable energy was calculated based on the Bolton (1967) formula as follows: 40.81 {0.87 [crude protein + 2.25 crude fat + nitrogen free extract] + 2.5}. The proximate analysis was conducted at the Laboratory of Nutrition and Feed Science, Faculty of Animal and Agricultural Sciences, Diponegoro University, Semarang.

body weight of 42.5 ± 2.3 g were used in this study. The ducks were obtained from a small-scale hatchery in Tegal, Central Java, Indonesia. Rearing lasted 35 days in elevated slatted bamboo-floor pens. The adaptation period was week 1 (days 1 to 7), and the treatment period was weeks 2 to 5 (days 8 to 35). The encapsulated treatments were given in the morning and mixed into the feed. Drinking water was provided ad libitum. The experimental diets were formulated based on the guidelines of the National Research Council (1994), as shown in Table 1.

Variables Measured

Gut weight and length. Digestive organs were collected at 21 and 35 days of age through a standard duck slaughtering procedure, which involved cutting the carotid artery, jugular vein, trachea, and esophagus (Hoque *et al*., 2025). The digestive organs were then removed and separated into their segments, namely the duodenum, jejunum, ileum, and caecum. Digestive organ weights were measured using an analytical balance. Organ lengths were measured with a measuring tape. The values were calculated as relative length and weight (Assis *et al*., 2021). Organ percentage was calculated as follows:
Organ percentage = organ weight / live weight x 100%

Gut microbiota. Lactic acid bacteria (LAB) and *coliform* populations were determined using the total plate count (TPC) method. Digesta samples were incubated at 37 ^{o}C for 24 hours for coliform and 48 hours for LAB. Colonies were counted according to bacterial type (Ashayerizadeh *et al*., 2024).

Villus height and crypt depth. Villus height and crypt depth were measured from ± 3 cm samples of small intestinal sections, including the duodenum, jejunum, and ileum. Samples were fixed in 10% formalin, processed, stained with hematoxylin-eosin (HE), and examined under a microscope (Umami *et al*., 2023).

Growth performance. Feed consumption, body weight gain, and feed conversion ratio were recorded throughout the rearing period. At 35 days, the final body weight was measured. Ducks were then slaughtered, and carcass weight was recorded. Carcass percentage was calculated following Umami *et al*. (2023):
Carcass percentage = carcass weight / live weight x 100%

Experimental Design and Statistical Analysis

The present study used a completely randomized design with 4 treatments and 6 replications, with 10 birds in each replicate. The dietary treatments were T0, basal diet without encapsulated *C. asiatica* extract (ECAE); T1, basal diet + 0.2% ECAE; T2, basal diet + 0.4% ECAE; and T3, basal diet + 0.6% ECAE. The data were statistically analyzed using analysis of variance at a 5% significance level. When the treatment showed a significant effect, Duncan's multiple range test was used to determine differences among treatments (Steel & Torrie, 1995).

RESULTS

Gut Development

The gut development parameters are shown in Table 2. At 21 days of age, most organ weight, length, and percentage of live weight values showed no significant differences ($p>0.05$). Only the jejunum length was significantly affected ($p<0.05$), with T0 and T3 showing longer values than T2, while T1 was intermediate. pH values of the gut (duodenum, jejunum, ileum, and caecum) were not significantly different by the treatment ($p>0.05$), with no differential differences between treatments. Results at 35 days of age, more parameters were significantly influenced by the treatments ($p<0.05$), particularly duodenum weight, length, and percentage, jejunum length, caecum weight, and partly caecum percentage.

Microbial Population

Encapsulated *C. asiatica* had no significant effect on *coliform* population ($p>0.05$), although a decreasing trend was observed at higher doses. However, it had a highly significant effect ($p<0.01$) on the lactic acid bacteria population, with T2 and T3 markedly higher than T0 and T1.

Intestinal Villi and Crypt Depth

Supplementation with encapsulated *C. asiatica* significantly affected intestinal structure, particularly in treatments T1, T2, and T3 compared to T0 (Table 4). Villus height and the V/C ratio in the duodenum showed significant differences, with T0 showing higher values than T1, T2, and T3 ($p<0.05$). However, crypt depth in the duodenum was not significantly affected by the treatments ($p>0.05$). In the jejunum, treatment T3 had a significant effect on both villus height and crypt depth, while the V/C ratio in T2 was not significantly different from that in T3. For villus height and the V/C ratio in the ileum, T2 and T3 showed significant differences compared to T1 and T0 ($p<0.01$). Ileal crypt depth in T1 and T0 was also significantly different from that in T2 and T3.

Duck Growth Performance

Based on Table 5, supplementation with encapsulated *C. asiatica* extract had a significant effect ($p<0.001$) on body weight gain, final body weight, and feed conversion ratio (FCR). However, it had no significant effect on feed intake, carcass weight, or carcass percentage ($p>0.05$).

The best results for body weight gain and final body weight were observed in treatment T1, along with the lowest FCR value. Treatment T3 also performed well and was not significantly different from T1 in several parameters, while T0 (control) showed lower weight gain and higher FCR.

Table 2. Gut development of ducks supplemented with encapsulated *Centella asiatica* extract

Variables	Treatments				SEM	p value
	T0	T1	T2	T3		
21 days old						
W duodenum (%)	3.87	3.15	4.13	3.98	0.179	0.224
W jejunum (%)	4.62	4.90	4.92	5.00	0.401	0.990
W ileum (%)	7.38	6.10	5.57	7.32	0.340	0.148
W caecum (%)	1.82	1.58	1.88	1.53	0.090	0.461
L duodenum (cm/kg)	34.60	30.73	33.65	32.20	0.720	0.254
L jejunum (cm/kg)	49.42^{a}	46.77^{ab}	39.58^{b}	48.65^{a}	1.419	0.044
L ileum (cm/kg)	65.93	59.85	65.33	62.42	1.134	0.205
P duodenum (%)	0.66	0.61	0.82	0.76	0.036	0.152
P jejunum (%)	0.81	0.95	0.97	0.92	0.076	0.890
P ileum (%)	1.25	1.18	1.11	1.38	0.053	0.314
P caecum (%)	0.31	0.31	0.38	0.30	0.020	0.467
pH duodenum	6.37	6.38	6.28	6.29	0.033	0.607
pH jejunum	6.35	6.41	6.23	6.40	0.044	0.494
pH ileum	6.37^{b}	6.85^{a}	6.62^{ab}	6.50^{b}	0.060	0.019
pH caecum	6.34^{b}	6.71^{a}	6.43^{ab}	6.41^{ab}	0.058	0.103
35 days old						
W duodenum (%)	5.45^{a}	4.08^{b}	4.27^{b}	3.87^{b}	0.192	0.008
W jejunum (%)	7.55	6.95	7.77	7.78	0.316	0.791
W ileum (%)	10.55	10.65	12.00	10.58	0.452	0.639
W caecum (%)	2.43^{a}	1.92^{b}	2.32^{ab}	1.93^{b}	0.083	0.043
L duodenum (cm/kg)	36.32^{a}	34.17^{a}	27.32^{b}	24.88^{b}	1.417	0.004
L jejunum (cm/kg)	53.35^{ab}	46.88^{b}	63.22^{a}	62.07^{a}	2.345	0.031
L ileum (cm/kg)	61.95	61.02	56.30	59.78	1.872	0.753
P duodenum (%)	0.67^{a}	0.52^{b}	0.53^{b}	0.48^{b}	0.023	0.014
P jejunum (%)	0.93	0.89	0.95	0.96	0.034	0.912
P ileum (%)	1.31	1.37	1.47	1.30	0.054	0.658
P caecum (%)	0.30^{a}	0.25^{ab}	0.29^{ab}	0.24^{b}	0.010	0.086
pH duodenum	6.30	6.19	6.01	6.29	0.064	0.365
pH jejunum	7.16	7.14	7.01	7.00	0.030	0.139
pH ileum	7.09	6.97	7.06	7.01	0.049	0.873
pH caecum	7.04	7.08	6.98	6.81	0.050	0.235

Note: ^{ab}Different superscripts within the same row indicate significant differences (p<0.05). T0: basal diet without encapsulated *Centella asiatica* extract (ECAE); T1: basal diet + 0.2% ECAE; T2: basal diet + 0.4% ECAE; T3: basal diet + 0.6% ECAE; W: weight; L: length; P: percentage.

Table 3. Lactic acid bacteria and *coliform* populations in the gut of ducks supplemented with encapsulated *Centella asiatica* extract

Variables	Treatments				SEM	p value
	T0	T1	T2	T3		
LAB (log CFU/g)	11.94^{b}	11.98^{b}	13.59^{a}	13.21^{a}	0.184	0.000
Coliform (log CFU/g)	5.09	5.38	6.03	4.79	0.583	0.708

Note: ^{ab}Different superscripts within the same row indicate significant differences (p<0.05). T0: basal diet without encapsulated *Centella asiatica* extract (ECAE); T1: basal diet + 0.2% ECAE; T2: basal diet + 0.4% ECAE; T3: basal diet + 0.6% ECAE; LAB: lactic acid bacte

Table 4. Villus height and crypt depth of ducks supplemented with encapsulated *Centella asiatica* extract

Variables	Treatments				SEM	p value
	T0	T1	T2	T3		
Villus height, duodenum (μm)	771.64^{a}	607.07^{b}	642.89^{b}	605.41^{b}	20.217	0.002
Crypt depth, duodenum (μm)	118.96	148.51	160.39	120.08	7.307	0.097
V/C ratio, duodenum	6.49^{a}	4.09^{b}	4.01^{b}	5.04^{b}	0.315	0.003
Villus height, jejunum (μm)	488.15^{d}	699.79^{b}	652.71^{c}	856.57^{a}	30.658	0.000
Crypt depth, jejunum (μm)	122.89^{a}	124.88^{a}	79.10^{b}	105.76^{a}	5.363	0.001
V/C ratio, jejunum	3.97^{b}	5.60^{b}	8.25^{a}	8.10^{a}	0.489	0.000
Villus height, ileum (μm)	409.93^{b}	296.60^{c}	651.63^{a}	648.10^{a}	35.611	0.005
Crypt depth, ileum (μm)	135.16^{a}	92.96^{b}	129.92^{a}	88.88^{b}	6.530	0.000
V/C ratio, ileum	3.03^{c}	3.19^{c}	5.02^{b}	7.29^{a}	0.437	0.000

Note: ^{abc}Different superscripts within the same row indicate significant differences (p<0.05). T0: basal diet without encapsulated *Centella asiatica* extract (ECAE); T1: basal diet + 0.2% ECAE; T2: basal diet + 0.4% ECAE; T3: basal diet + 0.6% ECAE

Table 5. Growth performance of ducks supplemented with encapsulated *Centella asiatica* extract

Variables	Treatments				SEM	p value
	T0	T1	T2	T3		
Feed intake (g)	2625.07	2625.46	2625.98	2625.90	0.174	0.222
Body weight gain (g)	770.83^{c}	806.92^{a}	778.83^{ab}	786.46^{b}	3.538	0.000
Feed conversion ratio	3.41^{a}	3.25^{c}	3.37^{ab}	3.34^{b}	0.015	0.000
Final body weight (g)	829.83^{b}	863.92^{a}	838.83^{b}	842.46^{b}	3.392	0.000
Carcass weight (g)	526.12	533.01	534.18	534.11	3.385	0.828
Carcass percentage (%)	64.45	68.17	65.71	65.80	1.062	0.625

Note: ^{abc}Different superscripts within the same row indicate significant differences (p<0.05). T0: basal diet without encapsulated *Centella asiatica* extract (ECAE); T1: basal diet + 0.2% ECAE; T2: basal diet + 0.4% ECAE; T3: basal diet + 0.6% ECAE

DISCUSSION

The addition of ECAE to the diet affected digestive organ development (Table 2), with more significant effects observed at 35 days of age than at 21 days of age. At 21 days of age, the results showed no significant differences in almost all variables, including weight, length, and organ percentage, except for jejunum length. In contrast, at 35 days of age, several parameters differed significantly among treatments. This condition may occur because, at 21 days of age, the digestive system of ducks is still immature and gut microbiota are still in a rapid growth phase. As a result, the response to ECAE treatments as phytobiotics may remain limited. The effect on growth and intestinal morphology becomes more evident in the finisher phase (22 to 42 days) than in the starter phase (1 to 21 days), which may explain why the response to feed additives was not significant during the earlier stage (Abdelli *et al*., 2021). This finding aligns with Obianwuna *et al*. (2024), who stated that livestock responses to treatments depend on the duration and dosage of administration.

Supplementation with encapsulated *C. asiatica* extract influenced gut development in 35-day-old ducks. Encapsulated *C. asiatica* extract (ECAE) supports the growth and regeneration of intestinal epithelial cells through the modulation of gut microbiota. This modulation increases the production of short-chain fatty acids (SCFAs) (Ge *et al*., 2023). The mechanism begins with the antibacterial properties of triterpenoid compounds in *C. asiatica*. According to Ramli *et al*. (2020), triterpenoid compounds can inhibit microbial growth by damaging microbial cell membranes and cell walls. These compounds selectively inhibit the growth of pathogens such as *coliform*, without disrupting beneficial bacteria. As a result, beneficial bacteria, such as lactic acid bacteria, can proliferate more effectively. The dominant lactic acid bacteria then ferment undigested feed and ECAE components, producing SCFAs, including acetate, butyrate, and propionate. Although SCFA levels were not measured in this study, butyrate is well known as an energy source for mitochondria in intestinal epithelial cells, promotes cell proliferation, and improves gut barrier function (Liu *et al*., 2021). In addition, Zhang *et al*. (2019) stated that stem cells in the intestinal crypt proliferate and differentiate into functional epithelial cells to replace old or damaged cells, resulting in higher and wider villus structures.

An interesting finding at 35 days was that duodenum weight, length, and percentage, as well as caecum weight, showed significant effects in the control treatment (T0). This condition suggests that smaller digestive organs can still function optimally in nutrient absorption, as supported by the body weight gain data in Table 5, where ECAE treatment produced a significant increase. Furthermore, digestive organ length and weight in this study are presented in relative terms, where the calculations are influenced by live weight. Consequently, higher body weight may lead to lower relative values for organ weight and length. This explains why the control treatment had lower body weight, while the relative weight and length of the digestive organs were higher. Wang *et al*. (2016) reported that broilers with lower body weight gain in the control group had higher relative intestinal weight than broilers with higher body weight gain in the treatment group. Differences in intestinal length values that were significant in absolute terms may become non-significant when presented as relative values or as a percentage of the organ relative to total live weight (Gorenz *et al*., 2024).

The effect of encapsulated *C. asiatica* extract on gastrointestinal organ development may result from the main mechanisms of its bioactive compounds, such as flavonoids, centellosides, antioxidants, and triterpenoids (Sabaragamuwa *et al*., 2018). These compounds can modulate metabolic pathways and gut microbiota, thereby supporting more efficient organ development. The encapsulation used in this study enhanced the stability and bioavailability of these compounds in the digestive tract. This finding aligns with Natsir *et al*. (2019), who showed that feed additives administered in encapsulated form produced better results than those given in non-encapsulated form. It is also supported by Ardiansah *et al*. (2020), who found that supplementation in encapsulated form resulted in better relative carcass performance, along with higher and wider villi, compared to the powdered form.

Supplementation with ECAE in feed significantly increased the population of gut lactic acid bacteria (LAB) in ducks. Table 3 shows that administration at the 0.4% (T2) and 0.6% (T3) levels resulted in higher LAB populations than the other treatments. The addition of ECAE can support LAB growth. Several references have reported antibacterial and antioxidant activities from the bioactive compounds in *C. asiatica*, which can modulate the composition of the gut microbiota (Rusli *et al*., 2025; Khursheed *et al*., 2024; Zeng *et al*., 2025). These compounds work by selectively inhibiting the growth of pathogenic bacteria while promoting the proliferation of beneficial microbes, thereby restoring microbiota homeostasis and preventing dysbiosis. Supplementation with prebiotics, probiotics, or other phytogenic feed additives can modify microbial balance and encourage eubiosis (Salahi *et al*., 2025). This observation is supported by previous research on the use of probiotics and organic acids, which were shown to suppress *Campylobacter* proliferation in broiler chickens (Mortada *et al*., 2020).

The statistical results for T0 and T1 showed no significant difference, whereas T2 and T3 showed significant effects. This outcome may be related to the treatment levels. At the low dose of 0.2%, the microbiota was not significantly modulated because the concentration of bioactive compounds in *C. asiatica* may not have reached the required threshold. Meanwhile, at the 0.4% and 0.6% levels, the bioactive compound content was sufficiently high to produce selective antimicrobial effects by suppressing pathogens while stimulating the growth of lactic acid bacteria. Triterpenoids and flavonoids can disrupt the cell membranes of pathogenic bacteria, thereby inhibiting their growth, while lactic acid bacteria continue to thrive. Bioactive compounds, such as flavonoids, alkaloids, phenols, saponins, and tannins in plants, can act as antibacterial agents against pathogens (Abdelli *et al*., 2021). This condition supports the continuous production of short-chain fatty acids (Fusco *et al*., 2023), creating an acidic environment that is favorable for LAB.

The addition of ECAE significantly altered the morphology of the small intestine. Supplementation at 0.6% resulted in higher villi in the jejunum and ileum compared to the 0.2% and 0.4% levels. The villus-to-crypt (V/C) ratio also increased significantly in the jejunum and ileum at the 0.6% supplementation level. These results indicate an increase in the absorption surface area, along with faster epithelial regeneration (Nguyen *et al*., 2021). These improvements were likely supported by the antimicrobial, antioxidant, and immunomodulatory mechanisms of *C. asiatica*, which can reduce oxidative stress and inflammation in the intestinal mucosa (Nemauluma *et al*., 2024; Urban *et al*., 2025). Flavonoids in *C. asiatica* can stimulate mucus secretion, leading to better villus protection and enhanced growth of beneficial bacteria (Prihambodo *et al*., 2020). Rusli *et al*. (2025) reported that flavonoids in *C. asiatica* leaves have proven antibacterial and antioxidant properties, which significantly improve small intestine health and function, particularly in the nutrient absorption process. The beneficial effects of this improvement include increased villus height and crypt depth. The elongation of villi and deepening of intestinal crypts accelerate epithelial cell turnover and enhance the intestinal absorption capacity.

Encapsulated *C. asiatica* is highly effective in improving villus morphology, even at low doses. The application of encapsulation to plant bioactive substances, such as essential oils or extracts, protects these substances from external factors and degradation, thereby supporting the long-term stability of the active ingredients (Zabot *et al*., 2022). This view is consistent with Ma'rifah *et al*. (2025), who reported that the addition of encapsulated starfruit extract to broiler chicken rations improved intestinal morphology, as shown by increased villus height and deeper small intestinal crypts.

Improvements in gut development, microbial balance, and intestinal morphology led to a significant increase in growth performance. Table 5 shows the best results at the 0.2% ECAE administration level, where final body weight and body weight gain increased while FCR decreased. These results indicate that the lowest ECAE level improved feed nutrient utilization through more efficient digestive organs, healthier microbiota, and a larger intestinal absorption surface area. This is supported by Ajayi *et al*. (2020), who reported an increase in daily and final body weight, along with a decrease in FCR, after the addition of *C. asiatica* leaf extract. Similarly, Ajibade *et al*. (2023) reported improvements in health and productivity in chickens supplemented with *C. asiatica*.

The growth performance parameters show that T2, overall, was able to improve growth and feed efficiency without affecting feed intake or carcass yield. This can be seen from the increase in body weight gain and final body weight, while the feed conversion ratio (FCR) decreased, indicating greater efficiency. These findings suggest that the addition of encapsulated *C. asiatica* extract (ECAE) supports better nutrient utilization while maintaining good growth performance in ducks. The findings are consistent with previous research showing that phytobiotic supplementation can increase final body weight and feed efficiency in Alabio meat ducks as an alternative to antibiotics (Biyatmoko *et al*., 2021). Overall, these results suggest that *C. asiatica* can be used as a natural growth promoter-based additive. Ogunka-Nnoka *et al*. (2020) stated that *C. asiatica* contains various bioactive compounds, such as flavonoids, phenolics, polyphenols, alkaloids, and phytic acid. These components can serve as natural feed additives for poultry.

The addition of encapsulated *C. asiatica* extract showed progressive improvements according to the treatment levels. Thus, supplementation with *C. asiatica* extract promotes more productive development from the duodenum to the jejunum and ileum, resulting in an intestine with better nutrient absorption capacity than the control treatment. This condition ultimately leads to better growth performance and feed efficiency.

CONCLUSION

Supplementation with encapsulated *Centella asiatica* extract at all levels (0.2%, 0.4%, and 0.6%) positively affected digestive organ development, intestinal morphology, gut microbial balance, and growth performance, with 0.6% encapsulated *C. asiatica* extract as the best supplementation level.

CONFLICT OF INTEREST

The authors declare no conflict of interest related to personal relationships, financial interests, or other organizations or individuals connected to the material used and discussed in this manuscript.

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DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

The authors state that generative AI tools were used solely to improve readability and language clarity under human oversight. The authors retain full responsibility for the scientific content, data analysis, and interpretation.

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