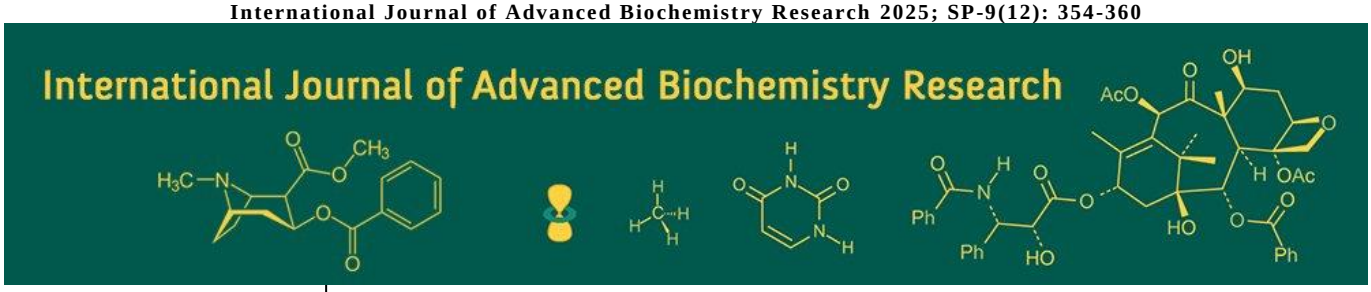

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Effects of lanthanum citrate supplementation on gut health, immunity and economic performance in broilers

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Abstract
The present study was conducted to evaluate the effects of dietary lanthanum citrate supplementation on gut health, immune response, intestinal histomorphology and economic performance in broiler chickens. A total of 270 straight-run Vencobb 400 broiler chicks were randomly allocated into three treatment groups: a control group fed a basal corn-soybean diet and two experimental groups supplemented with lanthanum citrate at 70 mg/kg and 140 mg/kg, respectively. Birds were reared for 35 days under uniform management conditions. Parameters assessed included total viable count (TVC), total coliform count (TCC), Newcastle disease haemagglutination inhibition (HI) titre, intestinal villus height, crypt depth, villus: crypt ratio and production economics.
Results indicated a significant reduction ($p \leq 0.01$) in both TVC and TCC in the group receiving 70 mg/kg lanthanum citrate compared to the control and high-dose groups, suggesting improved microbial balance and suppression of harmful gut bacteria. Intestinal morphometry revealed numerically higher villus height, lower crypt depth and a superior villus: crypt ratio in the 70 mg/kg group, indicating enhanced absorptive capacity and intestinal integrity. Although HI titres did not differ significantly across treatments, birds receiving 70 mg/kg lanthanum citrate exhibited a numerically higher immune response against Newcastle disease at the fifth week.
Economic analysis showed that the inclusion of lanthanum citrate at 70 mg/kg resulted in the highest net profit per bird and per kilogram of live weight, attributable to improved feed conversion and body weight gain. The 140 mg/kg inclusion level did not yield additional benefits and exhibited reduced economic efficiency.
Overall, the findings demonstrate that lanthanum citrate at 70 mg/kg optimizes gut health, enhances immunity, improves intestinal morphology and maximizes economic returns in broilers. Thus, lanthanum citrate may be considered a promising, non-antibiotic feed additive for sustainable broiler production.

Keywords: Lanthanum citrate, gut health, economic performance

Introduction
The poultry sector in India has expanded substantially over recent years, supported by notable increases in both chicken meat and egg production. Between 2021 and 2022, chicken meat output recorded an average annual growth rate of 5.98%, while egg production rose by 10.19%. India presently ranks as the world's second-largest producer of eggs following China with an annual output of 138.38 billion eggs and it stands fifth globally in chicken meat production at 4.99 million tonnes (FAOSTAT, 2022) [11]. Poultry meat has emerged as a dominant and economically accessible source of high-quality animal protein, owing to its superior production efficiency, relatively low cost, absence of religious prohibitions and broad consumer acceptability. Additionally, poultry farming contributes significantly to nutritional security and poverty alleviation, particularly in regions lacking dependable access to high-value animal-source foods (Kleyn and Ciacciariello, 2021) [20].
The rapid advancement of the industry is largely attributed to progress in poultry nutrition and feed technology. The adoption of balanced, nutrient-dense diets has enhanced growth trajectories and production performance (Angelakis *et al.*, 2013) [4]. Moreover, there is increasing interest in the application of economical, non-nutritive feed additives aimed at optimizing nutrient utilization and promoting growth (Huyghebaert *et al.*, 2011) [16].

Historically, antibiotic growth promoters (AGPs) were widely used to improve growth rates and feed efficiency in poultry. However, their prolonged usage raised considerable concern due to the emergence of antimicrobial resistance and the potential presence of antibiotic residues in meat and eggs, posing risks to public health (Ronquillo and Hernandez, 2017) [30]. Consequently, stringent regulations have been introduced worldwide to restrict or ban AGPs in animal feeds; the European Union prohibited their use in 2006 and the United States phased out AGPs between 2017 and 2022 (Castanon, 2007) [7]. This global shift has intensified the exploration of alternative growth-promoting strategies, including probiotics, prebiotics, enzymes, essential oils, herbal agents, immunomodulators, minerals and rare earth elements (REEs), (Wenk, 2003) [38].

Rare earth elements have garnered increasing interest in diverse fields including advanced technology, healthcare and animal production owing to their unique physicochemical properties. In animal agriculture, REEs have been investigated for several decades, with evidence suggesting that they can stimulate gastrointestinal development, enhance nutrient digestibility, improve feed efficiency and augment immune defense mechanisms (Redling, 2006) [29]. Nonetheless, the magnitude of these responses is influenced by both the form and concentration of the administered REE compounds.

The lanthanide family comprises 17 elements: scandium (Sc), yttrium (Y), lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb) and lutetium (Lu). Despite their designations as "rare," REEs are relatively abundant in the Earth's crust (Wald, 1989) [37]. They do not occur as pure metals but as constituents of complex mineral matrices. Their average crustal concentration (~0.015%) exceeds that of several industrial metals such as tin, cobalt, silver and mercury and approximates the abundance of copper, lead and zinc. Lanthanum is typically extracted from monazite and bastnasite ores, with major deposits located in China, Australia, India, Brazil, South Africa and other regions (Clark, 1984 [9]; Lottermoser, 1992 [24]; Chi *et al.*, 2000; Jun *et al.*, 2010) [19]. In China, REEs have been employed in agricultural production with notable success and favourable responses have been reported under European production conditions as well (Shen, 1991 [33]; Yang *et al.*, 2005 [41]; Rambeck *et al.*, 1999) [27].

REEs are available in inorganic and organic forms. Both categories have shown growth-promoting effects, though their efficacy differs by species. Inorganic salts such as REE chlorides have been found to improve growth performance in pigs, yet poultry studies have yielded inconsistent results (Schuller *et al.*, 2002) [31]. Organic REEs (OREs), which consist of trivalent REE ions chelated with organic ligands such as REE-enriched yeast, REE chitosan complexes, or REE-citrate compounds exhibit superior solubility and biological availability. They have been reported to enhance digestive enzyme activity, nutrient absorption and overall health parameters (He *et al.*, 2010).

Beyond their digestive benefits, REEs possess antimicrobial, antioxidant and immunomodulatory characteristics that may help animals better adapt to environmental stressors and infectious challenges (Evans, 1990; He *et al.*, 2000) [10]. Recent interest has focused particularly on organic REE-citrate complexes due to their high bioavailability and promising effects on growth and immune function in pigs and poultry (Zohravi, 2007 [44]; Forster *et al.*, 2008 [12]; Eleraky and Rambeck, 2011; Tran *et al.*, 2021) [36]. Organic REEs are generally considered more effective than their inorganic counterparts because organic ligands facilitate enhanced absorption and metabolic utilization (Case and Carlson, 2002). Studies further indicate that REEs may improve protein utilization through endocrine modulation involving growth hormone and triiodothyronine (T3) (Yang *et al.*, 1992 [41]; He *et al.*, 2010). Although REEs have shown positive effects on growth, excessively high inclusion rates may exert negative impacts (Kraatz *et al.*, 2004) [22].

Given the limited available research on Lanthanum citrate supplementation in broilers, there is a compelling need to evaluate its potential as a novel feed additive capable of improving digestive efficiency, immunity and overall performance. As the poultry industry continues to pursue cost-effective, non-antibiotic solutions to optimize productivity, understanding the influence of Lanthanum citrate on gut health and economic returns becomes particularly relevant.

Accordingly, the present study was undertaken with the following objectives:-

- To evaluate the effect of dietary Lanthanum citrate supplementation on gut health and immune response in broilers.
- To assess the influence of Lanthanum citrate supplementation on the economics of broiler production.

Materials and Methods

Antibiotic growth promoters in poultry have declined due to global antimicrobial resistance concerns, prompting exploration of alternative additives. Rare Earth Elements (REEs) have emerged for their potential to enhance gut health and nutrient utilization. Therefore, this study evaluated the effects of lanthanum citrate on broiler growth performance, gut microbiota, intestinal morphology and immune response.

Experimental Design

The trial was conducted on 270 straight-run day-old Vencobb 400 broilers were procured and randomly allocated into three treatment groups, each consisting of 90 birds and further divided into six replicates of 15 birds per group. Diets differed only in their level of lanthanum citrate supplementation:

- **Group A:** Basal corn-soybean meal diet (control).
- **Group B:** Basal diet + lanthanum citrate @ 70 mg/kg feed.
- **Group C:** Basal diet + lanthanum citrate @ 140 mg/kg feed.

Housing and Management

All broilers were reared on deep litter in open-sided housing under uniform environmental and managerial conditions throughout the 35-day experimental period. Diets were formulated as per Vencobb 400 nutrient guidelines and offered in three phases: pre-starter (1-7 d), starter (8-21 d) and finisher (22-35 d). Daily pre-weighed feed was provided replicate-wise, with refusals recorded to determine feed

intake. Clean drinking water was supplied *ad libitum* throughout the trial.

Upon arrival, chicks were offered anti-stress supplements via drinking water, vaccination protocols included:

- **Newcastle Disease (B1 strain):** Day 7
- **Infectious Bursal Disease:** Day 14
- **Newcastle Disease booster (B1 strain):** Day 21

Determination of total viable and coliform counts

At the conclusion of the study, six birds per treatment (three males and three females) were randomly selected and humanely sacrificed. Approximately 2 cm of ileal tissue was aseptically collected from each bird and transferred into sterile 50 ml containers containing phosphate-buffered saline (PBS, pH 6.8) and stored at 4 °C until analysis.

For microbial quantification, 0.1 ml aliquots from three serial dilutions of the intestinal contents were inoculated onto: Plate Count Agar for total viable count (TVC) and MacConkey Agar for total coliform count (TCC).

Plates were incubated at 37 °C for 24 hours, after which colonies were enumerated using a digital colony counter. Only plates containing 30-300 colonies were used to determine final microbial counts (Andrew, 1992) [3]. The microbial load was expressed as colony-forming units per gram (CFU/g) using the formula:

$$\text{CFU/gm} = \frac{\text{No. of colonies} \times \text{Total dilution factor}}{\text{Volume of culture plate}}$$

Haemagglutination Inhibition (HI) Antibody Titre for Newcastle Disease

At the end of 3rd and 5th weeks, 2 ml of blood was drawn from the brachial vein of six birds per treatment group. Blood samples were collected in clot-activator tubes, allowed to clot at a slanted position and centrifuged to obtain serum.

For HI testing, 25 µl of PBS was dispensed into 12 wells of a V-bottom microtiter plate. Two-fold serial dilutions of serum were prepared, followed by the addition of equal volumes of 4 HA units of Newcastle Disease virus. After 30 minutes of incubation at room temperature, 25 µl of a 1% chicken red blood cell suspension was added to each well. Plates were left undisturbed for 40 minutes and agglutination patterns were evaluated by plate tilting. The highest dilution showing complete inhibition of haemagglutination was recorded as the HI antibody titre.

Intestinal morphometric analysis (Villus Height and Crypt Depth)

At day 35, six birds per group (three males and three females) were weighed and euthanized by cervical dislocation. A 2-cm segment from the mid-duodenum was excised and fixed in 10% neutral buffered formalin for 48 hours. Tissue processing involved dehydration through graded ethanol, clearing in xylene and embedding in paraffin wax.

Sections of 5 µm thickness were stained with haematoxylin and eosin following standard histological procedures (Bancroft and Gamble, 2008) [5]. Microscopy was performed using a Radical RXLr-4 light microscope at 40× magnification. Digital images were analysed using ProCam.exe software.

Measurements included

- **Villus height:** Distance from tip of villus to villus-crypt junction
- **Crypt depth:** Distance from crypt base to crypt-villus opening

Economic Evaluation

The economic evaluation of broiler production was conducted at the end of the fifth week by incorporating all relevant cost components, including the expenses associated with feed, chicks, medications, production inputs and miscellaneous overheads. Upon completion of the trial, birds were marketed on a live-weight basis and the net profit was calculated both on a per-bird basis and per kilogram of live weight, using the prevailing market price for live broilers.

Results and Discussion

Total Viable Count (TVC) and Total Coliform Count (TCC)

The total viable count (TVC) and total coliform count (TCC) expressed as Log^{10} CFU/g of intestinal contents for birds in the different treatment groups at the end of the fifth week are presented in Table 1.

Table 1: ANOVA table for microbiological count Log^{10} (CFU/gm) of birds from different treatment groups

Groups	Treatments	Total viable count	Total coliform count
A	Control-Corn-soybean	9.44^{a}±0.08	8.67^{a}±0.13
B	Control + Lanthanum Citrate 70 mg/kg	8.73^{b}±0.09	8.15^{b}±0.03
C	Control + Lanthanum Citrate 140 mg/kg	9.38^{a}±0.14	8.72^{a}±0.07
SEM		0.10	0.08
N		6	6
P-value		0.001	0.001

Note: The means with common superscripts within a column do not differ significantly, ($p \leq 0.01$).

Total Viable Count (TVC)

The mean TVC values (Log^{10} CFU/g) for groups A, B and C were 9.44, 8.73 and 9.38, respectively. A reduction in TVC was observed in birds receiving lanthanum citrate-supplemented diets (groups B and C) compared with the control group. This suggests that lanthanum citrate exerted a suppressive effect on the intestinal microbial load.

Statistical analysis indicated that the differences in TVC among treatment groups were highly significant ($p \leq 0.01$). Birds in group B (lanthanum citrate @ 70 mg/kg) exhibited a significantly lower TVC than both group C (lanthanum citrate @ 140 mg/kg) and the control group. However, the TVC values in group C did not differ significantly from the control group. These results indicate that the inclusion of lanthanum citrate at 70 mg/kg was more effective in reducing intestinal microbial load than the higher dose of 140 mg/kg.

Total Coliform Count (TCC)

The mean TCC values (Log^{10} CFU/g) for groups A, B and C

were 8.67, 8.15 and 8.72, respectively. Birds in group B, receiving lanthanum citrate at 70 mg/kg of diet, demonstrated the lowest coliform count, followed by birds in group C and the control group.

Statistical evaluation revealed a highly significant difference among treatment groups ($p \leq 0.01$). Birds in group B had significantly lower TCC compared to both group C and the control group, indicating enhanced suppression of coliform bacteria at the 70 mg/kg supplementation level.

The present findings are consistent with earlier reports. Song and Park (2007) [34] demonstrated significant reductions in TVC in birds supplemented with 100 ppm REE. Peng *et al.* (2004) [26] documented antimicrobial properties of La^{3+}, likely attributable to alterations in the bacterial outer membrane structure leading to cellular damage. Wenhua *et al.* (2003) further noted that La^{3+} at low concentrations (0.5-30 µg/mL) markedly inhibited the uptake of external DNA by *E. coli*, thereby reducing transformation efficiency. Similar to the current observations, Agbede *et al.* (2011) [2] reported a significant decline in intestinal microbial load in birds receiving lanthanum oxide containing approximately 85.3% lanthanum. Rare earth elements have also been suggested to suppress harmful microbial populations while supporting beneficial gut microflora, which may enhance nutrient digestibility and ultimately improve bird productivity (Tariq *et al.*, 2020) [35].

In contrast, some studies have reported negligible effects of REE supplementation on gut microflora. Knebel (2004) [21] and Kraatz *et al.* (2004) [22] found no significant changes in intestinal microbial populations of poultry and pigs supplemented with REEs. Similarly, Schuller *et al.* (2002) [31] observed no statistically significant differences in TVC in birds supplemented with REE salts at dietary concentrations ranging from 75 to 300 mg/kg.

Intestinal villi length, crypt depth and villi length: Crypt depth ratio: The mean values for intestinal villi length, crypt depth and their respective ratios for the different treatment groups at the end of the fifth week are presented in Table 2.

Table 2: ANOVA for intestinal villi length, crypt depth (µm) and villi: Crypt ratio across treatment groups

Groups	Treatments	Villi length	Crypt depth	Ratio of Villi length / crypt depth
A	Control-Corn-soybean	1099.15±72.72	189.73±5.59	5.83±0.45
B	Control + Lanthanum Citrate 70 mg/kg	1335.23±126.39	181.19±11.77	7.39±0.58
C	Control + Lanthanum Citrate 140 mg/kg	1223.44±118.36	205.18±10.25	6.06±0.73
SEM		63.29	5.72	0.36
N		6	6	6
P VALUE		0.33	0.23	0.17

Villi Length

The average villi length for groups A, B and C was 1099.15, 1335.23 and 1223.44 µm, respectively. Numerical improvements in villus height were recorded in both lanthanum citrate-supplemented groups compared with the control, with the greatest villi height observed in birds receiving 70 mg/kg lanthanum citrate (group B). Statistical evaluation indicated that the differences among groups were non-significant ($p>0.05$), however, the clear numerical increase suggests a positive morphological response to lanthanum citrate supplementation.

Crypt Depth

The mean crypt depths of birds in groups A, B and C were 189.73, 181.19 and 205.18 µm, respectively. Birds receiving lanthanum citrate at 140 mg/kg (group C) exhibited the deepest crypts, whereas birds in group B recorded the shallowest crypts. Statistical analysis revealed that these variations were not significant ($p>0.05$). Despite the lack of statistical significance, the reduction in crypt depth in group B may indicate reduced epithelial cell turnover and improved intestinal health.

Villi length: Crypt depth Ratio

The villi length-to-crypt depth ratio, an important indicator of absorptive efficiency, was 5.83, 7.39 and 6.06 for groups A, B and C, respectively. Both lanthanum-supplemented groups showed numerically greater ratios than the control, with the highest ratio observed in group B (70 mg/kg). Statistical analysis indicated that these differences were non-significant ($p>0.05$). Nonetheless, the improved ratio in supplemented groups reflects a more favourable intestinal architecture conducive to enhanced nutrient absorption.

The histomorphology of the intestinal mucosa is a crucial indicator of gut health and nutrient assimilation efficiency in poultry. Limited literature is available regarding the impact of lanthanum citrate on intestinal morphology in chickens.

An increase in villi height is associated with a larger absorptive surface area, thereby improving nutrient uptake (Caspary, 1992) [6]. Conversely, shortened villi and increased crypt depth are generally indicative of impaired digestion and reduced absorptive capacity (Xu *et al.*, 2003) [39]. Previous studies (Langhout *et al.*, 1999 [23]; Yasar and Forbes, 1999; Shamoto and Yamauchi, 2000) [32] have similarly emphasized that greater villus height reflects improved intestinal functionality. According to Zhang *et al.* (2009) [43], taller villi enhance digestive enzyme secretion and facilitate more efficient nutrient transport to luminal capillaries, thereby supporting superior growth performance.

The present findings reveal that supplementation with lanthanum citrate at 70 mg/kg resulted in the greatest villi height and the most favourable villi: Crypt ratio, suggesting enhanced absorptive capacity and improved gut integrity. These morphological changes corresponded with improved growth performance parameters such as increased body weight gain and improved feed conversion ratio observed in the treated groups.

The histomorphological alterations observed in this study indicate that dietary inclusion of lanthanum citrate at 70 mg/kg may enhance intestinal structure through increased villus height and improved villi: Crypt ratio, thereby potentially improving nutrient absorption and overall broiler performance. These results provide novel insights into the potential application of lanthanum citrate as a functional feed additive in broiler nutrition.

HI antibody titre for Newcastle disease

The mean haemagglutination inhibition (HI) antibody titres (expressed at 8 HAU) for Newcastle disease at the third and fifth weeks of age are presented in Table 3**.** At the end of the third week, the average HI titres for groups A, B and C were identical, with all groups recording a mean value of 5.00. At the end of the fifth week, the average HI titres for groups A, B and C were 3.00, 5.00 and 3.00, respectively.

Table 3: ANOVA for HI antibody titre (@ 8 HAU) for Newcastle disease at the third and fifth week

Groups	Treatments	Week 3	Week 5
A	Control-Corn-soybean	5.00±1.00	3.00±0.45
B	Control + Lanthanum Citrate 70 mg/kg	5.00±1.00	5.00±1.00
C	Control + Lanthanum Citrate 140 mg/kg	5.00±1.00	3.00±0.45
SEM		0.54	0.44
N		6	6
P-Value		1.00	0.09

These data indicate that all groups exhibited comparable humoral immune responses at the third week post-vaccination. However, by the fifth week, birds supplemented with lanthanum citrate at 70 mg/kg (Group B) demonstrated a numerically higher HI antibody titre compared with both the control group and the group receiving 140 mg/kg lanthanum citrate (Group C), suggesting a possible immunomodulatory effect at the lower supplementation level.

Statistical analysis of HI antibody titres at both the third and fifth weeks revealed that the differences among treatment groups were not significant (p>0.05). Although not statistically significant, the numerically elevated titre in group B at week five may reflect an enhanced secondary immune response associated with lanthanum citrate supplementation at 70 mg/kg.

The available literature describing the immunological mechanisms of rare earth elements (REEs) is limited. Redling (2006) [29] suggested that REEs may modulate immune responses based on observations from various feeding trials. Also proposed that the anti-inflammatory and immune-stimulating properties of REEs may contribute to improved growth performance in animals.

More recently, Cheng *et al.* (2022) [8] demonstrated that dietary supplementation of Rare Earth Citrate Complexes (RECC) at optimal levels of 175-200 mg/kg improved both immune function and growth performance in broilers. These findings align with the numerical improvement in HI titres observed in the present study, suggesting that lanthanum citrate may exert beneficial effects on humoral immunity when included at appropriate dietary concentrations.

Economics of Production

The economic analysis of broiler production for the different treatment groups is summarized in Table 4**.** Among the input components considered, feed cost represented the primary variable expense due to differences in lanthanum citrate supplementation levels. The overall cost of production per bird included the expenses associated with feed, day-old chicks, medication, vaccination, electricity and miscellaneous overhead charges. The price of lanthanum citrate was calculated at ₹3.20 per gram for estimating feed cost in the respective treatment groups.

At the end of the fifth week, the net cost of production per bird for groups A, B and C was ₹189.22, ₹191.35 and ₹193.16, respectively. The control group (A) registered the lowest cost of production, followed sequentially by groups B and C. The selling price was standardized at ₹104 per kg live weight. Based on this rate, the net profit per bird for groups A, B and C was ₹18.78, ₹33.29 and ₹9.64, respectively. When expressed per kilogram of live weight, the net profit values were ₹9.34, ₹15.41 and ₹4.95 for groups A, B and C respectively.

It was evident from the economic analysis that group B (lanthanum citrate @ 70 mg/kg) achieved the highest profitability, both on a per-bird and per-kilogram basis. This enhanced profitability is attributable to the improved feed conversion ratio observed in this group, resulting in a lower feed cost per unit of body weight gain. Conversely, the lowest profitability was recorded in group C, despite a higher supplementation rate of lanthanum citrate, suggesting that increasing the dose beyond 70 mg/kg did not yield additional economic benefits.

Table 4: Economics of broiler production at the end of the fifth week

Parameters	Group A (Control group-Corn-soybean)	Group B (Control + Lanthanum citrate 70 mg/kg)	Group C (Control + Lanthanum citrate 140 mg/kg)
Chick cost (₹)	30.00	30.00	30.00
Feed intake (gm)			
1. Pre-starter	162.47	162.76	163.01
2. Starter	1058.96	1156.03	1090.33
3. Finisher	1915.84	1848.75	1938.81
Total feed intake (gm)	3137.26	3167.53	3192.14
Feed price per kg (₹)			
1. Pre-starter	45.73	45.95	46.17
2. Starter	46.28	46.50	46.72
3. Finisher	45.82	46.04	46.26
Feed cost per bird (₹)			
1. Pre-starter	7.43	7.48	7.53
2. Starter	49.01	53.76	50.94
3. Finisher	87.78	85.12	89.69
Total feed cost per bird (₹)	144.22	146.35	148.16
Miscellaneous cost per bird (₹)	15.00	15.00	15.00
Net cost of production per bird (₹)	189.22	191.35	193.16
Body weight at the end of the trial (gm)	2007.54	2163.05	1951.54
Return on sale @ ₹ 104 per kg	208.00	224.64	202.80
Net profit per bird (₹)	18.78	33.29	9.64
Net profit per bird per kg (₹)	9.34	15.41	4.95

Conclusion

The present study evaluated the effects of dietary supplementation of lanthanum citrate on gut microbiology, intestinal morphology, immune response and economic performance in broiler chickens.

Microbial Profile

The total viable count (TVC) and total coliform count (TCC) of intestinal contents at the fifth week showed mean values of 9.44, 8.73 and 9.38 Log10 CFU/g for TVC and 8.67, 8.15 and 8.72 Log10 CFU/g for TCC in groups A, B and C, respectively. Birds receiving lanthanum citrate particularly at 70 mg/kg (group B) exhibited markedly reduced microbial loads compared with the control group. Statistical analysis confirmed that both TVC and TCC differed significantly among treatment groups ($p \leq 0.01$), with group B showing significantly lower bacterial counts than both group C and the control. Differences between group C and the control were non-significant. These findings demonstrate that lanthanum citrate at 70 mg/kg effectively suppresses pathogenic intestinal microorganisms.

Intestinal Morphology

The mean villus height values were 1099.15, 1335.23 and 1223.44 µm, while the crypt depths were 189.73, 181.19 and 205.18 µm for groups A, B and C, respectively. Corresponding villi length: crypt depth ratios were 5.83, 7.39 and 6.06. Although statistical differences were non-significant ($p > 0.05$), birds supplemented with lanthanum citrate, especially at 70 mg/kg, exhibited numerically greater villus height and higher villi length: Crypt depth ratios coupled with shallower crypts. These morphological characteristics indicate an increased absorptive surface area and improved intestinal integrity. Thus, lanthanum citrate at 70 mg/kg appears to enhance nutrient absorption by promoting favourable histomorphological modifications in the small intestine.

Immune Response

HI antibody titres for Newcastle disease at the third week were identical (5.00) across all groups. By the fifth week, titres were 3.00, 5.00 and 3.00 for groups A, B and C, respectively. Despite the lack of statistically significant differences ($p > 0.05$), birds in group B exhibited a numerically higher immune response. These observations suggest a potential immunomodulatory effect of lanthanum citrate at 70 mg/kg, although further investigation with larger sample sizes may be warranted.

Economic Evaluation

The cost of production per bird was ₹189.22, ₹191.35 and ₹193.16 for groups A, B and C, respectively. Net profit per bird was highest in group B (₹33.29), followed by the control group (₹18.78) and group C (₹9.64). When expressed per kilogram of live weight, profits were ₹9.34, ₹15.41 and ₹4.95 for groups A, B and C, respectively. The enhanced profitability of group B can be attributed primarily to improved feed conversion efficiency and superior growth performance.

Overall Conclusion

The results of the current investigation demonstrate that dietary supplementation of lanthanum citrate at 70 mg/kg exerts beneficial effects on broiler chickens by:

- Reducing pathogenic microbial load in the intestine.
- Improving intestinal morphology and absorptive capacity.
- Supporting numerically enhanced humoral immune responses.
- Providing higher economic returns compared with both control birds and those receiving 140 mg/kg supplementation.

Therefore, lanthanum citrate at 70 mg/kg may be recommended as an effective functional feed additive to improve gut health, performance and profitability in broiler production systems.

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