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Comparative Effects of Feed Additives on Broiler Health and Farm Economics under a Controlled Study in Punjab

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ABSTRACT

Background: Broiler farming plays a vital role in supporting food security and rural livelihoods in India. However, with rising concerns over antibiotic resistance, there is a growing need to explore safer and more sustainable alternatives to antibiotic growth promoters (AGPs). This study examined how selected nutraceutical feed additives influence broiler growth, health and profitability under practical farming conditions in Punjab.

Methods: A controlled 42-day trial was conducted with 500 broiler chicks divided into five groups: control (no additive), herbal (1%), nano-zinc (1%), probiotics (0.5%) and enzyme blend (0.3%). Growth performance, serum health markers and economic indicators were recorded. While the biological trial was carried out on 500 birds, the economic evaluation was extrapolated on a standard commercial scale of 1,000 birds to ensure comparability and practical relevance. Data were analyzed to assess differences in productivity and financial returns across treatments.

Result: Birds fed with nano-zinc showed the highest body weight gain (2225 g), the better feed conversion ratio (1.67) and good economic profit (`165,100 per 1000 birds). The group fed with nano-zinc also recorded the best benefit-cost ratio (2.62) and lowest break-even cost, indicating significant economic viability. Enzyme- and probiotic-fed groups also performed well, though slightly behind nano-zinc. Improved serum protein levels and lowered liver enzyme values in this group suggested better physiological health and nutrient utilization. In contrast, the control group recorded lowest growth rate and poor returns.

Key words: Broiler performance, Economic efficiency, Feed additives, Nano-zinc, Serum biochemistry.

INTRODUCTION

Poultry farming, particularly broiler production, has emerged as one of the fastest-growing segments in the global livestock industry. In India, the sector plays a crucial role mere in ensuring food security through the supply of affordable animal protein but also in generating employment and supporting the rural economy. The state of Punjab, with its strong agricultural foundation and established poultry infrastructure, has witnessed a steady rise in broiler farming as a source of income diversification among farmers. Despite the high genetic potential of commercial broilers, their performance often falls short of optimal due to various production constraints, including suboptimal nutrition, disease burden and inefficient feed utilization (Singh and Goel, 2024).

Feed alone accounts for nearly 65-70% of the total cost of broiler production, making feed efficiency a critical determinant of profitability. Traditionally, antibiotic growth promoters (AGPs) have been used to improve performance, but growing concerns over antibiotic resistance and regulatory bans have shifted the focus towards natural and sustainable alternatives. In this context, nutraceutical feed additives such as probiotics, phytogenic compounds, enzymes and trace minerals especially, nano-form have gained considerable attention. These additives not only promote growth and feed efficiency but also enhance gut health, immunity and overall physiological performance of birds (Kumar and Singh, 2019). Probiotics, for instance,

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are known to improve intestinal microbial balance, suppress pathogens and stimulate nutrient absorption. Herbal feed additives derived from medicinal plants contain bioactive compounds that exhibit antimicrobial, antioxidant and anti-inflammatory properties. Similarly, exogenous enzymes aid in breaking down complex feed ingredients, thereby improving nutrient digestibility (Dinani *et al.,* 2022). Among mineral supplements, nano-zinc has shown promising results due to its superior bioavailability and role in enzymatic and immune functions. However, there is limited research evaluating the comparative effectiveness of these additives under field-like conditions, especially in integrated economic and physiological terms (Alagawany *et al.,* 2018; Geetha *et al.,* 2020).

The present study was undertaken to bridge this gap by assessing the biological, biochemical and economic performance of broiler chickens fed diets supplemented with different nutraceuticals under the agro-climatic conditions of Punjab. By integrating laboratory-based physiological assessments with farm-level economic evaluation, this research offers a comprehensive understanding of how advanced dietary strategies influence productivity and profitability. The findings aim to provide scientifically validated, field-relevant insights that can assist farmers, feed manufacturers and policymakers in making informed decisions to enhance sustainable broiler production in India (Dukare *et al.,* 2021).

MATERIALS AND METHODS

Study location

The present study was conducted in Ludhiana district of Punjab, a major hub for broiler poultry production in northern India. The region benefits from favourable climatic conditions, proximity to veterinary institutions and robust input and output markets. These characteristics make Ludhiana an ideal location for conducting integrated performance and economic evaluation studies on commercial broiler farming. The experimental work was carried out at Lovely Professional University, Phagwara, Punjab, India, during a three-year period from 2022 to 2025.

Experimental design and animal management

A completely randomized design (CRD) was employed to evaluate the effects of selected feed additives on the performance, blood biochemistry and economic profitability of broiler chickens. A total of 500 day-old Cobb 430 broiler chicks were procured from a certified hatchery and randomly allocated to five dietary treatments with 100 birds per treatment. Each treatment group was subdivided into three replicates consisting of approximately 33-34 birds each.

Birds were reared on deep litter system under standard management practices throughout the experimental period, comprising a starter phase (0-21 days) and a finisher phase (22-42 days). Feed and water were provided *ad libitum* and a uniform lighting schedule (23L:1D) was maintained. Routine vaccination and health care protocols were followed throughout the trial.

Dietary treatments

Experimental diets were formulated as per the Bureau of Indian Standards (BIS, 2013) nutritional specifications for broilers (Table 1). The five treatment groups were designed as follows:

T1 (Control): Basal diet without additives supplementation.
T2: Basal diet + 1% herbal additive.
T3: Basal diet + 1% nano-zinc supplement.
T4: Basal diet + 0.5% multi-strain probiotic.
T5: Basal diet + 0.3% enzyme complex.

All feed additives were sourced from reputed manufacturers and thoroughly mixed into the feed to ensure uniform distribution.

Data collection

Growth performance

Birds were weighed individually at the beginning of the trial and then every week end until day 42. Data collected included:

Initial and final body weight (g).
Total feed intake per bird (g).
Average daily gain (g/day).
Feed conversion ratio (FCR).
Dressing percentage (%).
Abdominal fat percentage (%).
Mortality rate (%).

FCR was computed as the ratio of total feed consumed to body weight gained. Dressing percentage and abdominal fat were measured by slaughtering five randomly selected birds from each replicate at the end of the trial.

Serum biochemical analysis

On day 42, blood samples were collected from 10 randomly selected birds per treatment *via* wing vein puncture. Samples were centrifuged at 3,000 rpm for 15 minutes to separate serum, which was analyzed using commercial diagnostic kits (Erba Diagnostics Mannheim GmbH, Germany) following the manufacturer's instructions. The serum biochemical parameters studied included:

Total protein, albumin and globulin (g/dL).
Total cholesterol (mg/dL).
AST and ALT enzyme levels (U/L).

Economic evaluation

Economic returns was assessed per 1000 birds for practical comparability. Key economic indicators calculated included:

Feed cost per bird (`), Total cost of production (`), Live body weight output (kg), Gross income (`), Net return (`), Benefit-cost ratio (BCR), Break-even price (`/kg).

Birds were assumed to be sold at a market rate of `120 per kg live weight, based on prevailing regional rates.

Formulae used

To derive the performance and economic indicators, the following formulae were applied:

$$\text{Feed conversion ratio (FCR)} = \frac{\text{Total feed intake (g)}}{\text{Total weight gain (g)}}$$

$$\text{Average daily gain (ADG)} = \frac{\text{Final weight (g) - Initial weight (g)}}{\text{42 days}}$$

$$\text{Dressing percentage} = \left(\frac{\text{Dressed weight}}{\text{Live weight}}\right) \times 100$$

Net return (`): Gross income - Total cost of production

$$\text{Benefit-cost ratio (BCR)} = \frac{\text{Gross income}}{\text{Total cost of production}}$$

$$\text{Break-even price (`/kg)} = \frac{\text{Total cost}}{\text{Total live weight (kg)}}$$

Statistical analysis

Data were subjected to one-way analysis of variance (ANOVA) using SPSS version 21.0. Where significant differences were observed ($p<0.05$), treatment means were compared using least significant difference (LSD) tests. The coefficient of variation (CV%) was reported to measure relative variability across treatments. Additionally, a Pearson correlation matrix was constructed to examine relationships between growth performance, serum biochemical and economic parameters.

RESULTS AND DISCUSSION

The effects of different dietary interventions on the growth performance, physiological health and economic viability of broiler chickens were critically assessed over a 42-day trial period. The results revealed significant differences among the treatment groups, indicating that the inclusion of tested feed additives had a significant influence on broiler productivity and profitability.

Table 1: Nutrient composition of experimental basal diets (BIS, 2013 standards).

Nutrient (%)	Starter phase (0-21 d)	Finisher phase (22-42 d)
Metabolizable energy (kcal/kg)	2,900	3,000
Crude protein	22.0	20.0
Lysine	1.10	1.00
Methionine	0.50	0.45
Calcium	1.00	0.90
Available phosphorus	0.45	0.40

Growth performance

Broilers receiving dietary supplements demonstrated noticeable improvements in growth performance over the a 42-day period when compared to the control group (T1). The highest final body weight was observed in birds fed with nano-zinc (T3), averaging 2225 grams, followed closely by the enzyme mix group (T5) at 2190 grams and the herbal group (T2) at 2148 grams. In contrast, the control group recorded the lowest final weight at 2055 grams (Table 2). The superior growth in the nano-zinc group may be linked to zinc's role in enzyme activation, immune function and cellular repair, all of which enhance nutrient metabolism and tissue development (Fig 1).

Average daily weight gain followed a similar trend, with T3 birds achieving 51.6 g/day, significantly higher than the control group at 48.0 g/day. The enzyme (T5: 50.8 g/day) and herbal (T2: 49.9 g/day) groups also performed well, indicating the potential of these additives to boost growth, likely by improving digestion and nutrient absorption (Table 2). In the study by El-Abbasy *et al.* (2025), nano-zinc was found to be significantly enhance body weight gain by increasing zinc bioavailability and cellular uptake, which in turn promoted improved protein synthesis and growth.

Feed efficiency, measured in terms of FCR, further highlighted the effectiveness of these supplements (Table 2). Birds in the nano-zinc group (T3) had the lowest FCR at 1.67, suggesting superior feed utilization. The enzyme mix (T5: 1.71) and herbal (T2: 1.76) groups also recorded improved FCR values compared to the control (T1: 1.86). This aligns with research findings nano-form zinc enhances absorption, thus requiring less intake for higher output (El-Shenawy *et al.,* 2022). These results emphasize the economic importance of improved feed efficiency, especially given that feed costs dominate broiler production expenses.

Total feed intake was slightly lower in supplemented groups, particularly in T3 (3712 g/bird), yet these birds still

Table 2: Growth performance, feed efficiency and mortality of broilers (Day 1-42).

Parameter	T1: Control	T2: Herbal (1%)	T3: Nano-Zn (1%)	T4: Probiotic (0.5%)	T5: Enzyme mix (0.3%)	p-value	CV%	LSD (0.05)
Initial body Wt (g)	42.5±0.6	42.7±0.5	42.6±0.7	42.4±0.4	42.3±0.5	0.982	1.22	NS
Final body Wt (g)	2055±32	2148±29	2225±31	2111±28	2190±33	0.002	3.01	58.4
Avg. daily gain (g/day)	48.0±0.7	49.9±0.6	51.6±0.6	48.4±0.7	50.8±0.8	0.001	2.87	1.08
Total feed intake (g/bird)	3822±36	3761±34	3712±33	3790±30	3735±31	0.018	1.55	64.7
FCR	1.86±0.03	1.76±0.02	1.67±0.02	1.80±0.02	1.71±0.02	<0.001	1.96	0.07
Mortality (%)	3.0	2.0	1.5	2.0	1.0	-	-	-
Dressing %	69.5±0.6	70.8±0.5	72.4±0.4	70.0±0.6	71.7±0.5	0.004	2.02	1.12
Abdominal fat (%)	1.85±0.12	1.72±0.09	1.51±0.08	1.78±0.10	1.61±0.09	0.011	3.86	0.14

(Mean ± SE, n = 100 birds per treatment, replicated 3 times).

achieved higher body weights, which reinforces their efficient nutrient utilization. The probiotic supplemented group (T4), despite having a similar feed intake to the control, showed modest improvements in body weight and FCR, supporting the known role of probiotics in gut health and digestive efficiency.

Dressing percentage, a key measure of carcass yield, was highest in the nano-zinc group (T3: 72.4%) and enzyme mix group (T5: 71.7%), compared to 69.5% in the control group (Table 2). The increase in dressing percentage in these groups likely results from better muscle development and reduced fat deposition, as reflected in their lower abdominal fat percentages T3 (1.51%) and T5 (1.61%) versus T1 (1.85%). In the study by Dahi *et al.*(2024), higher dressing percentage with nano zinc or enzyme supplementation was attributed to enhanced muscle accretion and reduced fat deposition, contributing to improved carcass quality in broiler chicks (Mamabolo *et al.,* 2025).

Mortality remained low across all treatments, ranging from 1.0% to 3.0%, with the lowest observed in the enzyme (T5: 1.0%) and nano-zinc (T3: 1.5%) groups (Table 2). This suggests that these supplements not only enhance growth but may also improve overall health and survivability, possibly through immune system support. In the studies by Saber and Alian (2024) and Waqas *et al.* (2024), improved survivability was attributed to nano zinc and enzyme blends, which enhanced immune modulation, thereby increasing resistance to disease and stress in broiler chickens.

Serum biochemical profile

The serum biochemical values at day 42 clearly indicate how different dietary supplements influenced the internal health of broiler chickens (Rathaur *et al.,* 2023). Birds in the nano-zinc group (T3) showed the highest total protein (6.53 g/dL), albumin (3.12 g/dL) and globulin (3.41 g/dL) levels (Table 3). These elevated protein fractions suggest enhanced protein synthesis, better nutrient absorption and improved liver function. The nano-form of zinc is known for its superior bioavailability, which likely supported more efficient enzymatic activity and tissue repair, thereby boosting protein metabolism. In the study by Fathi *et al.* (2016) nano-zinc was shown to improve liver function and serum protein fractions by enhancing enzyme cofactor activity and facilitating more efficient nutrient transport in broiler chickens.

Similarly, the herbal (T2) and enzyme (T5) groups also showed improved protein and globulin levels compared to the control, though ~~to~~ a lesser degree. This could be due to the bioactive phytochemicals in herbs and improved digestion with enzymes, which together help optimize nutrient utilization.

Cholesterol levels were significantly reduced in T3 (158 mg/dL), T5 (160 mg/dL) and T2 (172 mg/dL), compared to 189 mg/dL in the control. This decrease in cholesterol levels may be attributed to the lipid-modulating effects of zinc and herbal compounds. Zinc plays a role in lipid metabolism regulation, while herbal additives are known to inhibit cholesterol synthesis *via* their antioxidant and phytochemical constituents. Probiotic-fed birds (T4) also benefited, maintaining cholesterol within desirable

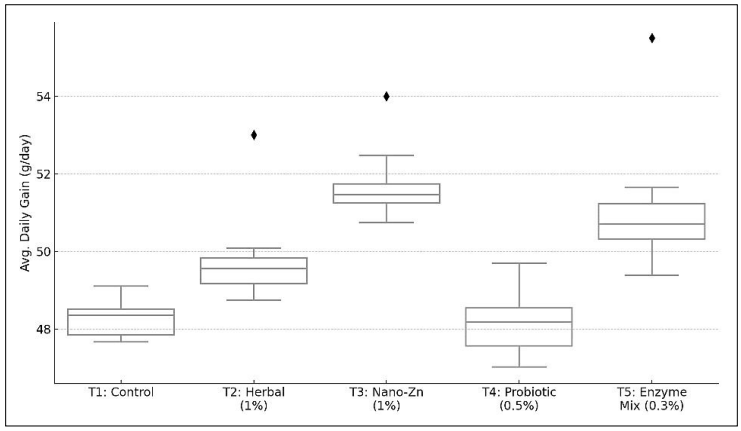


Fig 1: Average daily body weight gain.

Table 3: Serum biochemistry and liver enzymes at day 42.

Parameter	T1	T2	T3	T4	T5	p-value	Norm. range
Total protein (g/dL)	5.92	6.21	6.53	6.05	6.42	0.017	5.5-7.5
Albumin (g/dL)	2.95	3.08	3.12	3.00	3.10	0.041	2.5-3.5
Globulin (g/dL)	2.97	3.13	3.41	3.05	3.32	0.022	2.5-4.0
Cholesterol (mg/dL)	189	172	158	178	160	0.004	<200
AST (U/L)	192	178	165	185	170	0.006	150-250
ALT (U/L)	45	39	36	42	37	0.038	30-60

limits (178 mg/dL), possibly due to microbial activity that reduces cholesterol absorption in the gut (Table 3). In the study by El-Abbasy *et al.* (2025), zinc nanoparticles combined with herbal compounds, such as Moringa oleifera leaf powder, were found to reduce hepatic cholesterol synthesis through antioxidant-mediated inhibition of HMG-CoA reductase, contributing to improved lipid metabolism and overall health in broiler chickens.

Liver enzymes AST and ALT (Table 3) were lowest in T3 (165 and 36 U/L), indicating reduced hepatic stress and better liver protection. Nano-zinc's antioxidant properties likely helped to stabilize hepatocellular function. The enzyme (T5) and herbal (T2) groups also showed lower liver enzyme activity than the control, suggesting moderate liver support through improved digestion and detoxification processes. In the study by El-Shenawy *et al.* (2022), nano zinc was shown to stabilize hepatocyte membranes and reduce oxidative liver damage, thereby supporting liver health and enhancing resilience in broiler chickens challenged with Salmonella Kentucky.

The nano-zinc (T3) and herbal (T2) treatments not only improved serum protein and lipid profiles but also supported hepatic health, offering compelling evidence for their physiological benefits. These internal markers reinforce the growth and economic outcomes observed, showing that dietary additives can positively influence both productivity and systemic health.In the study by Badran *et al.* (2020), herbal bioactives such as flavonoids and terpenes, along with enzyme supplementation, were found to enhance nutrient absorption and support hepatic detoxification, thereby improving growth performance, immune response and antioxidant status in broiler chickens.

Economic evaluation

To assess practical viability (Table 4), the economics of each treatment was analyzed on a per-1,000 bird basis, reflecting commercial-scale broiler production (Ajaykumar *et al.,* 2024). The highest gross revenue was observed in the nano-zinc group (T3), amounting to ` 2,67,000, followed by the enzyme group (T5) at ` 2,62,800 and the probiotic group (T4) at ` 2,53,320. The increased returns in these groups are directly associated with higher final body weights and better dressing percentages, which translated into greater marketable yield. In the study by Basit *et al.* (2025), the use of feed additives such as nano zinc, enzyme blends and probiotics was shown to significantly improve growth performance and feed efficiency in broiler chickens, leading to higher revenue and net profits despite increased feed costs.

Despite having the highest feed cost per bird (` 71.5), the nano-zinc group (T3) still yielded the maximum net profit of ` 1,65,100, demonstrating the economic efficiency of this supplement. The enzyme-fed group (T5) was close behind with a net return of ` 1,62,300 and the probiotic group (T4) achieved ` 1,54,320. These figures underscore how strategic nutritional interventions can offset input costs through superior biological performance.

The BCR, a key indicator of investment efficiency, was also highest in the nano-zinc group (T3) at 2.62, indicating that for every ` 1 invested, ` 2.62 was returned. The enzyme group (T5: 2.61) and probiotic group (T4: 2.56) also showed strong BCR values, far surpassing the control group (T1: 2.51). These results confirming the economic value of feed additives in maximizing returns per unit cost.In the study by Ibrahim *et al.*(2021), nano-enhanced feed additives, such as garlic nanohydrogel, were shown to consistently deliver higher BCR by optimizing growth, enhancing gastrointestinal integrity and reducing disease-related losses, thereby improving overall performance metrics and lowering the relative cost per unit of weight gain in broiler chickens.

Another notable indicator was the break-even price, which was lowest in T3 at ` 45.3/kg, meaning farmers using

Table 4: Economic analysis per 1000 broilers.

Economic indicator	T1	T2	T3	T4	T5	% Change vs. T1
Feed cost per bird (`)	68.5	69.9	71.5	69.3	70.8	-
Total cost (`)	98,400	99,700	101,900	99,000	100,500	-
Live weight per bird (kg)	2.055	2.148	2.225	2.111	2.190	↑ 8.3% (T3)
Gross revenue (`)	246,600	257,760	267,000	253,320	262,800	↑ 8.2% (T3)
Net profit (`)	148,200	158,060	165,100	154,320	162,300	↑ 11.4% (T3)
Net profit/bird (`)	148.2	158.1	165.1	154.3	162.3	↑ 11.4% (T3)
Break-even price (`/kg)	47.9	46.5	45.3	47.0	45.9	↑ 5.4% (T3)
BCR	2.51	2.59	2.62	2.56	2.61	'↑ 4.4% (T3)

Table 5: Correlation matrix (Pearson r).

Variable	Final Wt	FCR	Net profit	Dressing %	Serum protein
Final Wt	1	-0.88	0.92	0.81	0.76
FCR	-0.88	1	-0.85	-0.78	-0.72
Net profit	0.92	-0.85	1	0.84	0.80
Dressing %	0.81	-0.78	0.84	1	0.69
Serum protein	0.76	-0.72	0.80	0.69	1

nano-zinc could remain profitable even in lower market price scenarios. In contrast, the control group had a break-even price of ` 47.9/kg, requiring higher market rates just to recover costs.

Although all supplemented groups economically out performed than control group, T3 emerged as the most cost-effective strategy, combining superior growth performance with maximum profitability. The probiotic and enzyme groups also delivered favorable outcomes, making them promising alternatives in antibiotic-free broiler production systems (Olanrewaju *et al.,* 2025).

Correlation and integration

A deeper look through correlation analysis revealed clear relationships among performance, physiological health and profitability (Table 5). Notably, FCR showed a strong negative correlation with net profit (r = -0.85), indicating that better feed efficiency is directly linked to higher financial returns. In simple terms, birds that required less feed per unit of weight gain contributed more to farm profitability.

Similarly, final body weight exhibited a strong positive correlation with net profit (r = 0.92) and dressing percentage (r = 0.81), reaffirming the economic advantage of higher yield per bird. Another important finding was the moderate-to-strong positive association between serum total protein levels and final weight (r = 0.76), highlighting the role of internal physiological health particularly protein metabolism as a driver of growth performance.

These interrelated outcomes emphasize the integrated nature of biological efficiency, health markers and economic returns. Treatments with nano-zinc and probiotics stood out across almost all parameters, indicating not only their biological efficacy but also their economic value in commercial settings. These results align with previous studies that support the inclusion of micronutrient and probiotic-based feed additives as sustainable alternatives in high-density broiler production systems (Rashad and Soliman, 2023).

CONCLUSION

The findings of the study concludes that incorporating nutraceutical feed additives not only improved bird health and performance but also contributed to better feed efficiency and carcass quality. From an economic stand-point, enhanced feed conversion and higher dressing yields translate into more cost-effective production critical in an industry where feed expenses dominate operational costs. Particularly, the additives like nano-zinc and enzymes showed the potential to deliver better returns on investment by boosting both productivity and survivability.

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Informed consent

All animal procedures for experiments were approved by the Committee of Experimental Animal care and handling techniques were approved by the University of Animal Care Committee.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish or preparation of the manuscript.

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