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Phytogenic–probiotic supplementation enhances growth and economic efficiency in commercial closed-house broiler production systems

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Abstract

The demand for broiler chicken meat continues to increase worldwide. However, production efficiency in closed-house cage system still faces challenges due to intestinal health issues and restrictions on the use of antibiotic growth promoters (AGP). These limitations drive the need for alternative feed additives that can improve production performance while maintaining production sustainability. This study aimed to evaluate the effectiveness of a combination of *Phyllanthus niruri* flour and probiotics (*Lactobacillus acidophilus* and *L. casei*) on the growth performance and economic efficiency of broiler chickens. A completely randomized design with three treatments was used: P0 (control), P1 (1% *P. niruri* flour + probiotics administered at 1 mL/L drinking water), and P2 (2% *P. niruri* flour + probiotics administered at 1 mL/L drinking water). A total of 15,000 broiler chickens were reared for 35 days in a commercial closed-house system. The results showed that birds in the P2 group had a significantly higher final body weight (2.31 ± 0.11 kg) compared with the control group (1.88 ± 0.20 kg; P = 0.021) and reduced the feed conversion ratio (FCR) from 1.55 to 1.43 (P = 0.001). The performance index also increased significantly from 382 to 436 (P = 0.001), whereas mortality decreased numerically from 4.20% to 1.98% without statistical significance (P = 0.118). The economic evaluation indicated that the phytogenic–probiotic supplementation tended to improve economic efficiency, with the highest revenue-to-cost ratio (1.20) observed in P2. Overall, phytogenic–probiotic supplementation improved growth performance and showed potential to enhance economic efficiency under commercial production conditions. However, because only combination treatments were evaluated, the individual effects of phytogenic and probiotic supplementation could not be distinguished. These findings provide field-scale evidence that phytogenic–probiotic supplementation may serve as a sustainable alternative strategy to support broiler production performance.

1. Introduction

The demand for broiler chicken meat continues to increase globally due to population growth and the need for affordable animal protein, making the poultry industry one of the fastest-growing sectors in food production. Modern production systems such as closed-house systems have been widely adopted to increase productivity through better environmental control and management efficiency. However, this intensive system also presents various challenges, especially related to decreased feed efficiency, intestinal microbiota imbalances, and increased environmental stress that affects growth performance and health of chickens (Krysiak et al. 2021; Feng et al. 2023). In addition, restrictions on the use of antibiotic growth promoters (AGP) have complicated efforts to maintain production stability, as they have the potential to increase susceptibility to digestive disorders and decrease feed conversion efficiency (Anggriawan et al. 2024a; Aminullah et al. 2025). In these conditions, the poultry industry is required to develop alternative nutrition strategies that not only improve production performance, but also maintain intestinal health and economic efficiency in a sustainable manner (Obianwuna et al. 2024; Van Wagenberg et al. 2020).

The modern poultry industry faces serious challenges after the ban on the use of antibiotic growth promoters (AGP) in feed because this policy has increased the risk of intestinal health disorders and reduces the stability of broiler chicken production performance (Anggriawan et al. 2024a; Krysiak et al. 2021). This condition causes an increase in feed conversion ratio (FCR) and mortality rates due to an imbalance of the intestinal microbiota in intensive production systems (Arif et al. 2021; Feng et al. 2023). Farmers may experience reduced production efficiency because digestive disorders impair the normal absorption of nutrients and optimal growth of broiler chickens (Soumeh et al. 2021; Ogbuewu et al. 2020). Closed-house cage systems increase environmental pressure and population density, which exacerbates physiological stress and worsen production performance (Zammit and Park 2023). Therefore, the poultry industry needs safe, effective, and sustainable feed additive alternatives to replace AGPs in maintaining gut health and production efficiency (Anggriawan et al. 2024b; Aminullah et al. 2025; Obianwuna et al. 2024). Researchers have developed a probiotic- and phytogenic-based approach because both components can improve the microbiota balance and increase the immune response of broiler chickens (Alghirani et al. 2022; Salarmoini and Fooladi 2025). However, previous research still showed mixed results when the two materials were used separately in commercial-scale intensive production systems (Dev et al. 2020; Brugaletta et al. 2020).

Several studies have used probiotics as feed additives to improve the balance of the gut microbiota in broiler chickens so that digestive efficiency and growth performance can be improved (Ghasemi et al. 2020; Krysiak et al. 2021; Feng et al. 2023). *Lactobacillus sp.* based probiotics act by modulating the intestinal microbial community and improving the integrity of the intestinal mucosa in broiler chickens in intensive rearing systems (Arif et al. 2021; Soumeh et al. 2021; Candra and Anggriawan 2024; Anggriawan et al. 2024c). Phytogenic-based feed additives have also been developed to improve the immune response and antioxidant activity in poultry so that they can suppress oxidative stress and pathogenic infections (Aminullah et al. 2025; Urban et al. 2025). *Phyllanthus niruri* contains bioactive compounds that acts as immunomodulators and antioxidants in improving gut health and broiler chicken production performance (Pasaribu et al. 2023; Sabdoningrum et al. 2023). Other studies have combined probiotics and phytogenic compounds into phytogenic–probiotic combination to improve production performance and digestive tract health in broiler chickens (Dev et al. 2020; Song et al. 2022). Phytogenic–probiotic combinations work by strengthening the colonization of beneficial bacteria while providing a substrate that supports the growth and activity of these microbes in the gut (Śliżewska et al. 2020; Khosravi et al. 2025). The phytogenic–probiotic approach is currently an emerging research area because it is able to provide more consistent improvements than the use of probiotics or phytogenic additives alone in modern broiler production systems (Nisar et al. 2021; Younis et al. 2024).

Most previous studies have evaluated the use of probiotics or phytogenic–probiotic combinations on a limited experimental scale with relatively small numbers of birds, so the results have not fully represented commercial production conditions with large populations (>5,000 heads) (Brugaletta et al. 2020; Khosravi et al. 2025). Previous studies have evaluated probiotics or phytogenic additives individually, whereas the present study evaluated their combined application under commercial production conditions (Aminullah et al. 2025; Obianwuna et al. 2024). Several studies have reported that probiotics containing *Lactobacillus acidophilus* and *L. casei*. can improve the growth performance and gut health of broiler chickens through modulation of microbiota and increased digestive efficiency (Arif et al. 2021; Feng et al. 2023), but these studies have not combined probiotics with specific phytogenic ingredients such as *Phyllanthus niruri* which have high immunomodulatory and antioxidant potential (Pasaribu et al. 2023; Sabdoningrum et al. 2023). In addition, most studies still focus on biological parameters such as body weight and FCR without integrating comprehensive economic feasibility analysis as a basis for decision-making at the industry level (Van Wagenberg et al. 2020; Mohammed et al. 2022). Therefore, this study fills the gap by evaluating the effects of phytogenic–probiotic s based on *Phyllanthus niruri* and *Lactobacillus acidophilus* and *L. casei* on a commercial scale and integrating analyses of production performance and economic efficiency in closed-house cage systems.

This study aimed to comprehensively evaluate the effects of phytogenic–probiotic s based on *Phyllanthus niruri* and *Lactobacillus acidophilus* and *L. casei.* on growth performance and economic efficiency of broiler chickens in a closed-house cage system, a representative of modern intensive production conditions. This study specifically tested the effect of the combination of *Phyllanthus niruri* flour as a phytogenic feed additive with lactic acid bacterial probiotics on the growth, feed efficiency, and mortality rate of broiler chickens during one maintenance period. In addition, this study evaluated economic feasibility through indicators of production costs, revenue-to-cost ratios, and break-even points to determine the potential adoption of this feeding strategy on a commercial scale. This study addresses an important research gap in previous research that generally only evaluated probiotics or phytogenics separately and rarely integrated biological and economic analyses in a single integrated research framework. This research provides novel evidence through the application of phytogenic–probiotic combinations in large commercial flocks in closed-house systems that have high environmental pressure and require optimal performance stability. Therefore, this study hypothesizes that phytogenic–probiotic supplementation based on *Phyllanthus niruri* and *Lactobacillus acidophilus* and *L. casei* significantly improves production performance, improves feed efficiency, reduces mortality, and increases economic efficiency of broiler chickens compared to systems without supplementation.

2. Materials and Methods

2.1 Experimental Design

All experimental procedures involving broiler chickens were conducted in accordance with institutional guidelines for the care and use of animals in research. The experimental protocol was reviewed and approved by the Institutional Animal Care and Use Committee (IACUC) of Universitas Kahuripan Kediri, Indonesia, under approval number B-115/UKK-ETIK/IV/2026. Throughout the experimental period, animal welfare and health status were monitored daily to minimize stress, discomfort, and unnecessary suffering. A completely randomized design (CRD) was used, involving 15,000 day-old broiler chicks assigned to three feeding regimens at random. Each treatment was replicated in five independent pens, with 1,000 birds housed in each pen, resulting in a total of 15 experimental units. Three treatments were applied: P0 (basal diet, control), P1 (basal diet + 1% *Phyllanthus niruri* flour + probiotic containing *Lactobacillus acidophilus* and *Lactobacillus casei* administered at 1 mL/L drinking water), and P2 (basal diet + 2% *Phyllanthus niruri* flour + the same probiotic preparation administered at 1 mL/L drinking water). The pen, rather than the individual bird, was defined as the experimental unit for all statistical analyses; therefore, the effective sample size was $n = 5$ replicate pens per treatment. Although each pen contained a large number of birds, this improved the commercial representativeness of the study rather than the statistical replication. Growth performance and economic analyses were performed using each replicate pen as the experimental unit. The birds were kept under identical management conditions in closed-house, environmentally controlled enclosures. To reduce environmental bias, birds were assigned to pens at random.

2.2 Birds and Management

A total of 15,000 day-old commercial broiler chicks (Cobb 500 strain; male chicks) were used in this study. Birds were vaccinated according to a standard commercial vaccination program (Newcastle disease at day 4; Infectious bursal disease at day 10). The stocking density was maintained at approximately 10–12 birds/m² (equivalent to 30–32 kg/m² at harvest). Brooding temperature was initially set at 32–34 °C and gradually reduced to 24–26 °C by day 21. A continuous lighting program (23L:1D) was applied during the starter phase, followed by 20L:4D during the grower-finisher phase.

2.3 Treatments

The P0 treatment served as the control group without supplementation of *Phyllanthus niruri* flour or probiotics. The P1 treatment consisted of a basal diet supplemented with 1% *Phyllanthus niruri* flour and probiotic supplementation via drinking water at a dosage of 1 mL/L. The P2 treatment consisted of 2% *Phyllanthus niruri* flour incorporated into the basal diet combined with the same probiotic supplementation administered via drinking water at 1 mL/L.

2.4 Phytogenic and probiotic description

Phyllanthus niruri used in this study was obtained from a certified herbal supplier in East Java, Indonesia. The whole plant material was washed, oven-dried at 45 °C until constant weight, ground into a powder, and passed through a 60-mesh sieve before incorporation into the experimental diets. Based on supplier specifications and previously published analyses, the major bioactive constituents of the powder included flavonoids, tannins, saponins, lignans, and phenolic compounds, which have been associated with antioxidant, antimicrobial, and immunomodulatory activities in poultry. However, no additional phytochemical quantification was performed on the specific batch used in the present study. The probiotic preparation used in this study was a commercial preparation containing *Lactobacillus acidophilus* and *L. casei* (PROBIOCELL, Indonesia). The product contained a viable count of 1×10^8 CFU/mL at the time of application. The probiotic was diluted in drinking water at a dosage of 1 mL/L, providing approximately 1×10^5 CFU/mL in the final drinking solution. The viability of the probiotic was confirmed using standard plate count methods prior to administration. The product was stored at 4 °C to maintain bacterial viability throughout the experimental period. The combined supplementation of phytogenic compounds and probiotic bacteria was evaluated as a practical feeding strategy to improve intestinal health and broiler performance. However, the present experimental design was not intended to distinguish the individual contribution of each additive (Dev et al. 2020; Song et al. 2022; Pasaribu et al. 2023).

2.5 Basal Diet Composition

The basal diet was formulated to meet or exceed the nutrient requirements for broiler chickens as recommended by the National Research Council (NRC 1994). A commercial complete feed (Hi-Pro-Vite 511 Bravo) based on a corn–soybean meal formulation was used throughout the experimental period. The diet contained approximately 21–23% crude protein during the starter phase and 19–21% during the finisher phase, with metabolizable energy ranging from 2900 to 3000 kcal/kg. Other nutrient components included crude fat ≥ 5.0%, crude fiber ≤ 5.0%, calcium ≥ 0.90%, and available phosphorus ≥ 0.60%. These nutrient levels are consistent with standard recommendations for optimal growth performance and feed efficiency in broiler production systems (NRC 1994; Leeson and Summers 2005). Detailed nutrient composition of the basal diet is shown in Table 1.

Table 1. Nutrient composition of the commercial basal diet (Hi-Pro-Vite 511 Bravo)

Parameter	Composition
Crude protein (%)	22 - 23
Metabolizable energy (kcal/kg)	2950 – 3000
Crude fat (%)	≥ 5.00
Crude fiber (%)	≤ 5.00
Moisture (%)	≤ 13.00
Ash (%)	≤ 7.00
Calcium (%)	≥ 0.90

2.6 Housing System

The study was conducted in a commercial closed-house facility consisting of 15 identical floor pens. Each pen was equipped with independent feeders and drinkers to avoid cross-treatment interference. Environmental conditions including temperature, humidity, ventilation, and lighting program were maintained uniformly across all pens throughout the experimental period. The mechanical ventilation system was optimized by researchers through the use of exhaust fans and cooling pads to maintain air quality and suppress the accumulation of harmful gases. Stocking density was maintained as per intensive industry standards to simulate large-scale commercial production conditions. This closed house system improves production efficiency but also increases the risk of environmental stress so that it requires appropriate nutritional interventions such as the use of phytogenic–probiotic combinations (Zammit and Park 2023).

2.7 Growth Performance

Body weight (BW) of chicken was measured at regular intervals to evaluate the growth performance during the rearing period. Feed Conversion Ratio (FCR), as the main indicator of feed efficiency in intensive production systems, was calculated. Mortality was recorded to evaluate the health and survival levels of chickens during the study. The performance index was calculated, which is an integrative parameter combining growth, feed efficiency, and survival rate of chickens. These parameters were measured systematically to provide a comprehensive picture of the influence of phytogenic–probiotic s on the production performance of broiler chickens (Arif et al. 2021; Feng et al. 2023; Nisar et al. 2021).

2.8 Economic Analysis

Production costs were calculated based on field data using standardized cost components in terms of Indonesian Rupiah (IDR), including feed (IDR/kg), day-old chicks (DOC, IDR/chick), labor (IDR/cycle), veterinary and medication costs (IDR/cycle), housing operational costs (electricity, litter, and maintenance), as well as additional costs for phytogenic (*Phyllanthus niruri* flour, IDR/kg) and probiotic supplementation (IDR/mL). Feed price was assumed at IDR 6,000/kg, DOC at IDR 8,000/chick, probiotic cost at IDR 60/mL, and *Phyllanthus niruri* flour at IDR 20,000/kg, based on average market prices in East Java during the study period (2025–2026). Revenue was calculated by multiplying live weight (kg) by the average market price of broiler chickens (IDR/kg), which was assumed at IDR 21,000 /kg. Sensitivity to price fluctuation was not modeled in this study and represents a limitation of the economic analysis. Revenue was determined based on the sale of live birds and calculated from the harvest weight multiplied by the actual market price so that it reflects commercial production conditions in the closed-house system (Anggriawan and Kurniawan 2020b).

The Break-Even Point (BEP) was calculated using the standard formula: total production cost divided by total production output (kg live weight), resulting in BEP expressed as IDR/kg. Production costs were categorized into fixed costs (housing, equipment depreciation, labor) and variable costs (feed, DOC, additives, medication). In this study, BEP represents the minimum selling price (IDR/kg live weight) required to fully recover production costs. BEP was expressed as IDR/kg live weight (IDR/kg) to reflect the minimum selling price required to avoid losses (Van Wagenberg et al. 2020). This study analyzed the revenue-to-cost (R/C) ratio and benefit-to-cost (B/C) ratio by comparing the total revenue and total benefits to the total production cost, respectively, to assess the level of business feasibility, where the R/C value > 1 indicates an economically viable business (Andriani et al. 2020; Patel et al. 2023).

The Payback Period (PP) was estimated as the time required to recover initial investment costs based on net profit per production cycle. Given that broiler production operates in short cycles (35 days), PP values should be interpreted cautiously as an indicative metric rather than a precise financial recovery period. Payback Period (PP) was calculated as:

PP (months) = Initial investment / Net profit per month

Assumptions: one production cycle = 35 days (~1.2 months), net profit per cycle was converted to monthly basis, initial investment included housing infrastructure, equipment depreciation, and operational preparation costs. This calculation was used to estimate the time required to recover the initial investment under each treatment condition (Anggriawan et al. 2025; Mohammed et al. 2022). This economic analysis allowed integration of biological performance with business profitability so as to provide an applicable decision-making basis for commercial farmers (Van Wagenberg et al. 2020). It is important to note that the economic analysis in this study was based on a single production cycle and fixed price assumptions. Variability in market prices (feed, additives, and live bird prices), inflation, and regional economic differences were not incorporated into the model. Therefore, the results should be interpreted as indicative rather than predictive, and further studies using sensitivity or stochastic economic analysis are recommended

2.9 Data Analysis

Data were analyzed using one-way analysis of variance (ANOVA) under a completely randomized design using SPSS version 26 (IBM Corp., Armonk, NY, USA). The replicate pen was considered the experimental unit for all statistical analyses (n = 5 pens per treatment). Consequently, statistical inference was based on five independent replicates per treatment rather than on the total number of birds housed. The large number of birds per pen improved the precision of pen-level measurements but did not increase the number of independent experimental replicates (Brugaletta et al. 2020; Song et al. 2022). In addition to probability testing, effect sizes were calculated to quantify the magnitude of treatment effects. Partial eta squared (η^2) values were obtained from the one-way ANOVA model and are reported alongside exact P values. Effect sizes were interpreted according to conventional benchmarks, where η^2 values of 0.01, 0.06, and 0.14 represent small, medium, and large effects, respectively. Prior to ANOVA, data were tested for normality using the Shapiro–Wilk test and for homogeneity of variance using Levene's test to ensure that the assumptions of the model were met. Residuals were also examined to confirm the validity of the statistical model. When significant differences were detected (P < 0.05), treatment means were compared using Tukey's Honestly Significant Difference (HSD) test. Results are presented as mean ± standard error of the mean (SEM). In addition, Pearson correlation analysis was performed to evaluate the relationships between biological performance and economic parameters, following approaches used in previous studies (Obianwuna et al. 2024; Anggriawan et al. 2026).

3. Results

3.1 Growth performance

The results showed that phytogenic–probiotic supplementation based on *Phyllanthus niruri*, *Lactobacillus acidophilus*, and *L. casei* significantly influenced the growth performance of broiler chickens in the closed house cage system. Table 2 show that final body weight (BW) increased markedly with increasing supplementation level, with the P2 group (2% *Phyllanthus niruri* + probiotics) exhibiting the highest final body weight (2.31 ± 0.11 kg) compared with the control (1.88 ± 0.20 kg; P = 0.021), as illustrated in Fig. 1. Values are presented as mean ± SEM, and different superscript letters within rows indicate significant differences among treatments (p < 0.05). This increase indicates that phytogenic–probiotic supplementation improved feed utilization efficiency,

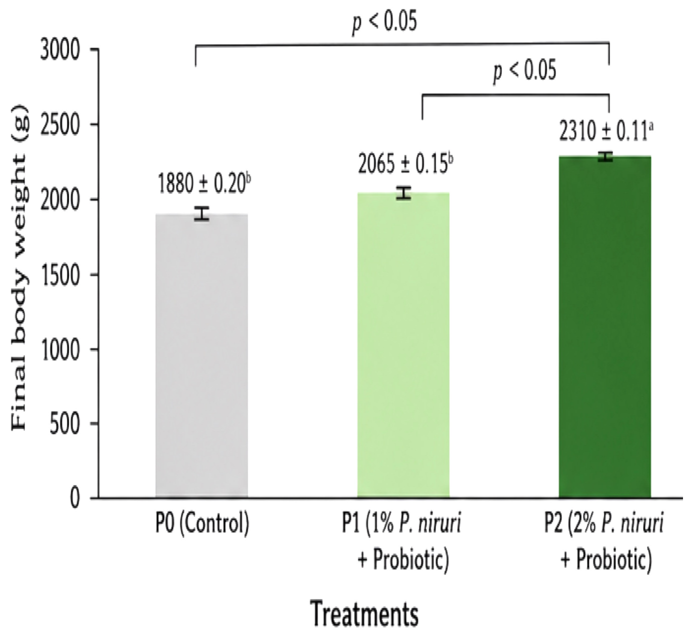

Fig. 1. Effects of phytogenic–probiotic supplementation on body weight of broiler chickens

Table 2. Growth performance of broiler chickens supplemented with phytogenic–probiotic combinations during the 35-day rearing period

Parameter	P0 (Control)	P1 (1% *Phyllanthus niruri* + Probiotic)	P2 (2% *Phyllanthus niruri* + Probiotic)	P-value	Partial η^2
Body Weight (kg)	1.88 ± 0.20^{a}	2.02 ± 0.27^{ab}	2.31 ± 0.11^{b}	0.021	0.47
Feed Conversion Ratio	1.55 ± 0.01^{c}	1.49 ± 0.02^{b}	1.43 ± 0.02^{a}	0.001	0.71
Mortality (%)	4.20 ± 1.17	3.20 ± 0.94	1.98 ± 1.08	0.118	0.19
Performance Index	382 ± 29.78^{a}	407 ± 24.51^{b}	436 ± 23.96^{c}	0.001	0.74

Values are presented as mean ± SEM (n = 5 replicate pens per treatment); Different superscript letters within rows indicate significant differences among treatments according to Tukey's HSD test (P < 0.05); Partial η^2 values are reported as effect size estimates from one-way ANOVA

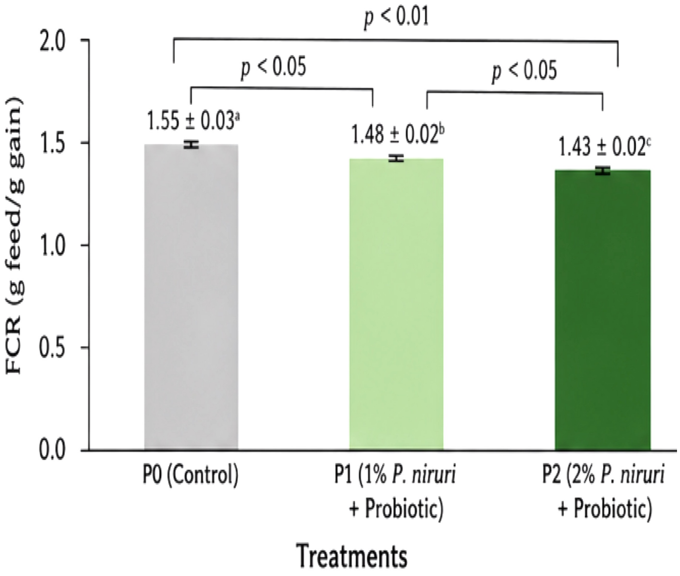

Fig. 2. *Effects of phytogenic–probiotic supplementation on feed conversion ratio (FCR) of broiler chickens*

however, the underlying biological mechanisms were not directly evaluated in this study. In addition, the Feed Conversion Ratio (FCR) showed a significant decrease from P0 (1.55) to P2 (1.43) (P = 0.001), indicating better feed utilization efficiency in phytogenic–probiotic treatments, as presented in Fig. 2. The lower FCR indicates improved feed utilization efficiency in the phytogenic–probiotic treatment. A linear dose-response relationship was observed, indicating that increasing the inclusion level of the phytogenic–probiotic combination was associated with progressive improvements in broiler performance. Overall, feed intake (FI) showed a stable trend between treatments, but the efficiency of utilization increased in the phytogenic–probiotic group, which was reflected in increased body weight and decreased FCR. This pattern indicates improved nutrient utilization efficiency rather than increased feed intake.

3.2 Mortality and Performance Index

Mortality was numerically lower in the P2 treatment (1.98%) compared with the control (4.20%), although the difference was not statistically significant (P = 0.118). The data presented in Table 2 show that the mortality rate decreased from 4.20% in control to 1.98% in P2 treatment, although statistically there was no significant difference (p>0.05). Although the reduction in mortality was not statistically significant (P = 0.118), the numerical difference may indicate a biological tendency that warrants further investigation because it reflects the improved health status and resistance to environmental stress and infection, although these aspects were not directly assessed in this study. Furthermore, the performance index (PI) increased significantly from 382 in the control to 436 in the P2 treatment (P = 0.001), as shown in Fig. 3. This increase in PI reflects the combined improvement in growth, feed efficiency, and bird viability, integrating these parameters into a single comprehensive indicator. This increase in PI reflects improvements in growth, feed efficiency, and survival rate. Thus, the results of this study confirm that the administration of *Phyllanthus niruri* flour-based phytogenic–probiotic s and probiotics not only improves growth performance, but also may be associated with overall health and productivity indicators in broiler chickens in an intensive production system.

3.3 Economic performance

Table 3 show that the administration of phytogenic–probiotic combination of *Phyllanthus niruri* and *Lactobacillus acidophilus* and *L. casei* suggests a trend toward improved economic efficiency under the defined cost and price assumptions used in this study in closed house cage systems, although not all parameters show statistically significant differences. This trend is reflected in the gradual but nonsignificant increase in profit indicators such as the R/C ratio and B/C ratio with increasing supplementation levels, indicating improved economic performance. A detailed economic analysis for each treatment is presented in Table 4. Feed costs increased progressively from P0 to P2 due to higher production output and feed utilization associated with

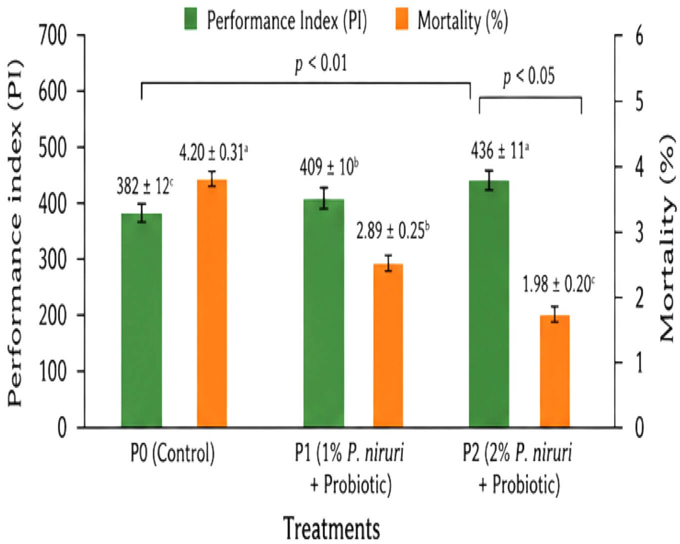

Fig. 3. *Effects of phytogenic–probiotic supplementation on performance index and mortality of broiler chickens*

Table 3. Economic performance of broiler chicken production supplemented with phytogenic–probiotic combinations

Parameter	P0 (Control)	P1 (1% *Phyllanthus niruri* + Probiotic)	P2 (2% *Phyllanthus niruri* + Probiotic)	P-value	Partial η²
R/C Ratio	1.12 ± 0.07	1.16 ± 0.10	1.20 ± 0.01	0.184	0.12
BEP (IDR/kg live weight)	20,329 ± 1,266	19,631 ± 1,626	20,756 ± 169	0.271	0.09
Payback Period (months)	5.99 ± 2.40	5.64 ± 2.65	5.12 ± 1.37	0.412	0.05
B/C Ratio	0.12 ± 0.07	0.16 ± 0.10	0.20 ± 0.01	0.176	0.13

Values are presented as mean ± SEM (n = 5 replicate pens per treatment); Economic values are expressed in Indonesian Rupiah (IDR); Partial η² values indicate the magnitude of treatment effects; R/C = Revenue-to-cost; BEP = Break-even-point; B/C = Benefit-to-cost

Table 4. Detailed economic analysis of broiler production under phytogenic–probiotic supplementation

Parameter	P0 (Control)	P1 (1% *Phyllanthus niruri* + Probiotic)	P2 (2% *Phyllanthus niruri* + Probiotic)
Feed cost (IDR)	16,758,000 ± 428,000	17,496,000 ± 512,000	19,410,000 ± 463,000
Additive cost (IDR)	0 ± 0	842,000 ± 36,000	1,584,000 ± 52,000
Total production cost (IDR)	33,742,000 ± 1,266,000	35,431,000 ± 1,626,000	39,612,000 ± 169,000
Revenue (IDR)	37,791,000 ± 2,114,000	41,100,000 ± 2,486,000	47,534,000 ± 1,973,000
Net profit (IDR)	4,049,000 ± 848,000	5,669,000 ± 1,024,000	7,922,000 ± 1,118,000

Values are presented as mean ± SEM (n = 5 replicate pens per treatment); Feed cost was calculated based on feed intake and feed price (IDR 6,000/kg); Revenue was estimated from total live body weight and market price (IDR 21,000/kg live weight)

increased body weight. Additive cost was highest in the P2 treatment because of the higher inclusion level of *Phyllanthus niruri* flour combined with probiotic supplementation. Despite the increased production cost, the P2 treatment generated the highest revenue and net profit, indicating that improved biological performance contributed positively to economic returns. The R/C ratio increased from 1.12 in the control (P0) to 1.20 in the P2 treatment, although the difference was not statistically significant (P = 0.184). Based on the R/C ratio threshold (>1), all treatments were categorized as economically feasible under the current market assumptions, but phytogenic–probiotic supplementation showed a tendency to increase profitability. These results indicate that all treatments were economically feasible under the current assumptions.

The Break-Even Point (BEP, IDR/kg live weight) did not differ significantly among treatments (P = 0.271). The BEP value represents the minimum selling price required to cover total production costs. Lower BEP values indicate lower economic risk because profitability can be achieved at a lower market selling price. Under the assumptions used in this study, phytogenic–probiotic supplementation did not significantly affect the minimum selling price required to reach break-even conditions. The Payback Period (PP) showed a numerical decrease from P0 to P2; however, the differences among treatments were not statistically significant (P = 0.412). This trend suggests that phytogenic–probiotic supplementation may contribute to faster capital recovery through improved production efficiency, although further studies with longer production cycles are needed to confirm this effect. In addition, the B/C ratio showed an upward trend from 0.12 (P0) to 0.20 (P2), although the difference was not statistically significant (P = 0.176). This increase strengthens the indication that phytogenic–probiotic combinations contribute to an increase in profit margins per business unit. Overall, these results–probiotic combinations suggest that phytogenic–probiotic combinations may contribute to improved economic efficiency on economic efficiency, especially through increased productivity that contributes to increased income per head, as reported in studies related to the use of probiotic-based and phytogenic feed additives.

3.4 Correlation between biological performance and economic efficiency

Correlation analysis showed that body weight was negatively correlated with FCR (r = −0.68; p = 0.001), indicating improved feed efficiency at higher growth performance. Furthermore, body weight was positively associated with R/C ratio (r = 0.59; p = 0.184), although the association was not statistically significant. These relationships confirm that production efficiency is a key driver of profitability in broiler production systems.

4. Discussion

Phytogenic–probiotic administration based on *Phyllanthus niruri* and *Lactobacillus acidophilus* and *L. casei* significantly improved growth performance of broiler chickens which may be associated with improved digestive efficiency, as reported in previous studies, although these mechanisms were not directly evaluated in the present study. Previous studies have suggested that phytogenic compounds and probiotics may exert complementary biological functions. However, because only combined treatments were evaluated in the present study, the individual or synergistic contributions of each additive cannot be confirmed (Song et al. 2022; Khosravi et al. 2025). Previous studies have reported that *Lactobacillus spp*. may suppress pathogenic bacterial populations and may stimulate digestive enzyme activity; however, these mechanisms were not evaluated in the present study (Arif et al. 2021; Feng et al. 2023). On the other hand, previous studies have suggested that *Phyllanthus niruri* may support intestinal integrity and antioxidant status, although these parameters were not measured in the current experiment, thereby potentially supporting a more efficient and stable digestive environment (Aminullah et al. 2025; Obianwuna et al. 2024). The combined application of these two components may be associated with improved feed conversion efficiency, as reflected in the higher body weight and lower FCR observed in the phytogenic–probiotic treatment. However, the underlying biological mechanisms were not directly evaluated in the present study and therefore the observed effects were interpreted based on previous findings.

The results of this study showed strong consistency with the international literature that reports that phytogenic–probiotic supplementation can improve growth performance and feed efficiency in broiler chickens through improved physiological function of the digestive tract. Previous studies have reported that phytogenic–probiotic combinations increase enzymatic activity and intestinal absorptive surface area, although these mechanisms were not directly evaluated in the present study, thereby increasing nutrient utilization efficiency and tissue growth (Leite et al. 2020; Dev et al. 2020; Nisar et al. 2021). In addition, the dose-dependent performance enhancement in this study demonstrates a dose-dependent response to the combined supplementation evaluated in this experiment and has been reported in earlier studies as well (Younis et al. 2024; Hossain et al. 2025). However, the absence of significant differences in feed consumption suggests that improved performance is more influenced by metabolic efficiency than increased intake, which is in line with the finding that phytogenic–probiotic combinations play a greater role in optimizing nutrient utilization than stimulating feed consumption (Soumeh et al. 2021). Thus, the results of this study are not only consistent with previous findings, but also strengthen the evidence that the local herb-based phytogenic–probiotic combination approach has high potential as a strategy to improve the production performance of broiler chickens in a sustainable manner.

Comparisons between P1 and P2 treatments showed that increasing the phytogenic–probiotic combination dose from 1% to 2% resulted in a consistent biological response to broiler chicken growth performance. The data showed that the P2 group produced a significantly higher final body weight and performance index than P1, followed by a more efficient reduction in FCR values. This pattern indicates a dose–response relationship that tends to be linear, where increasing the level of *Phyllanthus niruri* combined with probiotics *Lactobacillus acidophilus* and *L. casei* gradually improved the efficiency of nutrient utilization and production performance. These findings are in line with various studies that report that phytogenic–probiotic combination in higher doses can improve the balance of the gut microbiota, increase the activity of digestive enzymes, and strengthen the integrity of the intestinal mucosa, thus having a direct impact on improving growth performance (Dev et al. 2020; Song et al. 2022; Khosravi et al. 2025; Du et al. 2023; Nisar et al. 2021). In addition, the role of *Lactobacillus*-based probiotics in suppressing pathogenic bacterial populations and improving nutrient digestion is also important factors explaining the decrease in FCR at higher doses (Arif et al. 2021; Feng et al. 2023; Soumeh et al. 2021). Thus, the increased performance of P2 compared to P1 confirms that increasing the inclusion level of the phytogenic–probiotic supplementation was associated with improved performance. Nevertheless, this study cannot determine whether these responses resulted from the individual effects of phytogenic compounds, probiotics, or their interaction because separate treatment groups were not included (Aminullah et al. 2025; Obianwuna et al. 2024; Urban et al. 2025).

Although the response shown tends to be linear, the results of this study also indicate the potential biological threshold for the use of phytogenic–probiotic combination, especially when associated with economic parameters such as Payback Period which actually increases at the highest dose. This condition suggests that dose increases are not always followed by proportionate economic efficiency, leading to a partial optimal pattern between biological performance and economic returns. Physiologically, this phenomenon can be explained through the concept that the capacity of the digestive and metabolic systems of chickens has a limit in responding to feed additive stimulation, where after a certain point, an increase in the dose only provides an incremental benefit (diminishing return) or even increases the metabolic load (Śliżewska et al. 2020; Younis et al. 2024; Salarmoini and Fooladi 2025). In addition, increasing inputs at high levels can also change the structure of production costs, thereby extending the return on capital even though technical performance improves (Van Wagenberg et al. 2020; Mohammed et al. 2022; Anggriawan et al. 2025a). Therefore, the main novelty of this study lies in the ability to identify the biological threshold effect, which is the point at which an increase in phytogenic–probiotic combination doses still provides maximum biological benefits, but begins to show limitations in terms of economic efficiency. These findings make an important contribution to determining the optimal dose of phytogenic–probiotic supplementation that are not only biologically effective, but also economically rational in modern broiler production systems.

The improvement of biological performance in this study has direct implications for improved economic efficiency of broiler businesses through a more optimal nutrient utilization mechanism. The decrease in the Feed Conversion Ratio (FCR) value in phytogenic–probiotic combination treatment shows that chicken are able to convert feed into body weight more efficiently. Consequently, the feed costs, which represent the largest proportion of total production cost, may be reduced proportionally due to improved feed conversion efficiency, although the relative contribution of each cost component of supplement was not separately quantified in this study. Improved modulation of the intestinal microbiota may contribute to enhancement of favourable gut microbiota and suppression of pathogenic bacteria, as suggested in previous studies as well, although microbiota composition was not analyzed in this study (Arif et al. 2021; Feng et al. 2023; Khosravi et al. 2025; Song et al. 2022). In parallel, the increase in final body weight (BW) in the P2 treatment contributes to an increase in production output per head, which ultimately increases the value of business revenue. This causal relationship between increased feed efficiency and growth has been consistently reported as a major factor in increasing profit margins in intensive broiler production systems (Dev et al. 2020; Nisar et al. 2021; Soumeh et al. 2021; Obianwuna et al. 2024). Thus, the phytogenic–probiotic combination not only works at the physiological level, but also produces a derivative effect in the form of an increase in overall production efficiency.

From the perspective of financial feasibility, the results of this study indicate that phytogenic–probiotic combination may show a numerical trend toward higher profitability under the specific price assumptions used; however, economic outcomes may vary depending on market fluctuations and regional price variability. The increasing trend in R/C ratio and B/C ratio observed in phytogenic–probiotic combination treatments suggests that each unit of production cost generated higher economic returns, indicating that the production system remained financially feasible. In addition, the numerical reduction in Payback Period observed in the P2 treatment suggests that improved production efficiency may contribute to faster capital recovery. However, because the differences were not statistically significant, this parameter should be interpreted cautiously and requires further validation under broader commercial production conditions. These findings indicate that improved biological performance may contribute positively to economic efficiency through increased productivity and technical performance. Overall, the results suggest that the application of *Phyllanthus niruri*-based phytogenic–probiotic supplementation has potential as an economically viable and biologically relevant feed additive strategy for modern broiler production systems, particularly in closed-house systems that require high efficiency and production stability (Andriani et al. 2020; Mohammed et al. 2022; Van Wagenberg et al. 2020; Patel et al. 2023).

Closed-house systems provide a controlled environment that can minimize fluctuations in temperature, humidity, and air quality so that the chicken's physiological response to nutrient interventions becomes more stable and measurable. These relatively homogeneous environmental conditions may facilitate a more consistent production response to phytogenic–probiotic supplementation. However, digestive efficiency, gut microbiota balance, and nutrient utilization were not directly measured in this study, as reflected in the improvement in body weight and FCR values in this study. These findings reinforce the finding that probiotics and phytogenic–probiotic combination work optimally when environmental factors are controlled, as low stress pressure will support the colonization of beneficial bacteria as well as intestinal barrier function (Arif et al. 2021; Prentza et al. 2022; Feng et al. 2023; Du et al. 2023; Khosravi et al. 2025). In addition, the phytogenic compounds present in *Phyllanthus niruri* act as immunomodulators and antioxidants that are increasingly effective in minimally stressful environmental conditions, so that they can improve metabolic efficiency and overall production performance (Aminullah et al. 2025; Obianwuna et al. 2024; Pasaribu et al. 2023). Thus, the interaction between environmental control and phytogenic–probiotic combination creates a more precise production system, where biological variability can be reduced and the response to treatment becomes more pronounced.

From an industry perspective, the application of phytogenic–probiotic combinations in closed-house systems has strategic implications in supporting large-scale intensive production because this technology not only improves biological performance but also provides opportunities to improve business efficiency in a sustainable manner. Closed-house systems that are commonly used in large populations allow for the widespread adoption of feed additive technology with a high level of yield consistency, making it suitable for integration in modern production management based on efficiency and standardization (Anggriawan and Kurniawan 2020b). Further, the increased productivity resulting from phytogenic–probiotic combination was numerically associated with higher profit margins, although in some cases it requires a higher initial investment as reflected in economic parameters such as the Payback Period (Andriani et al. 2020; Mohammed et al. 2022; Van Wagenberg et al. 2020). The main added value of this approach lies in the *scalability* aspect, where phytogenic–probiotic combination can be widely applied at various business scales without significant changes to the infrastructure, thus allowing for replication of research results at the commercial industry level. Thus, the combination of closed house and phytogenic–probiotic systems is not only biologically relevant, but also has high prospects as a practical and sustainable solution in increasing the competitiveness of the modern poultry industry (Anggriawan et al. 2024a; Patel et al. 2023).

5. Study limitations

This study did not directly evaluate gut microbiota composition, digestive enzyme activity, intestinal morphology, or antioxidant status. Therefore, the proposed biological mechanisms were interpreted based on previous literature. Future studies are needed to confirm the physiological pathways underlying the phytogenic–probiotic effects observed in broiler chickens. Because the pen rather than the individual bird constituted the experimental unit, statistical inference was based on five independent replicate pens per treatment. Although each pen contained 1,000 birds, the experimental unit remained the pen ($n = 5$ per treatment). Therefore, the large number of birds improved the practical relevance of the findings but did not increase statistical power or the number of independent observations. Accordingly, the results should be interpreted within the limitations of pen-level replication. Another limitation of this study is that only combined phytogenic–probiotic treatments were evaluated. Therefore, the present experimental design does not allow separation of the individual effects of *Phyllanthus niruri* and probiotic supplementation, nor does it permit confirmation of a synergistic interaction between these two additives. Future studies should include phytogenic-only and probiotic-only treatment groups using a factorial experimental design. In addition, specific strain identification of the probiotic cultures was not available from the commercial manufacturer. Therefore, the present study could not evaluate potential strain-specific effects of *Lactobacillus acidophilus* and *Lactobacillus casei*, which should be considered when interpreting the results. Future studies should include fully characterized probiotic strains to improve reproducibility and facilitate comparisons among experiments. No microbiological validation was performed in the present study. Intestinal bacterial counts, microbial diversity analysis, or metagenomic characterization were not evaluated. Consequently, any interpretation regarding gut microbiota modulation remains speculative and should be interpreted with caution. Future studies should incorporate microbiological analyses to verify the mechanisms underlying the observed production responses.

6. Conclusions

Phytogenic–probiotic combination based on *Phyllanthus niruri* and probiotics *Lactobacillus acidophilus* and *L. casei* significantly improved growth performance and feed efficiency in broiler chickens under the conditions of this study. However, the underlying mechanisms related to gut microbiota, digestibility, and nutrient absorption were not directly evaluated and require further investigation. In practical terms, these findings confirm that the application of *Phyllanthus niruri*-based phytogenic–probiotic combination has the potential to be an effective, economical, and sustainable feed additive strategy as a substitute for AGP to increase the productivity and competitiveness of broiler businesses in intensive production systems. Because the experimental design included only combination treatments, the present study cannot distinguish the independent effects of phytogenic compounds and probiotics or demonstrate a synergistic interaction between them.

Declarations

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