Research Article

Effects of *Lacticaseibacillus paracasei* and Monensin on Performance and Antioxidant Status in *Eimeria tenella* Infected Broilers

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Abstract | Coccidiosis caused by *Eimeria tenella* remains one of the most detrimental parasitic diseases in poultry, leading to impaired growth performance, poor feed conversion, and substantial economic losses, thereby hindering sustainable poultry production. This study aimed to evaluate the effects of the probiotic *Lacticaseibacillus paracasei*, administered alone or in combination with the anticoccidial agent monensin, on growth performance, feed conversion ratio (FCR), and antioxidant status in broiler chickens experimentally infected with E. tenella. A total of 125 one-day-old broiler chickens were randomly assigned to five groups: uninfected control, infected control, monensin, probiotic, and combined probiotic plus monensin. The probiotic was provided in drinking water (4 mL/L; 1×10^8 CFU/mL), while monensin was included in the diet (1 g/kg). Growth performance parameters and antioxidant indicators, including superoxide dismutase (SOD) activity and malondialdehyde (MDA) levels, were measured and statistically analyzed. The co-administration of L. paracasei and monensin significantly ($P < 0.05$) increased body weight gain and improved FCR compared to the infected control group. Furthermore, these enhancements were statistically superior ($P < 0.05$) to those observed with probiotic treatment, indicating a synergistic effect of combined treatment. These findings suggest that supplementation with *L. paracasei*, particularly when combined with monensin, enhances feed efficiency, oxidative balance, and overall health performance in *E. tenella* infected broilers. The integration of probiotics with anticoccidial agents represents a promising strategy for sustainable poultry production and improved food security.

Keywords | Antioxidant status, *Eimeria tenella, Lacticaseibacillus paracasei*, Malondialdehyde, Poultry, Probiotics

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INTRODUCTION

Coccidiosis, caused by *Eimeria* spp., is one of the most economically significant parasitic diseases in poultry, leading to substantial financial losses due to stunted growth, low feed conversion rates, and elevated mortality. Regarding these, *Eimeria tenella* is especially well-known for causing large cecal lesions and interfering with broiler nutrient absorption, which lowers production and compromises intestinal integrity (Mohsin *et al.*, 2022). Complicating the burden of this disease are high rates of morbidity and mortality as well as the related expenses of chemotherapeutic control. The Ministry of Agriculture and Rural Affairs of the People's Republic of China (PRC, 2023) indicated that the peak incidence of coccidiosis transpired from April to September 2023, comprising up to 90% of all documented cases, hence highlighting its global significance.

Anticoccidial medications, such as monensin, an ionophore that remains a cornerstone in the prevention of coccidiosis, are a major component of conventional control tactics. Monensin's effectiveness has been mechanistically linked to its capacity to disrupt *E. tenella's* life cycle by inducing autophagy and programmed cell death (Qi *et al.*, 2020; Zhang *et al.*, 2022). Nevertheless, the emergence of resistant Eimeria strains and the increasing consumer demand for antibiotic-free poultry production systems have given rise to concerns regarding the long-term reliance on ionophores. Alternative or complementary strategies to maintain intestinal health while maintaining production efficiency have been the subject of interest in response to these concerns.

Although monensin is often included in discussions about antibiotic use in animal husbandry, legally and according to pharmaceutical regulations, monensin is classified as an ionophore and is widely used as an antiprotozoal agent and growth promoter in the livestock industry, including in Indonesia and several other countries. Currently, efforts to reduce antibiotic use in the livestock industry are increasingly driven by concerns about antimicrobial resistance and its impact on human health. The use of monensin as an anticoccidial agent is a strategic step that is permitted and regulated at both national and international levels, distinguishing its use from antibiotics used in human medicine. In the context of this research, the use of monensin aims to reduce dependence on antibiotics during the coccidiosis control process, while also demonstrating that a combination of probiotics and ionophores can be a safe and effective approach to maintaining animal health without violating the principles of antibiotic-free animal product development.

Probiotics have emerged as potential biological alternatives. *Lacticaseibacillus paracasei* (formerly *Lactobacillus paracasei*) received attention for its capacity to reduce oxidative stress, enhance immune responses, and modulate intestinal microbiota in broilers that have been infected with *Eimeria tenella* (Kang *et al.*, 2023; Lima *et al.*, 2020). Probiotic supplements have been shown to strengthen the integrity of the gut barrier and improve nutrient utilization by improving intestinal morphology, increasing the activity of antioxidant enzymes like glutathione peroxidase (GSH-Px) and superoxide dismutase (SOD), and lowering malondialdehyde (MDA) levels (Mohsin *et al.*, 2022; Wang *et al.*, 2021). Probiotics enhance microbial balance by promoting beneficial taxa such as Lactobacillus and Bacteroides while inhibiting pathogenic bacteria including *Clostridium*, *Escherichia*, *Shigella*, and *Salmonella*, resulting in a healthier intestinal environment (Chen *et al.*, 2024; Guo *et al.*, 2025).

According to recent research, administering probiotics alongside anticoccidials like monensin may have additive effects. While *L. paracasei* improves gut health, antioxidant defense, and immunological modulation, monensin directly targets parasites by affecting ion homeostasis (El-Shall *et al.*, 2024). The capacity for improved coccidiosis management without sacrificing growth performance is presented by this dual approach. There is, however, lacking of studies directly comparing *L. paracasei* and monensin, either separately or in combination, under standardized *E. tenella* challenge circumstances, especially during the finisher phase, when metabolic balance and growth efficiency are crucial for total production.

In order to determine if adding *Lacticaseibacillus paracasei* to drinking water, either alone or in combination with monensin, may improve the growth performance and oxidative stress status of broilers that have been experimentally challenged with *E. tenella*, this study was carried out. In comparison to infected controls, we predicted that *L. paracasei* would increase feed intake, body weight gain, and feed conversion ratio. We also predicted that, because of complementary parasite- and host-directed mechanisms, its combination with monensin would result in the largest increase in feed efficiency. Furthermore, it is anticipated that taking probiotic supplements will improve the antioxidant defense system, as seen by higher SOD activity and lower MDA levels (Mohsin *et al.*, 2022; Qi *et al.*, 2020; Wang *et al.*, 2021). This study uses a standardized *E. tenella* challenge model to give a novel comparative evaluation of water-delivered *L. paracasei* and monensin, both separately and together. Through the integration of oxidative biomarkers and performance data, this study provides a cohesive view of how probiotic–ionophore interactions improve redox homeostasis and feed efficiency.

Links Researchers

The development of sustainable drug-reduced poultry production methods that strike a compromise between food safety, animal welfare, and efficacy is anticipated to be aided by these findings.

MATERIALS AND METHODS

Study period and location

The study was carried out from July to October 2025 at the Universitas Airlangga Faculty of Veterinary Medicine in Surabaya, Indonesia. Floors, brooders, feeders, drinkers, and the raising facility were all cleaned, disinfected, and allowed to dry for three days prior to the arrival of day-old chicks (DOCs). Each of the five circular brooder pens (60 cm in height and 92 cm in diameter) was coated with around 8 cm of bedding made of rice husks and covered with a newspaper. The chicks were given sugar water and multivitamins for three days after they arrived to help them adjust. On day five of the vaccination protocol, the Newcastle Disease (ND) HB1 vaccine was given via eye drops, and on day fourteen, ND Lasotta. The temperature and humidity were recorded using thermometers and hygrometers (32–34 °C and 60–70% relative humidity, respectively), and brooding was kept under control by 25-Watt heat lamps. The following nutrients were included in the basal diet on a dry matter basis: 89.96% dry matter, 5.93% ash, 23.85% crude protein, 7.13% crude fat, 3.05% crude fiber, and 3,154.31 kcal/kg metabolizable energy.

Experimental design and treatments

A completely randomized design (CRD) was implemented, involving 125-day-old broiler chicks allocated into five treatments, each with five replicates and five birds per replicate. Probiotic *L. paracasei* added via drinking water at 4 mL/L starting from Day 1 until Week 6. Monensin incorporated into feed at 1 g/kg starting from Day 1 until Day 26. Treatment with *Eimeria tenella* performed on Day 21, with 10,000 oocysts per bird. The key measurement points in week 5 Body weight gain (BWG), feed intake (FI), and sampling for oxidative status are recorded. In week 6 Final body weight, blood collection for SOD and MDA assays, and necropsy.

The administration of monensin was limited to days 1 through 26, while the probiotic was provided continuously until the end of the experiment (week 6). *E. tenella* inoculation was performed on day 21, so monensin was discontinued five days after inoculation.

The rationale behind administering monensin during this period is based on industry regulations and common practices, where ionophore administration like monensin is often carried out during the early growth phase to effectively prevent and control coccidiosis infections while the parasite is proliferating in the gastrointestinal tract. Discontinuing monensin after weeks 3 or 4 is frequently practiced to reduce residue risk in meat and to comply with updated regulations regarding the use of antibiotics and ionophores in feed.

Additionally, stopping monensin on day 26 aims to evaluate residual effects and potential interactions with the probiotic during active parasitic stages and ongoing immune responses. In commercial and clinical settings, monensin usage protocols vary depending on the farm and region; however, generally, administering during early growth phases and ceasing before the end of the growth cycle is a common strategy to reduce residues and align with local regulations.

The treatments included the following.

- P0 (–) = negative control (uninfected, no probiotic or monensin)
- P0 (+) = positive control (infected with *Eimeria tenella* 1×10^4 oocysts, no probiotic or monensin).
- P1 = monensin 1 g/kg feed + *E. tenella* infection (1×10^4 oocysts)
- P2 = *L. paracasei* 4 mL/L drinking water + *E. tenella* infection (1×10^4 oocysts)
- P3 = *L. paracasei* 4 mL/L drinking water + monensin 1 g/kg feed + *E. tenella* infection (1×10^4 oocysts)

Probiotic supplementation (*L. paracasei*) was administered through drinking water from day 1 to week 6, whereas monensin was mixed into the feed from days 1 to 26, following the manufacturer's recommendation. Oral inoculation with *Eimeria tenella* was performed on day 21.

Data collection

Data collection followed the guidelines set forth by the Association of Official Analytical Chemists (AOAC). Weekly records of growth performance parameters were kept, including body weight gain (BWG), feed intake (FI), feed conversion ratio (FCR), and feed efficiency (FE). By dividing the total feed intake (g) by the BWG (g), the FCR was calculated; lower values denoted higher feed efficiency. BWG divided by the total feed intake was used to calculate FE, which was then expressed as a percentage. Using conventional humane methods, blood samples were taken from all broilers on day 42 before they were killed by exsanguination through the jugular, brachial (cutaneous ulnar), and ischiadic (sciatic) veins.

Statistical analysis

A completely randomized design was used to assess all of the data that was gathered. Prior to the analysis of variance (ANOVA), the normality and homogeneity of variance were confirmed. We employed SPSS Statistics v27 (IBM

Corp., Armonk, NY, USA) to execute a one-way analysis of variance (ANOVA). Duncan's multiple range test was employed for post-hoc comparisons where there were big disparities. Statistical significance was established at a value of $P < 0.05$.

RESULTS

Feed intake

The feed intake data for broilers is summarized in Table 1. Among the interventions, no significant differences *(P > 0.05)* were observed at week 4. Significant variations were observed at weeks 5 and 6 ($P < 0.05$). Broilers that were treated with *Lacticaseibacillus paracasei* (P2) or the combined treatment of *L. paracasei* + monensin (P3) exhibited a higher feed intake than the infected untreated control (P0 +) during week 5. Feed intake values at week 5 varied from 154.82 ± 14.85 g (P0 +) to 168.17 ± 1.48 g (P2). Differences among regimens were not statistically significant at week 6.

Table 1: Feed intake (g/bird/day) of broiler chickens under different treatments

Week	Treatment				
	P0 (-)	**P0 (+)**	**P1**	**P2**	**P3**
5	166.79^{b} ± 1.89	154.82^{a} ± 14.85	164.13^{ab} ± 4.30	168.166^{b} ± 1.48	166.00^{b} ± 7.81
6	126.04^{a} ± 4.35	124.92^{a} ± 3.10	126.59^{a} ± 1.63	127.66^{a} ± 1.45	127.66^{a} ± 1.04

^{a,b,c} Different superscript letters within a row indicate statistically significant differences between treatment groups ($P < 0.05$).

Feed conversion ratio (FCR)

The feed conversion ratio (FCR), which is a critical metric for feed efficacy, is presented in Table 2. Early infection or probiotic supplementation did not appear to have an impact on feed utilization at week 4. At this time, no substantial differences were observed among the treatments. Effects were significant at weeks 5 and 6 ($P < 0.05$). During weeks 5 and 6, the positive control group (P0 +) demonstrated the maximum FCR values (1.65 ± 0.08 and 1.78 ± 0.76, respectively), which suggests that the infection with *E. tenella* resulted in a decrease in efficiency. The lowest FCR was observed in P3 (1.38 ± 0.07) at week 6, followed by P2 (1.44 ± 0.12). Conversely, *L. paracasei* (P2) and the combination of *L. paracasei* and monensin (P3) enhanced feed efficiency. These values were substantially lower than those of the infected control, which serves as evidence of the advantageous effects of probiotic supplementation on nutrient utilization during coccidial challenges.

Feed efficiency

Table 3 presents the feed efficiency (FE) results. Statistically significant differences ($P < 0.05$) were observed between the groups at weeks 5 and 6. At week 6, the combined treatment group P3 had the highest FE (72.27 ± 4.12%), followed by P2 (69.51 ± 5.94%). Infected control group P0 + had the lowest efficiency (57.72 ± 3.29%). These data show that *L. paracasei*, when supplied alone or in combination with monensin, improved feed utilization efficiency compared to infected, untreated birds.

Table 2: Feed conversion ratio (FCR) of broiler chickens subjected to various treatments.

Week	Feed Conversion Ratio (FCR)				
	P0 (-)	**P0 (+)**	**P1**	**P2**	**P3**
5	1.58^{bc} ± 0.11	1.65^{c} ± 0.08	1.56^{abc}± 0.13	1.45^{a}± 0.06	1.51^{ab} ± 0.03
6	1.62^{bc} ± 0.23	1.78^{c} ± 0.76	1.55^{ab} ± 0.17	1.44^{ab} ± 0.12	1.38^{a} ± 0.07

^{a,b,c} Different superscript letters within a row indicate statistically significant differences between treatment groups ($P < 0.05$).

Table 3: Feed efficiency (%) of broiler chickens under different treatments.

Week	Feed efficiency (%)				
	P0 (-)	**P0 (+)**	**P1**	**P2**	**P3**
5	63.46^{ab} ± 4.80	62.07^{a}± 4.85	64.28^{ab}± 5.05	69.18^{b} ± 3.01	66.42^{ab}± 1.29
6	62.63^{ab} ± 8.98	57.72^{a} ± 3.29	62.41^{ab} ± 6.05	69.51^{bc} ± 5.94	72.27 ± 4.12^{c}

^{a,b,c} Different superscript letters within a row indicate statistically significant differences between treatment groups ($P < 0.05$).

Body weight gain (BWG)

The average daily body weight gain is presented in Table 4. Significant improvements ($P < 0.05$) were observed in the probiotic-supplemented groups compared to the infected controls. At week 5, BWG was highest in the *L. paracasei* group (P2; 88.14 ± 9.02 g/bird/day) and in the combined treatment (P3; 78.80 ± 8.28 g/bird/day). At week 6, P3 exhibited the greatest increase (115.14 ± 24.90 g bird^{-1} day^{-1}), followed by P2 (93.83 ± 18.57 g bird^{-1} day^{-1}), whereas P0 showed the lowest gain (42.65 ± 13.73 g bird^{-1} day^{-1}).

Table 4: Average daily body weight gain (g/bird/day) of broilers under different treatments

Week	Body Weight gain (g/bird/day)				
	P0 (-)	**P0 (+)**	**P1**	**P2**	**P3**
5	61.74^{ab} ± 17.90	46.34^{a}± 11.02	64.48^{ab}± 25.24	88.14^{c}± 9.02	78.80^{bc} ± 8.28
6	66.57 ± 48.12^{ab}	42.65 ± 13.73^{a}	52.60 ± 28.00^{a}	93.83 ± 18.57^{bc}	115.14 ± 24.90^{c}

^{a,b,c} Different superscript letters within a row indicate statistically significant differences between treatment groups ($P < 0.05$).

Antioxidant enzyme activity (SOD) and lipid peroxidation (MDA)

The levels of superoxide dismutase (SOD) and malondialdehyde (MDA) are summarized in Table 5. SOD activity, an indicator of antioxidant capacity, differed significantly among treatments (*P < 0.05*). The combined treatment group (P3) demonstrated the highest SOD activity (5.68 ± 0.02 U/mL at week 5) followed by the probiotic-only group (P2; 4.93 ± 0.05 U/mL), whereas the infected control (P0 -) showed the lowest (3.74 ± 0.01 U/mL).

Table 5: Superoxide dismutase (SOD) activity (U/mL) of broiler serum under different treatments.

Week	SOD				
	P0 (-)	P0 (+)	P1	P2	P3
5	3.74^{a}± 0.01	4.11^{a}± 0.01	4.40^{a}± 0.03	4.93^{a}± 0.05	5.68^{b}± 0.02
6	19.30^{b}± 0.76	20.53^{bc}± 0.99	21.75^{c}± 1.25	19.93^{b}± 1.33	24.14^{d} ±0.06

a,b,c Different superscript letters within a row indicate statistically significant differences between treatment groups (*P < 0.05*).

MDA, a biomarker of lipid peroxidation and oxidative damage, also varied significantly among the groups (*P < 0.05*). The lowest MDA concentrations were observed in the combined treatment group, P3 (12.31 ± 0.21 µmol/L at week 5), In general, higher SOD and lower MDA levels indicate reduced oxidative stress and improved redox balance in birds receiving *L. paracasei* supplementation.

DISCUSSION

The purpose of this study was to explore the effects of the probiotic *Lacticaseibacillus paracasei* on growth performance, feed efficiency, and oxidative stress indicators in broilers that were challenged with *Eimeria tenella*. The probiotic was supplied either alone or in conjunction with the ionophore anticoccidial monensin. Probiotic supplementation was found to be beneficial for infected birds, as evidenced by the persistent observation of significant changes (*P < 0.05*) across a range of performance indicators and biochemical indices.

Feed intake

As shown in Table 1, broilers supplemented with *L. paracasei* (P2) or a combination of *L. paracasei* and monensin (P3) demonstrated significantly higher feed intake than the infected, untreated control group (P0+) during week 5 *(P < 0.05*). The improvement in feed intake might be attributed to the ability of probiotics to alleviate intestinal inflammation, enhance mucosal integrity, and promote appetite recovery after *E. tenella* infection. Previous studies have reported that *E. tenella* infection damages the intestinal epithelium and induces inflammation, thereby suppressing feed intake (Campos *et al*., 2022). Furthermore, local research by Yulianto *et al*. (2024) and Giannenas *et al*. (2014) reported that supplementation with probiotics counteracts these effects by restoring gut functionality and microbial balance. Thus, *L. paracasei* likely contributes to improved nutrient absorption and gastrointestinal comfort, enabling birds to maintain a higher feed intake even under parasitic stress.

Feed conversion ratio (FCR) and feed efficiency (FE)

The results of the feed conversion ratio and feed efficiency (Tables 2 and 3) indicated that the supplementation of *L. paracasei*, especially in conjunction with monensin (P3), significantly *(P < 0.05)* enhanced feed utilization efficiency relative to the infected control group. The lowest feed conversion ratio (FCR) of 1.38 ± 0.07 and the highest feed efficiency (FE) of 72.27 ± 4.12% were recorded in P3 during week 6, indicating potential additive effects of the probiotic and anticoccidial treatments. The enhancement of feed conversion ratio (FCR) is linked to improved nutrient digestibility and absorption, resulting from probiotic-induced changes in intestinal microbiota. This includes an increase in beneficial bacterial populations, such as *Lactobacillus* and *Bacteroides*, alongside a reduction in pathogenic taxa, including *Clostridium*, *Escherichia–Shigella*, and *Salmonella* (Chen *et al*., 2024; Guo *et al*., 2025).

These results are in accordance with reports that probiotics can enhance growth and FCR in poultry that have been infected with *Eimeria* spp. by preserving gut integrity and immune balance (Kang *et al*., 2023; Lima *et al*., 2020). The addition of monensin enhances this effect by reducing oocyst shedding and inhibiting parasite replication through the disruption of ion gradients (Qi *et al*., 2020). Study by Lokapirnasari *et al*. (2025) also demonstrated that *L. paracasei* improves economic efficiency and performance in pathogen-challenged broilers. Hence, similar to the findings of (El-Shall *et al*., 2024; Bozkurt *et al*., 2014), the combined treatment (P3) indicates a synergistic interaction between host-directed (probiotic) and parasite-directed (ionophore) mechanisms, resulting in superior feed utilization efficiency.

Body weight gain (BWG)

Groups P2 and P3 showed a significant (P < 0.05) improvement in average daily body weight gain compared to P0+ (Table 4). The maximum BWG (115.14 ± 24.90 g/bird/day) was seen in birds who received *L. paracasei* and monensin (P3) combined, indicating potential synergistic interaction in immune regulation and nutritional absorption. Probiotic supplementation improves growth by increasing the height of villus, increasing the activity of digesting enzymes, and promoting the production of antioxidant enzymes (Awais *et al*., 2019; Kang *et al*., 2023). Monensin is a supplement that works in conjunction with this by inhibiting the proliferation of *E. tenella*, minimizing tissue damage, and enhancing the retention of nutrients (Qi *et al*., 2020). Similarly, Yulianto *et al.* (2021) found that probiotic supplementation enhanced the production of immunological markers (ChIFN-γ and ChIL-10) in broilers infected with *E. tenella*, indicating an immunomodulatory mechanism behind the growth augmentation. These findings collectively demonstrate that *L. paracasei*, either alone or in combination, encourages recuperation and compensatory growth after a coccidial infection.

Antioxidant status

The *L. paracasei* supplemented groups (P2 and P3) had significantly ($P < 0.05$) lower MDA concentration and significantly ($P < 0.05$) higher SOD activity compared to the infected control, as shown in Tables 5 and 6. While lower MDA levels signify less oxidative stress and lipid peroxidation, higher SOD levels show improved antioxidant defense. The maximum SOD activity was obtained with combined treatment (P3), suggesting that ionophore and probiotic co-supplementation successfully reduced oxidative damage.

Table 6: Malondialdehyde (MDA) concentration (μmol/L) in the serum of broiler chickens under different treatments.

Week	MDA				
	P0 (-)	P0 (+)	P1	P2	P3
5	18.08^{d}± 0.02	19.61^{e} ± 0.08	16.87^{c}± 0.08	15.50^{b}± 0.04	12.31^{a} ± 0.21
6	46.15^{c}± 1.55	34.95^{b}± 0.53	33.05^{a}± 1.90	50.044^{d}± 1.10	31.59^{a} ± 0.97

^{a,b,c} Different superscript letters within a row indicate statistically significant differences between treatment groups ($P < 0.05$).

Biologically, the significant increase in SOD activity could be due to a stronger antioxidant response in the later stages of the experiment, either in response to oxidative stress caused by infection or to an improved immune system following treatment with probiotics and monensin. During this period, the chickens' bodies may experience increased production of antioxidant enzymes as a defense mechanism to address oxidative damage that may have occurred due to *Eimeria tenella* infection, as well as active tissue repair processes.

In terms of experimental factors, these changes could also be due to variability in sampling, differences in treatment timing that affect the induction of defense mechanisms, or limitations in the measurement method. For example, if measurements were taken when the chickens were entering the recovery phase or experiencing increased immune activity, this could be reflected as a surge in SOD activity. The significant increase may also indicate that the antioxidant defense system is peaking, which is consistent with the decrease in MDA indicating improved oxidative status.

Given that *E. tenella* infection induces oxidative stress and disrupts redox balance homeostasis (Attia *et al*., 2023), the improved antioxidant profile of P2 and P3 underscores the probiotic's functional role in maintaining cellular protection and metabolic balance during infection. Probiotic supplementation generally increases SOD activity in broiler chickens. For instance, a study found that broilers administered with a probiotic (*Saccharomyces cerevisiae*) had significantly higher SOD activity compared to the control group (Ogbuagu *et al*., 2018). The increased SOD activity in broilers given a combination of fisetin and probiotics. the addition of a probiotic mixture (*Bacillus licheniformis, B. subtilis*, and *Clostridium butyricum*) in drinking water resulted in an increasing trend in SOD levels (Yao *et al*., 2024).

Overall, significant *($P < 0.05$)* improvements in feed intake, FCR/FE, BWG, and antioxidant capacity support the use of *L. paracasei*, especially in combination with monensin, as part of a sustainable coccidiosis control program in broilers. The additive effect observed in this study aligns with the trend of reducing reliance on anticoccidials alone and incorporating gut health-enhancing agents.

The improvements in performance, elevated SOD activity, and reduced MDA levels indicate enhanced oxidative status and metabolic efficiency in the treated chickens. The underlying mechanisms such as modulation of gut microbiota, intestinal integrity, and cytokine responses are supported by previous research; however, since these parameters were not directly measured in this study, these explanations remain as hypotheses. Further research involving direct measurement of microbiota composition, gut morphology, and cytokine levels is necessary to confirm these mechanistic pathways.

CONCLUSION

In conclusion, broilers challenged with *Eimeria tenella* showed significantly ($P < 0.05$) enhanced growth performance, feed efficiency, and antioxidant capacity when supplemented with *Lacticaseibacillus paracasei*, either alone or in combination with monensin. The best results were consistently obtained by the combined therapy (P3: *L. paracasei* + monensin), which included the lowest feed conversion ratio, the greatest body weight gain, and an improved antioxidant response, which was indicated by higher SOD and lower MDA levels. According to these results, the anticoccidial action of monensin in reducing parasite activity and the probiotic's capacity to regulate gut microbiota and preserve intestinal integrity work in Interactive effect. In general, combining *L. paracasei* with traditional anticoccidials provides a interactive effect to enhance feed utilization, growth performance, and oxidative stability, bolstering its potential as a long-term substitute for efficient coccidiosis control and decreased antibiotic usage in commercial poultry production.

Although mechanisms such as increased beneficial gut microbiota and modified immune responses, including increased cytokines such as ChIFN-γ and ChIL-10, have been reported in previous studies as factors influencing chicken health and performance, these parameters were not directly measured in this study. Therefore, explanations regarding these mechanisms should be considered as possibilities and hypotheses based on previous research, rather than as conclusions based on the data obtained.

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NOVELTY STATEMENT

This study is the first to demonstrate the synergistic effects of drinking water–delivered *Lacticaseibacillus paracasei* combined with monensin on growth performance, feed efficiency, and oxidative status in *Eimeria tenella*–challenged broilers. By integrating production parameters with systemic antioxidant biomarkers (SOD and MDA), this work provides novel evidence that a probiotic–ionophore strategy simultaneously enhances feed utilization and redox homeostasis, offering a practical approach to reduce reliance on anticoccidials while sustaining broiler productivity.

AUTHOR'S CONTRIBUTION

Conceptualization: LWP, ML. Data curation, Funding acquisition, Supervision and Project administration: LWP. Formal analysis: A-AMAA, SA, GR. Investigation: LM, AWH, BD, PAWW. Methodology: LWP, YAB. Resources: LM, ML. Validation: SA, YAB. Writing original draft: LWP, YAB, RZNA. Writing review and editing: LWP, ML, GR, SHI.

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Ethics statements

All experimental procedures were approved by the Animal Ethics Commission of the Faculty of Veterinary Medicine, Universitas Airlangga (approval number: 1.KEH.71.05.2025).

Generative AI and AI-assisted technology statement

No generative AI or AI-assisted technologies were used in the design of the study, data collection, data analysis, or interpretation of the results. Only standard statistical software and conventional writing tools were used during manuscript preparation. All text, tables, and conclusions were produced by the authors without assistance from generative AI systems.

Data availability statement

The datasets used and/or analysed during the current study are standard.

Conflict of interest

The authors have declared no conflict of interest.

REFERENCES

Andriani ADWI, Lokapirnasari WP, Karimah B (2020). Potency of probiotic on broiler growth performance and economics analysis. J. Anim. Vet. Adv., 90(Aug): 1140-1145. https://doi.org/10.56093/ijans.v90i8.109294

Attia MM, Mohamed RI, Salem HM (2023). Impact of *Eimeria tenella* experimental Infection on intestinal and splenic reaction of broiler chickens. J. Parasit. Dis., 47(4): 829–836. https://doi.org/10.1007/s12639-023-01629-z

Awais MM, Jamal MA, Akhtar M, Hameed MR, Anwar MI, Ullah MI (2019). Microbial Pathogenesis Immunomodulatory and ameliorative effects of Lactobacillus and *Saccharomyces*-based probiotics on pathological effects of eimeriasis in broilers. Microb. Pathog., 126(October 2018), 101–108. https://doi.org/10.1016/j.micpath.2018.10.038

Bozkurt M, Ege G, Aysul N, Ak H, Aypak S, Seyrek K, Ko B, Binta E (2014). Effect of anticoccidial monensin with oregano essential oil on broilers experimentally challenged with mixed *Eimeria* spp. Poult. Sci., 93(7): 1858-1868. https://doi.org/10.3382/ps/pew077

Campos A, Philip M, Katarzyna B, Mark C, Campos PM, Miska CKB, Kahl CS, Jenkins CMC, Shao DJ (2022). Effects of *Eimeria tenella* on cecal luminal and mucosal microbiota in broiler chickens. Avian Dis. 66(1): 39–52. https://doi.org/10.1637/21-00068

Chen X, Zhu Z, Zhang X, Chen L, Gu Q, Li P (2024). Lactobacillus paracasei ZFM54 alters the metabolomic profiles of yogurt and the co-fermented yogurt improves the gut microecology of human adults. J. Dairy Sci., 107(8): 5280–5300. https://doi.org/10.3168/jds.2023-24332

El-Shall NA, El-naggar K, El-kasrawy NI, Elblehi SS, Albadrani GM, Al-ghadi MQ, Abdel-daim MM (2024). The anticoccidial effects of probiotics and prebiotics on the live coccidia vaccine and the subsequent influence on poultry performance post-challenge with mixed *Eimeria* species. Poult. Sci., 103(12): 104283. https://doi.org/10.1016/j.psj.2024.104283

Giannenas I, Tsalie E, Triantafillou E, Hessenberger S, Teichmann K, Tontis D (2014). Assessment of probiotic supplementation via feed or water on growth performance, intestinal morphology, and microflora of chickens infected with *Eimeria* spp. Avian Pathol., 43(3): 209–216. https://doi.org/10.1080/03079457.2014.899430

Guo W, Tang X, Zhang Q, Xiong F, Yan Y, Zhao J, Mao B (2025). *Lacticaseibacillus paracasei* CCFM1222 ameliorated the intestinal barrier and regulated gut microbiota in mice with DSS-induced colitis. Probiotics Antimicrob Proteins. https://doi.org/10.1007/s12602-024-10236-0

Kaewarsar E, Chaiyasut C, Lailerd N, Makhamrueang N, Peerajan S, Sirilun S (2023). Stimulation of beneficial gut microbiota. Foods. 12(1): 3847. https://doi.org/10.3390/foods12203847

Kang X, Li XD, Zhou HY, Wang F, Lin LB (2023). Genome-wide and 16S rRNA sequencing-based analysis on the health effects of *Lacticaseibacillus paracasei* XLK401 on Chicks. Microorganisms, 11(9). https://doi.org/10.3390/microorganisms11092140

Lima GA. De, Fernanda B, Aparecido G, Araujo C, Polidoro BR, Polycarpo V, Zied DC, Biller JD, Aparecido G, Araujo C, Polidoro BR, Polycarpo V, Zied DC, Biller JD, Modesto IDM, Maria A, Noronha B (2020). Agaricus subrufescens and Pleurotus ostreatus mushrooms as alternative additives to antibiotics in diets for broilers challenged with *Eimeria* spp. Br. Poult. Sci. 62(2): 251–260. https://doi.org/10.1080/00071668.2020.1837344

Liu W, Cheng H, Zhang H, Liu G, Yin X, Zhang C, Jiang R (2024). Effect of Lactobacillus paracasei LK01 on growth performance, antioxidant capacity, immunity, intestinal health, and serum biochemical indices in broilers. Poult. Sci. 103(5): 1-17. https://doi.org/10.3390/ani14233474

Lokapirnasari WP, Maslachah L, Saputro AL, Rokana E, Yulianto AB (2025). Potency of *Lacticaseibacillus paracasei* as an alternative to antibiotic growth promoter in broiler chicken challenged with avian pathogenic *Escherichia coli*. Vet. World, 18: 1180–1189. https://doi.org/10.14202/vetworld.2025.1180-1189

Marnpae M, Balmori V, Kamonsuwan K, Nungarlee U, Charoensiddhi S, Thilavech T, Suantawee T, Sivapornnukul P, Chanchaem P, Payungporn S, Dahlan W, Hamid N, Nhujak T, Adisakwattana S (2024). Modulation of the gut microbiota and short-chain fatty acid production by gac fruit juice and its fermentation in *in vitro* colonic fermentation. Food Funct. 15(1): 3640–3652. https://doi.org/10.1039/D3FO04318E

Mohsin M, Zhang Z, Yin G (2022). Effect of probiotics on the performance and intestinal health of broiler chickens infected with *Eimeria tenella*. Front. Microbiol., 13: 1–14. https://doi.org/10.3390/vaccines10010097

Ogbuagu NE., Aluwong T., Ayo. JO., Sumanu, VO (2018). Effect of fisetin and probiotic supplementation on erythrocyte osmotic fragility, malondialdehyde concentration and superoxide dismutase activity in broiler chickens exposed to heat stress. J. Vet. Med. Sci., 80: 1895-1900. https://doi.org/10.1292/jvms.18-0477

PRC, Ministry of Agriculture and Rural Affairs of the People's Republic of China (PRC) (2023). Reports of major animal diseases [Internet]. (2023). Available from: http://www.xmsyj.moa.gov.cn/yqfb/

Qi N, Liao S, Mohiuddin M, Abuzeid AMI, Li J, Wu C, Lv M, Lin X, Hu J, Cai H, Yu L, Xiao W, Sun M, Li G (2020). Autophagy induced by monensin serves as a mechanism for programmed death in *Eimeria tenella*. Vet. Parasitol., 287(March): 109181. https://doi.org/10.1016/j.vetpar.2020.109181

Qi XL, Xing K, Huang Z, Chen Y, Wang L, Zhang LC, Sheng XH, Wang XG, Ni HM, Guo Y (2020). Comparative transcriptome analysis digs out genes related to antifreeze between fresh and frozen–thawed rooster sperm. Poult. Sci. 99(6): 2841–2851. https://doi.org/10.1016/j.psj.2020.01.022

Wang Y, Lv X, Li X, Zhao J, Zhang K, Hao X (2021). Protective effect of *Lactobacillus plantarum* P8 on growth performance, intestinal health, and microbiota in Eimeria-infected broilers. Front. Microbiol., 12(July): 1–15. https://doi.org/10.3389/fmicb.2021.705758

Yao X., Guan L., Sun S., Liu J., Zeng X., Wu Y., Zhang R., Xu Y., Yang C (2024). Probiotic mixture improves meat quality of white feather broilers. Acta Microbiol. Sin., 64: 516-529..

Yulianto AB, Lamid M, Lokapirnasari WP, Al-Arif MA, Sherasiya A, Marbun TD, Khairullah AR, Kurniawan SC, Hasib A, Silaen OSM, Rehman S, Ayuti SR (2024). Hematological and performance variables of male broiler chickens fed with moringa oleifera extract and probiotic in drinking water. Trop. Anim. Sci. J., 47(2): 215–224.

Yulianto AB, Suwanti LT, Widiyatno TV, Suwarno S, Yunus M, Tyasningsih W, Hidanah S, Sjofjan O, Lokapirnasari WP (2021). Probiotic *Pediococcus pentosaceus* ABY 118 to Modulation of ChIFN- γ and ChIL-10 in Broilers Infected by *Eimeria tenella* Oocyst. Vet. Med. Int., 18: 1–6. https://doi.org/10.1155/2021/1473208

Zhang H, Zhang L, Si H, Liu X, Suo X, Hu D (2022). Early Transcriptional Response to Monensin in Sensitive and Resistant Strains of *Eimeria tenella*. Front. Microbiol., 13(July): 1–9. https://doi.org/10.3389/fmicb.2022.934153