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The Potential of Nanoemulsion Extracts of Red Ginger (*Zingiber officinale* Roxb. var Rubra) and Turmeric (*Curcuma domestica* VAL.) on the Productivity of Broiler

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ABSTRACT

The increasing demand for animal protein has driven the search for natural feed additives that can replace antibiotic growth promoters (AGPs) in order to avoid the risks of bacterial resistance and antibiotic residues. Red ginger (*Zingiber officinale Roxb. var Rubra*) and turmeric (*Curcuma domestica* VAL.) are known to contain active compounds such as gingerol and curcumin, which function as antimicrobials, anti-inflammatories, and immunomodulators. However, the limited bioavailability of active ingredients in conventional forms limits their effectiveness. Nanoemulsion technology is applied to increase the absorption of active ingredients through smaller and more stable particle sizes. The objective of this study was to analyze the potential of red ginger and turmeric extract nanoemulsions, both individually and in combination, on broiler productivity. This research was carried out at the Politeknik Negeri Lampung using a completely randomized design (CRD) with 4 treatments and 5 replicates, with each replicate comprising 5 chickens. The treatments consisted of: P0 control; P1 administration of red ginger nanoemulsion (4mg/kg BW); P2 administration of turmeric nanoemulsion (4mg/kg BW); P3 administration of a combination of red ginger (2mg/kg BW) and turmeric (2mg/kg BW) nanoemulsions. The administration of red ginger and turmeric nanoemulsions was carried out from day 7 to day 28 via drinking water. The results showed that the best outcomes were obtained with a combination of red ginger and turmeric nanoemulsion (P3), producing the best performance with the highest feed intake (2053.9g/head), PBB 1500.8g/head, the highest feed efficiency of 74.80%, and the lowest FCR of 1.38. These findings demonstrate that the combination of turmeric and ginger nanoemulsions can serve as a natural alternative to NGPs, supporting more efficient and sustainable poultry production.

Keywords: Broiler, Nanoemulsion, Productivity, Red ginger, Turmeric.

INTRODUCTION

Poultry were the highest users of antibiotics in the animal production sector in 2019 (Burow et al. 2020). Uncontrolled use of antibiotics, both to improve health and as feed additives in broilers, has led to an increase in cases of antibiotic resistance (Hamid et al. 2019). Antibiotics are also associated with several residual risks in broiler meat that can endanger human health, such as allergies, cancer, toxicity, and other health issues (an). The prohibition on the use of antibiotics as feed additives is stipulated in Article 16 of the Ministry of Agriculture Regulation No. 14/2017 on the Classification of Veterinary Drugs, effective January 1, 2018. Broiler chickens are susceptible to disease outbreaks, necessitating the use of antibiotic growth promoters (AGPs) to maintain immunity and growth (Akhsan et al. 2020). An alternative to AGPs is exploring plant-based antibiotics (herbal) as natural feed additive candidates with multiple effects, such as enhancing broiler productivity. The combination of ginger and turmeric extracts significantly improves the growth performance of broiler chickens, as evidenced by increased weight gain and improved feed conversion ratio. This effect is associated with the bioactive compounds gingerol and curcumin, which increase digestive enzyme activity, stimulate feed intake, and improve gastrointestinal health (Tasya et al. 2025). Global health issues have prompted efforts to develop alternative antibiotics using herbal plant extracts

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that can be used as natural growth promoters. Herbal ingredients can function to stimulate appetite, increase digestive enzyme secretion, activate immune and antiviral responses, and provide antioxidant and anthelminthic effects (Omar et al. 2016).

Red ginger (*Zingiber officinale* Roxb. var Rubra) is a rhizome commonly used by the public as a kitchen spice and herb. Red ginger contains higher levels of 6-gingerol, 8-gingerol, 10-gingerol, and 6-shogaol compared to elephant ginger, at 18.03, 4.09, 4.61 and 1.36mg/g, respectively, making it widely consumed by the community as a medicinal ingredient (Omar et al. 2016). Red ginger contains volatile compounds, namely terpenoids and non-volatile compounds consisting of gingerol, shogaol, paradol, zingerone, and their derivatives, as well as flavonoids and polyphenols.

Turmeric (*Curcuma longa* L) contains curcuminoids in the form of curcumin and essential oils. Turmeric has pharmacological properties, particularly anti-inflammatory, antioxidant and anticancer effects (Anas et al. 2024; Candra et al. 2024; Kaur et al. 2024; Perez et al. 2025). Curcumin, the primary curcuminoid, has shown potential in modulating signaling pathways involved in cancer, reducing oxidative stress, and providing radiation protection (Cozmin et al. 2024). The antimicrobial properties of turmeric can eliminate antibiotic-resistant pathogens and biofilms, making it a promising agent in food safety and infection prevention (Aderemi and Alabi 2023; Beshiru et al. 2024; El-Saadony et al. 2025). The administration of turmeric can reduce heat stress in broiler chickens, reinforcing the value of this herb as an effective natural phytoantibiotic in poultry production (Candra et al. 2025).

Nanoemulsions are drug delivery systems in the form of transparent emulsion formulations with small particle sizes ranging from 20 to 500nm (Jaiswal et al. 2015; Jacob et al. 2024; Vikal et al. 2025). Nanoemulsions have advantages such as enhancing bioavailability, being suitable for oral drug administration, being thermodynamically stable, and having a large surface area that allows rapid penetration of active ingredients (Gurumukhi 2025; Vikal et al. 2025). Nanoemulsions can improve the stability of active compounds against environmental degradation and enhance the absorption of macromolecular compounds (Jacob et al. 2024).

The application of nanoemulsion technology to red ginger and turmeric extracts is believed to enhance the bioavailability and efficacy of their active compounds. Although each has been proven beneficial separately, no studies have evaluated the potential of combining both in nanoemulsion form as a multifunctional feed additive capable of simultaneously improving the productivity of broiler chickens. Therefore, this approach has great potential to be developed in efforts to improve broiler performance comprehensively. The objective of this study was to analyze the potential of red ginger and turmeric extract nanoemulsions, both individually and in combination, on broiler productivity.

MATERIALS AND METHODS

Materials

The materials used in this research included red ginger nanoemulsion, turmeric nanoemulsion, A total of 100 day-old chicks of the MB 202 strain obtained from PT Japfa Comfeed Indonesia, HI-PRO 611®, and HI-PRO 611B® as broiler feed obtained from PT. Charoen Pokphand Indonesia, with the nutritional content listed in Table 1, disinfectant. The tools used in this research include broiler chicken cages along with feed and water equipment as a means of raising broiler chickens.

Table 1: Nutrient content in broiler feed days 1-28 using HI-PRO 611 and HI-PRO 611B Comfeed®

Nutrient	Parameter	
	HI PRO 611	HI PRO 611B
Water Content (%)	Max. 14	Max. 13
Ash (%)	Max. 8	Max. 9
Crude Protein (%)	21-23	21-23
Crude Fat (%)	Min. 5	Min. 4
Crude Fibre (%)	Min. 0.5	Min. 0.5
Calcium (%)	0.8–1.1	0.7–1.2
Phospor (Enzim Phytase) (%)	Min. 0.5	Min. 0.5
Aflatoxin Total	Max. 50µg/kg	Max. 50µg/kg
Lysin (%)	Min. 1.2	Min. 1.2
Methionine (%)	Min. 0.45	Min. 0.45
Methionine + Cysteine (%)	Min. 0.8	Min. 0.8
Tryptophan (%)	Min. 0.19	Min. 0.19
Threonine (%)	Min. 0.75	Min. 0.75

Max=Maximum, Min=Minimum.

Experimental design

This research was carried out using a completely randomized design (CRD) consisting of 4 treatments and 5 replications, and each replication contained 5 broilers. In this study, the treatment was the administration of red ginger and turmeric nanoemulsions. Red ginger and turmeric nanoemulsions are given to broiler chickens at the age of 7-28 days. The treatments were: P0=Drinking water without adding extract (control), P1=Administration of red ginger nanoemulsion (4mg/kg BW); P2=Administration of turmeric nanoemulsion (4mg/kg BW); P3=Administration of a combination of red ginger (2mg/kg BW) and turmeric (2mg/kg BW) nanoemulsions. The chicken-rearing design in this research can be seen in the following Table 2.

Extraction and nanoemulsion preparation

Fresh herbs are cleaned and washed with running water, then drained. The herbs are sliced thinly into 6–7mm pieces. The sliced red herbs are dried in the sun or in an oven at 49–55°C for 2 days until the moisture content is less than 10%, then ground and sieved with an 80-mesh sieve to obtain herbal powder.

Extraction is performed using the maceration method. 50g of herbal powder is placed in a bottle and mixed with 250mL of 96% ethanol, sealed, and left for 3×24 hours, with homogenization performed every hour. The extract is poured off, and the residue is squeezed and separated into another bottle. The remaining residue is added with 250mL of 96% ethanol and macerated again for 24 hours, and the maceration results are combined. Next, concentration is performed using a rotary evaporator at a temperature of 55–65°C to obtain a concentrated extract. The yield is calculated by comparing the initial weight with the final weight of the extract produced (Shaffira et al. 2023).

Table 2: Technical administration of ginger and turmeric nanoemulsion in drinking water

Days to-	Drinking water type
1-7	Broiler chickens were given ad libitum drinking water without the addition of turmeric nanoemulsion.
8-28	1. P0 giving ad libitum drinking water without the addition of red ginger and turmeric nanoemulsions. 2. P1 giving drinking water with the addition of 4mg/kg BW red ginger nanoemulsion. 3. P2 was given drinking water with the addition of 4mg/kg BW turmeric nanoemulsion. 4. P3 was given drinking water with the addition of a combination of red ginger nanoemulsion 2mg/kg BW and turmeric 2mg/kg BW.

Table 3: Broiler productivity with the administration of red ginger extract and turmeric extract nanoemulsion in drinking water

Variable	Treatment			
	P0	P1	P2	P3
Feed Intake (g/head)	1941.40±93.44 [a]	1953.75±27.43 [a]	1927.40±64.96 [a]	2053.9±48.17 [b]
Body Weight Gain (g/head)	1310.40±67.8 [a] 6	1365.60±24.87 [a]	1378.40±70.08 [a]	1500.80±39.11 [b]
Feed Conversion Ratio (FCR)	1.5 ±0.00 [a]	1.42 ±0.04[b]	1.42±0.04 [b]	1.38 ±0.04 [b]
Feed Efficiency (%)	68.48 ±1.88 [a]	71.69±1.14 [b]	73.31±2.10 [bc]	74.80 ±1.76 [c]

Notes: Superscripts with the same letter indicate no significant difference in the row/column; P0 = Ad libitum drinking water without the addition of red ginger and turmeric nanoemulsion (control); P1 = Water intake with addition of red ginger nanoemulsion at 4mg/kg body weight; P2 = Water intake with addition of turmeric nanoemulsion at 4mg/kg body weight; P3 = Water intake with the addition of a combination of red ginger nanoemulsion at 2mg/kg body weight and turmeric nanoemulsion at 2mg/kg body weight.

The nanoemulsion was formulated using the homogenization method with the extract, VCO, Tween 80, PEG 400, and distilled water in a ratio of 1:3:21:10:65 (Manullang and Parinding 2023). All ingredients except distilled water were mixed using a magnetic stirrer at a speed of 1000rpm for 10 minutes, then distilled water was slowly added while increasing the speed to 1250rpm for 10 minutes (Orinetha et al. 2022). Red ginger and turmeric nanoemulsions were tested for their particle size and zeta potential using a particle size analyzer (PSA) with the dynamic light scattering method (Chan et al. 2017).

Data analysis

The research data were analyzed using one-way analysis of variance (ANOVA). ANOVA applied to SPSS conforms to a completely randomized design. The difference between treatments was analyzed using Duncan's multiple distance test, $P<0.05$, using SPSS version 25.

RESULTS

Extraction and nanoemulsion production

A total of 500g of red ginger simplisia produced 20mL of extract with a yield of 6.99%, while 500g of turmeric simplisia produced 20mL of extract with a yield of 6.49%. The flavonoid test results showed that red ginger had a content of 43.26mg/g, while turmeric had a content of 289.08mg/g. The results of phytochemical testing show that red ginger and turmeric extracts contain the main bioactive compounds: alkaloids, flavonoids, saponins, and tannins /polyphenols. The nanoemulsion formulation produced 2L each with red ginger nanoparticle size of 210.9nm and turmeric 162.2nm, and red ginger zeta potential of –41.7mV and turmeric –31.3mV.

Broiler chicken productivity

The results of research on rearing broiler chickens given nanoemulsion of red ginger extract and turmeric extract as herbs in drinking water on broiler productivity, including feed intake, body weight gain, feed conversion, and feed efficiency, can be seen in Table 3.

DISCUSSION

Feed intake

Based on the results of statistical analysis, it shows that the highest average feed consumption was found in treatment P3, which was 2053.15g/head, while the lowest was found in treatment P2, which was 1927.40g/head. Treatments P0 and P1 had average feed intake of 1941.45g and 1953.75g, respectively. The analysis of variance (ANOVA) showed that there was a significant difference between treatments in terms of feed intake, with a significance level of 0.025 ($P<0.05$). This indicates that the treatments administered had a significant effect on feed intake. Further testing using the LSD method showed that treatment P3 was significantly different from the other treatments (P0, P1, and P2), with significance values of 0.013, 0.024, and 0.006, respectively. Meanwhile, there were no significant differences between treatments P0, P1, and P2 ($P>0.05$). These results were further supported by Duncan's test, which showed that treatment P3 formed a separate group that was not homogeneous with the other three treatments. Thus, it can be concluded that treatment P3 consistently resulted in higher feed intake and was significantly different from the other treatments. This indicates that treatment P3 was able to significantly increase feed intake.

A significant increase in feed intake was observed in treatment P3 (2053.9g/head), which involved the administration of a combination of red ginger and turmeric nanoemulsions, indicating that the nanoemulsion formulation plays a crucial role in enhancing the absorption efficiency of herbal active compounds by broiler chickens. Compared to the treatment without nanoemulsion (P0), as well as the single treatments of red ginger (P1) and turmeric (P2), the combination of nanoemulsion in P3 showed a synergistic and statistically significant effect. This is supported by recent findings that nano-enabled phytogenic feed additives, including nano-curcumin and nano-ginger, improve intestinal morphology and beneficial gut microflora in broiler chickens, enhancing nutrient absorption and overall growth performance (Anwar 2025).

In nanoemulsion form, herbal extract particles are much smaller (nano<200nm), resulting in a larger surface

area, higher solubility, and increased bioavailability compared to coarse or conventional extracts. Research by Hedayati et al. (2021) also demonstrated that herbal extract nanoemulsions can penetrate the intestinal mucosal membrane more efficiently, leading to improved digestive function and metabolism in broiler chickens. Additionally, the main active compounds in ginger are gingerol and shogaol, while turmeric contains curcumin, both of which are known for their antimicrobial, anti-inflammatory, and antioxidant properties. In nanoemulsion form, these compounds become more stable and biologically active. This strengthens the hypothesis that the combination of red ginger and turmeric nanoemulsions can improve the digestive environment, increase appetite, and ultimately promote higher feed intake.

The administration of a combination of red ginger and turmeric nanoemulsions in broiler drinking water has been shown to have a positive impact on feed intake. These results are consistent with the findings of Sihombing (2023), who reported that a combination of ginger and turmeric can increase broiler productivity, including feed intake, weight gain, feed efficiency, and improve feed conversion. Putri et al. (2025) also reported that extracts of brotowali, red ginger, and propolis significantly increased weight gain and feed conversion, and affected immunity and meat quality in broilers when added to drinking water.

Body weight gain

The results of the study indicate that the administration of a combination of red ginger and turmeric nanoemulsions (P3) resulted in the highest weight gain (WG) of 1500.80g/head, which was significantly different ($P<0.05$) compared to the control (P0, 1310.40g/head). The treatments P1 (red ginger alone) and P2 (turmeric alone) also showed an increase in weight compared to the control, although not all differences were statistically significant. These results indicate a synergistic effect of the combination of both in enhancing broiler productivity.

The use of herbal nanoemulsions has significant potential in improving the bioactive absorption efficiency of medicinal plants. Nanoemulsions increase bioavailability due to their small particle size (<200nm), which expands the surface area and accelerates the diffusion of active compounds in the digestive tract (McClements 2012). Bioactive compounds such as gingerol from ginger and curcumin from turmeric are known to have antioxidant, antimicrobial, and immunostimulatory effects, which can improve livestock growth performance.

The gingerol compound in red ginger acts as a stimulant for metabolism and digestion, improving digestive enzyme function and increasing nutrient absorption (Mashhadi et al. 2013). Meanwhile, curcumin from turmeric exhibits anti-inflammatory activity and modulates gut microbiota, thereby supporting gut health and optimal (Rahmani et al. 2018). Therefore, the combination of both in nanoemulsion form maximizes their efficiency as natural phytobiotics, replacing the use of antibiotic growth promoters (AGP), which are now restricted. This study aligns with the findings that nano-ginger and related phytogenic nano-particles significantly increased broiler body weight and improved feed conversion ratio, similar to effects observed with antibiotic supplementation in broilers (Hassan et al. 2024). Additionally, supplementation with temulawak extract nanoemulsion has been demonstrated to improve broiler production performance, including body weight gain and feed efficiency, supporting their use as AGP alternatives (Orinetha et al. 2022; Utari et al. 2025). In treatment P3, feed efficiency reached 74.80%, significantly higher than the control group's 69.30%. This supports the notion that weight gain is not only due to increased feed consumption, but also due to more efficient nutrient utilization thanks to Sthe active compounds in the nanoemulsion. Overall, these results show that the use of herbal extract nanoemulsions, particularly the combination of red ginger and turmeric, significantly improves broiler growth performance. The use of nano technology also allows for the use of smaller but effective doses, providing a potential alternative to AGPs, which are now banned.

Feed conversion ratio

Feed conversion ratio (FCR) is an indicator of feed efficiency in producing weight gain in broilers. Based on the analysis results presented in Table 5, it was found that the control group (P0) had an FCR value of 1.5, while the treatment groups P1 (ginger nanoemulsion) and P2 (turmeric nanoemulsion) showed an FCR value of 1.42. The treatment group P3, which received a combination of ginger and turmeric nanoemulsions, recorded the lowest FCR value of 1.38. This value indicates that broilers receiving the combination of two herbal nanoemulsions require the least amount of feed to achieve optimal body weight. The lower the FCR value, the more efficient the feed utilization, meaning that the growth and metabolic performance of the chickens are more optimal.

Statistical test results show that the difference in FCR between treatment groups is statistically significant ($P=0.001$), indicating that the administration of nanoemulsion has a significant effect on feed efficiency. Further testing using LSD (least significant difference) showed that P3 was significantly different from P0 (difference of 0.12; $P=0.000$) and also significantly different from P1 and P2. Meanwhile, P1 and P2 did not show significant differences between each other ($P=1.000$), meaning that the separate administration of ginger and turmeric had comparable effects on FCR. Meanwhile, the results of the homogeneity of variance test (Levene's Test) showed a significance value > 0.05 ($P=0.109$), indicating that the data between treatments had homogeneous variance and met the criteria for ANOVA analysis. The results of Duncan's Multiple Range Test also showed that treatment P3 belonged to a separate subset with the best efficiency.

Based on research by Shaffira et al. (2023), it was reported that the FCR of broilers fed red ginger extract ranged from 1.44 to 1.41, indicating an increase in feed efficiency compared to the control (FCR=1.48). These results align with findings from the study, where treatments P1 and P2 (with ginger and turmeric nanoemulsions) recorded FCR values of 1.42 each, and P3 (a combination of both) yielded the lowest FCR of 1.38. This reinforces that both conventional herbal extracts and nanoemulsion forms can have a positive effect on feed efficiency. However, a significant advantage is observed in the nanoemulsion form, which demonstrates higher efficiency

compared to conventional extracts.

The improvement in feed efficiency observed in the P3 group is closely related to the physicochemical characteristics of nanoemulsions, which enhance the bioavailability of active compounds. At the nanometer scale (<100nm), active compounds such as gingerol and curcumin can penetrate the digestive cell membrane more quickly and effectively. Badran et al. (2021) stated that nano-curcumin significantly improves FCR and nutrient digestion capacity compared to the conventional form. Curcumin in nano form is more efficient than the conventional form because it accelerates nutrient absorption in the digestive tract. Additionally, gingerol in ginger has a stimulating effect on the secretion of digestive enzymes, such as amylase and protease, which also accelerate feed degradation and nutrient absorption (Hassan et al. 2024).

The combination of the two compounds in nano form also has a synergistic effect on the stability of the intestinal microflora. These phytobiotic compounds have selective antimicrobial properties, capable of inhibiting the growth of pathogens such as *Escherichia coli* and *Salmonella* sp., while simultaneously promoting the growth of beneficial bacteria such as *Lactobacillus* and *Bifidobacteria*. A healthy gut microbiota improves intestinal wall integrity and enhances nutrient absorption. A study by Baskara et al. (2020) supports these findings, noting that nano-emulsified essential oils serve as a powerful natural alternative to antibiotics, improving feed efficiency and digestive health. This explains why P3 demonstrates the best FCR, as it not only enhances metabolism but also naturally supports the digestive and immune systems of broilers.

The administration of a combination of red ginger and turmeric nanoemulsions has been proven to significantly improve feed efficiency. In addition to supporting broiler growth performance, these results also demonstrate the potential for replacing synthetic antibiotics with natural nanoherbal-based ingredients. The use of a combination of two active substances in low doses but in nano form provides optimal and cost-effective results, and is antibiotic-free.

Feed efficiency

The results showed that the broiler group given a combination of red ginger and turmeric extract nanoemulsions (P3) had the highest feed efficiency of 74.808%, which was significantly different ($P<0.05$) from the control group (P0) with the lowest efficiency of 69.306%. The P1 (ginger) and P2 (turmeric) treatments resulted in efficiencies of 71.694% and 73.312%, respectively, both of which were also higher than the control. The results of the ANOVA analysis showed a significance value of $P=0.001$, indicating a significant effect of the nanoemulsion treatment on feed efficiency. Furthermore, the LSD test results showed that group P3 was significantly different from P0 ($P=0.000$) and also from P1 ($P=0.011$). Group P2 was also significantly different from the control ($P = 0.002$), but not significantly different from P1 or P3. This indicates that the combination of two types of phytobiotic nanoemulsions is more effective than single administration, and all treatments are more efficient than without nanoemulsion. The Duncan test results reinforce the LSD results by grouping P0 in the lowest subset, P1 and P2 in the middle subset, and P3 in the highest subset of feed efficiency.

The improvement in feed efficiency in the P3 treatment group is due to the increased bioavailability of active compounds in the form of nanoemulsions. Red ginger contains gingerol, while turmeric is rich in curcumin, both of which have anti-inflammatory, antioxidant, and digestive stimulant properties. In nanoform, these compounds have extremely small particle sizes (<100 nm), enabling faster absorption by the intestinal wall and direct entry into the bloodstream (Badran et al. 2021). This accelerates metabolic processes, enhances nutrient absorption, and reduces energy loss due to inefficient digestion.

According to Hassan et al. (2024), the administration of ginger and thyme nanoemulsions to broilers can improve feed efficiency by increasing the secretion of digestive enzymes such as trypsin, amylase, and lipase, as well as reducing the growth of pathogenic bacteria in the intestine. The reduction in harmful microorganisms such as Escherichia coli and Salmonella makes the digestive system more stable and functional, enabling chickens to utilize feed more effectively. Baskara et al. (2020) found that nano-emulsified essential oils have comparable efficacy to synthetic growth promoters in improving feed conversion and efficiency. This indicates that nanoemulsions of herbal extracts have the potential to replace growth antibiotics in modern livestock systems.

The combination of ginger and turmeric nanoemulsions in group P3 also showed a synergistic effect, where feed efficiency increased more than with single administration. This is in line with the findings of Hassan et al. (2024), who reported that the combination of phytobiotics had an additive effect on chicken performance, particularly in terms of growth and feed conversion. Additionally, this improvement in efficiency also contributes to economic aspects, as feed is the largest cost component in broiler chicken farming. Therefore, the use of herbal nanoemulsion combinations can serve as a practical and sustainable strategy to enhance production efficiency and reduce reliance on synthetic antibiotics.

Conclusion

The conclusion of this research shows that the administration of red ginger and turmeric extract nanoemulsions, either alone or in combination, in drinking water had a significant effect on broiler productivity, including weight gain and feed conversion ratio (FCR). The treatment with the best results was the administration of a combination of red ginger nanoemulsion at 2mg/kg body weight and turmeric at 2mg/kg body weight (P3), which demonstrated the most optimal feed utilization efficiency. The physicochemical characteristics of nanoemulsions that enhance the bioavailability of gingerol and curcumin support broiler digestive and metabolic performance and provide a synergistic effect on intestinal microflora stability, making them a natural alternative to antibiotics for improving broiler productivity in a sustainable manner.

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Author's Contribution: SA executed the work (collection of data, analysis, and writing of manuscript); DDP participated in analysis and interpretation of data and writing of manuscript; N participated in designing the study and drafting of the manuscript; YS participated in designing the study, analysis of data and drafting of the manuscript. All authors read and approved the final manuscript.

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