Research Article

# Effect of Zingerone on Growth Performance, Feed Intake and Utilisation Efficiency, Carcass Yield and Viscera Macromorphometry

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**Abstract** | The potential of zingerone to replace zinc bacitracin as a growth promoter in broiler chicken feed was evaluated by determining its effects on growth performance, feed intake and utilisation efficiency, gastrointestinal tract (GIT) organ, and GIT accessory organ macromorphometry, visceral fat mass and carcass yield. One hundred and twenty unsexed 1-day-old Cobb 500 broiler chicks (10 chicks per replicate with 3 replicates per diet) were randomly assigned to four dietary treatments where zingerone replaced zinc bacitracin (ZnBcn) at 0 mg/kg (control: 500 mg/kg of zinc bacitracin), 40 mg/kg; 80 mg/kg and 120 mg/kg in the starter, grower and finisher diets. The broiler chicks were fed *ad libitum* for 6 weeks: starter (days 1-14), grower (days 15-28), and finisher (days 29-42). Induction and weekly body mass, daily feed intake (FI), and terminal body mass (TBM) were measured. Body mass gain (BMG), average daily gain (ADG), and feed conversion ratio (FCR) were computed. On slaughter, GIT and accessory GIT viscera organs were extracted and small and large intestine lengths and mass were measured. Empty carcass mass was measured and the dressing percentage was computed. Across growth phases and overall, dietary zingerone had similar effects ($p > 0.05$) as ZnBcn on the chicken's TBM, BMG, ADG, FI, and FCR. It also had similar effects ($p > 0.05$) on empty carcass mass, dressing percentage, and viscera macromorphometry as a control. Zingerone at 40, 80 and 120 mg/kg of feed can be used as a growth promoter in place of zinc bacitracin in broiler chicken diets without compromising growth performance, feed intake and utilisation efficiency, carcass yield, and viscera macromorphometry of broiler chicken.

**Keywords** | Growth promoters, Antibiotics, Zingerone, Growth performance, Meat yield

**Received** | January 18, 2023; **Accepted** | April 15, 2023; **Published** | June 25, 2023
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**Citation** | Mdoda B, Machabi F, Lembede BW, Chivandi E (2023). Effect of zingerone on growth performance, feed intake and utilisation efficiency, carcass yield and viscera macromorphometry. J. Anim. Health Prod. 11(3): 277-285.
**DOI** | http://dx.doi.org/10.17582/journal.jahp/2023/11.3.277.285
**ISSN** | 2308-2801



## INTRODUCTION

Growth performance is the central performance attribute that poultry breeders focus on in order to improve and increase production by commercial poultry producers (Tallentire et al., 2018). Poultry breeders intensively select poultry strains with faster growth rates, efficient feed conversation rates, and higher breast meat yield (Torrey et al., 2021). The use of genetically improved poultry breeds by sub-Saharan Africa (SSA) poultry producers has made the regional poultry industry a major contributor to animal-derived sources of protein for human consumption (Nkukwana, 2018). In addition to being a major source of animal-derived protein for human consumption and helping improve household food security, the SSA poultry industry also supports livelihoods by employing a significant number of people in the region (Ayayee et al., 2020). In SSA, the demand for poultry, especially broiler chicken meat is increasing and is expected to continue increasing annually up to 2050 (Yuan and Chamber, 2020). The regional increase in the demand for chicken meat and hence the increase in its per capita consumption (Bruinsma, 2017) is driven by the sustained growth in the human population, improvement of the socio-economic status, and expansion of urban settlements (Godfray et al., 2018). Despite the observable growth in the SSA poultry industry, especially broiler chicken meat production, the poultry industry fails to meet the demand for chicken meat, and the shortfall is met by imports (Mensah and Enahoro, 2022) from Brazil and European Union countries.

Poultry producers, in addition to using genetically improved poultry breeds, also deploy technologies that help optimize growth performance and feed utilisation efficiency and thus shorten the production cycle (Yadav and Jha, 2019). One such technology is the supplementation of broiler and pullet chicken feeds with sub-therapeutic doses of antibiotics that act as growth promoters which enhance feed intake and utilisation efficiency (Mehdi et al., 2018). This use of antibiotics as growth promoters contributes significantly to improvement in growth performance, meat and egg yield (Callaway et al., 2021). Zinc bacitracin, a polypeptide antibiotic, is routinely added to broiler and pullet chicken feed as a growth promoter (Attia et al., 2016). Dietary zinc bacitracin has been shown to reduce the feed conversion ratio and improve the slaughter mass and meat yield of broiler chicken (Crisol-Martínez et al., 2017). Although the use of sub-therapeutic doses of antibiotics in poultry feeds boosts productivity, prolonged use of these antibiotic growth promoters has been shown to be the reason behind the development and spread of antibiotic-resistant bacteria strains that have caused antibiotic resistance, a global public health challenge (Suresh et al., 2018). Antibiotic resistance is in the top five threats to global human health and annually it causes the death of approximately 700,000 people (World Health Organization, 2019). Due to the negative effects of antibiotics used as growth promoters on the environment (Bougnom et al., 2019) as well as human and animal health, some developed countries have enacted legislation to minimise, curb and prohibit the use of antibiotics as growth promoters in poultry feeds (Laxminarayan et al., 2015). It has however been shown that the withdrawal of antibiotics as growth promoters in poultry feeds results in a significant reduction in productive performance, product quality, and profitability (Cardinal et al., 2019) which if not mitigated compromises the supply of poultry meat and eggs for human consumption. In order to prevent antibiotic-induced resistance and its associated environmental and health challenges, research is evaluating potential plant-derived alternatives that can promote and boost poultry productivity and profitability (Aitfella Lahlou et al., 2021).

Ginger (*Zingiber officinale* Roscoe), family *Zingiberaceae*, a perennial plant (Alsherbiny et al., 2019) is globally used as a medicinal plant (Mehrzadi et al., 2021). Phytochemicals gingerols, shogaols, and zingerone impart ginger its medicinal properties (Hosseinzadeh et al., 2017). When used as a feed supplement in broiler chicken feeds, ginger stimulated improved growth performance and enhanced feed utilisation efficiency (Zhang et al., 2009). Substantial evidence demonstrates that the use of gingerol, shogaol, and paradol as feed supplements enhances chicken growth performance (Ali et al., 2019; Wen et al., 2020). However, the potential of zingerone, one of the major active compounds in ginger (Gungor et al., 2020), to fortify broiler chicken feeds as a growth promoter, has not been evaluated. In rodent models zingerone has been shown to possess anti-inflammatory, antioxidant (Mehrzadi et al., 2021), hepato-protective (Narayanan and Jesudoss, 2016), nephro-protective (Firoz et al., 2020), gastro-protective (Karampour et al., 2019), appetite and growth stimulating and immune-enhancing properties (Poornamathy and Parameswari, 2019). These health beneficial biological properties suggest that zingerone can possibly substitute antibiotics as a growth promoter hence we evaluated the potential of zingerone to substitute zinc bacitracin as a growth promoter in broiler chicken feeds by determining its effects on growth performance, feed utilisation efficiency, meat yield, gastrointestinal tract organ, and accessory organ macromorphometry.

## MATERIALS AND METHODS

### Study site and ethical clearance

The feeding trial and assays of collected samples were done at the Wits Research Animal Facility (WRAF) and Wits School of Physiology laboratories, respectively. Following the granting of ethical clearance by the Animal Research Ethics Committee (ethics approval number 2020/10/02C) of the University of the Witwatersrand, handling of the birds during the trial followed the Helsinki protocol for use of animals in research.

### Animals, housing and feeding

One hundred and twenty, one-day-old, unsexed Cobb 500 broiler chicks vaccinated against Newcastle disease sourced from Alfa Kuikenplaas Chicks, Pretoria, South Africa, were used in the feeding trial. The chicks were allowed a 2-day habituation period during which they were fed a plain formulated starter diet before the commencement of the feeding trial. During the 2-day habituation period, the chicks were dewormed with piperazine (Kyron Laboratories Pty Ltd, Johannesburg, South Africa) added in drinking water at 90mg/L. The chicks were housed in a deep litter system with clean dry wood shavings providing bedding. Ten chicks were housed in a pen [1.7m (L) x 1.1m (W) x 1.3 m (H)]. Room temperature where the pens were housed was controlled at 34-29°C for the starter growth phase and 28-26°C and 25-23°C for the grower and finisher phases, respectively, and relative humidity was maintained at 60-80% as recommended for Cobb 500 chicken (Cobb-Vantress.Com, 2021). A 12-hour lighting cycle was maintained with lights on from 06h00 to 18h00. During the starter growth phase, infrared lighting provided additional warmth. The chicks had *ad libitum* access to feed and clean drinking water. The starter, grower, and finisher diets were each fed for two weeks.

### Feed ingredients and diet formulation

The whole yellow maize was obtained from Obaro [Pretoria, South Africa (SA)]. Epol (Pty Ltd) Animal Feed Manufacturers (Johannesburg, SA) supplied the soybean meal, wheat bran, salt, dicalcium phosphate, and feed-grade limestone. Corn gluten meal-60 was purchased from Ingrain Company (Germiston, SA). The vitamin-mineral premix, synthetic lysine, and methionine were purchased from Trouw Nutrition (Johannesburg, SA). Zingerone was purchased from Sigma-Aldrich (Pty Ltd) (Germany) and zinc bacitracin was sourced from Zeuw Raw Material (Boksburg, SA). Canola oil cake was obtained from Makro Wholesalers (Johannesburg, SA). The broiler brooding (starter), grower, and finishing diets were formulated to meet the nutritional requirements of broiler chicken for the three growth stages, respectively as recommended by the National Research Council (1994). Table 1 show the feed ingredients, proximate, fibre, calcium, and phosphorus content as well as gross energy in the starter, grower, and finisher diets, respectively.

### Experimental design

One hundred and twenty (120) three-day-old unsexed Cobb 500 broiler chicks were allocated to four dietary treatments with 30 birds per dietary treatment: each dietary treatment was replicated thrice with 10 chicks per replicate. The 3-day-old chicks were randomly allocated to 4 starter diets where interventions were added to the diets as follows: diet 1 - zinc bacitracin at 500 mg/kg of feed, diet 2 - zingerone at 40 mg/kg of feed (w/w), diet 3 - zingerone at 80 mg/kg of feed (w/w) and diet 4 - zingerone at 120 mg/kg of feed (w/w). The chicks were fed for 2 weeks on the fortified starter diets and then transferred to grower diets and fed for 2 weeks and finally onto the finisher and fed for another 2 weeks. The zinc bacitracin and zingerone concentration in the grower and finisher were maintained at doses of the starter thus chicks were moved onto a corresponding diet for each growth phase. The zinc bacitracin dose was as recommended by Animate Animal Health (2020) while zingerone doses adopted were used in rats with no side effects on growth performance, gastrointestinal tract viscera, and health (Mani et al., 2016; Karampour et al., 2019).

### Measurements: body mass and feed intake

The induction body mass, weekly body mass, daily feed intake, and terminal body mass of the chicken were measured using an electronic scale (Waterproof Electronic Portable Scale, Clover Scales, Johannesburg, South Africa). As part of monitoring the growth and general health of the chicken, body masses were measured twice weekly. Feed intake was determined daily by subtracting refusals from the total feed given.

### Computations

Body mass gain (BMG), average daily gain (ADG) and feed conversion ratio (FCR) were computed from the body mass and feed intake (FI) data collected in the starter, grower, and finisher phase and the overall using the following equations:

$BMG_{(starter)}$ = body $mass_{(day\ 14)}$ – body $mass_{(day\ 1)}$; $BMG_{(grower)}$ = body $mass_{(day\ 28)}$ – body $mass_{(day\ 15)}$; $BMG_{(finisher)}$ = body $mass_{(day\ 42)}$ – body $mass_{(day\ 29)}$ and $BMG_{(trial)}$ = body $mass_{(day\ 42)}$ – body $mass_{(day\ 1)}$. ADG (g) = BMG/length (in days of feeding). FI (g) = feed offered – feed refusal. FCR = feed intake (g) / mass gain (g) (Onu et al., 2004).

### Terminal procedures and measurements

At the end feeding trial, the chickens were fasted for 4 hours but with *ad libitum* access to clean drinking water and then killed. Each chicken was humanely decapitated with a guillotine (Harvard Apparatus, Holliston, Massachusetts, United States), blood collected into heparinised blood collection tubes (Vacuette, Greiner Bio-One, Frickenhausen, German), feathers plucked off and dissected through a midline incision using a pair of scissors. Gastrointestinal tract (GIT) organs and the pancreas masses of each broiler were measured on an electronic scale (Snowrex Electronic Scale, Clover Scales, Johannesburg, South Africa). Small and large intestines lengths were measured using a rule attached to the cooled dissection board. Digesta from each GIT organ was gently removed before weighing of each GIT organ. Each dressed carcass had the hot carcass mass measured on an electronic scale (Waterproof Electronic Portable Scale, Clover Scales, Johannesburg, South Africa).

### Data analysis

Data was presented as mean ± standard deviation. Data were analysed using GraphPad Prism 8 statistical software (Graph-Pad Software Inc., San Diego, CA, USA). Data on the effects of dietary substitution of zinc bacitracin with zingerone on weekly growth performance and daily feed intake were analysed using repeated measures one-way ANOVA and parametric data on body mass gain, average daily gain and feed conversion ratio, empty carcass mass and viscera masses and lengths were analysed using the one-way ANOVA. Differences between the treatment means were determined using Tukey's *post hoc* test. Statistical significance was set at $p < 0.05$.

**Table 1:** Ingredients and chemical nutrient composition of the starter, grower and finisher diets

| Ingredients | Starter diets | | | | Grower diets | | | | Finisher diets | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Diet 1 | Diet 2 | Diet 3 | Diet 4 | Diet 1 | Diet 2 | Diet 3 | Diet 4 | Diet 1 | Diet 2 | Diet 3 | Diet 4 |
| Yellow maize meal (g/kg) | 447.94 | 447.94 | 447.94 | 447.94 | 494.09 | 494.09 | 494.09 | 494.09 | 520.65 | 520.65 | 520.65 | 520.65 |
| Soyabean meal (g/kg) | 383.95 | 383.95 | 383.95 | 383.95 | 264.69 | 264.69 | 264.69 | 264.69 | 225.62 | 225.62 | 225.62 | 225.62 |
| Corn gluten meal (g/kg) | 118.84 | 118.84 | 118.84 | 118.84 | 88.23 | 88.23 | 88.23 | 88.23 | 82.44 | 82.44 | 82.44 | 82.44 |
| Wheat bran (g/kg) | 18.28 | 18.28 | 18.28 | 18.28 | 105.88 | 105.88 | 105.88 | 105.88 | 121.49 | 121.49 | 121.49 | 121.49 |
| Canola oil (g/kg) | - | - | - | - | 22.94 | 22.94 | 22.94 | 22.94 | 26.03 | 26.03 | 26.03 | 26.03 |
| Limestone (g/kg) | 20.11 | 20.11 | 20.11 | 20.11 | 14.12 | 14.12 | 14.12 | 14.12 | 13.88 | 13.88 | 13.88 | 13.88 |
| *DL*-Methionine, 99% (g/kg) | 1.28 | 1.28 | 1.28 | 1.28 | 1.24 | 1.24 | 1.24 | 1.24 | 1.21 | 1.21 | 1.21 | 1.21 |
| Dicalcium Phosphate (g/kg) | 2.74 | 2.74 | 2.74 | 2.74 | 2.21 | 2.21 | 2.21 | 2.21 | 2.17 | 2.17 | 2.17 | 2.17 |
| Salt (g/kg) | 2.29 | 2.29 | 2.29 | 2.29 | 2.21 | 2.21 | 2.21 | 2.21 | 2.17 | 2.17 | 2.17 | 2.17 |
| Vit and Min premix (g/kg) | 4.57 | 4.57 | 4.57 | 4.57 | 4.41 | 4.41 | 4.41 | 4.41 | 4.34 | 4.34 | 4.34 | 4.34 |
| Zinc bacitracin (mg/kg) | 500 | - | - | - | 500 | - | - | - | 500 | - | - | - |
| Zingerone (mg/kg) | - | 40.00 | 80.00 | 120.00 | - | 40.00 | 80.00 | 120.00 | - | 40.00 | 80.00 | 120.00 |
| Chemical nutritional composition | | | | | | | | | | | | |
| Dry matter (%) | 89.54 | 88.52 | 90.16 | 89.89 | 90.12 | 89.93 | 88.38 | 89.35 | 90.50 | 89.58 | 90.82 | 90.18 |
| Crude protein (% DM) | 27.20 | 28.30 | 30.40 | 31.18 | 21.27 | 25.25 | 24.91 | 23.96 | 21.82 | 22.47 | 23.51 | 23.36 |
| Ether extract (% DM) | 2.21 | 2.17 | 2.34 | 2.09 | 3.27 | 3.32 | 3.35 | 3.41 | 3.52 | 3.53 | 3.55 | 3.60 |
| Crude fibre (% DM) | 3.58 | 3.54 | 3.86 | 3.81 | 3.72 | 4.57 | 4.50 | 5.46 | 3.92 | 3.69 | 3.71 | 3.74 |
| Calcium (% DM) | 0.71 | 0.83 | 0.92 | 0.85 | 0.54 | 0.54 | 1.06 | 0.94 | 0.54 | 0.33 | 0.54 | 0.60 |
| Phosphate (% DM) | 0.42 | 0.43 | 0.44 | 0.44 | 0.38 | 0.48 | 0.48 | 0.49 | 0.41 | 0.37 | 0.41 | 0.48 |
| Gross energy (MJ/kg DM) | 18.01 | 18.60 | 18.47 | 18.28 | 18.25 | 18.38 | 18.15 | 18.07 | 18.29 | 17.39 | 18.57 | 18.45 |

Vitamin-mineral premix: each kg contained vitamin A 4000 000IU, vitamin D3 600 000IU, vitamin E 8000IU, vitamin K3 0.258g, vitamin B1 0.6g, vitamin B2 1.6g, niacin 11.94g, calcium pantothenate 3.92g, vitamin B12 0.1g, vitamin B6 0.98, choline 72.73g, folic acid 0.288g, biotin 0.0008g, $MnSO_4$ 9.92g, Zn 6.3g, Cu 0.252g, KI 0.2g, Co 0.0042g, Fe 2.1g, Se 0.0036g.

## RESULTS

### Performance measures: growth, feed economy and carcass yield

The effect of substituting zinc bacitracin with graded levels of zingerone on Cobb 500 broiler chicken in the starter, grower, finisher, and combined trial performance is presented in Table 2. Dietary zingerone had similar effects ($p > 0.05$) as ZnBcn on terminal body mass, BMG, ADG, FI, and FCR. It also had similar effects ($p > 0.05$) on slaughter body mass, empty carcass mass, and dressing percentage as a control diet (Table 3).

**Table 2:** Effect of supplemental zingerone on growth performance and feed utilisation efficiency of Cobb 500 broiler chickens

| Parameter | Growth phases | Dietary treatments | | | | Significance level |
|---|---|---|---|---|---|---|
| | | Diet 1 | Diet 2 | Diet 3 | Diet 4 | |
| Induction mass (g) | | 61.13 ± 1.06 | 60.25 ± 2.12 | 60.72 ± 3.84 | 61.27 ± 1.78 | ns |
| Terminal body mass (g) [42 days] | | 2130.57 ± 167.19 | 2374.38 ± 188.06 | 2272.18 ± 250.22 | 2180.75 ± 165.71 | ns |
| Body mass gain [BMG] (g) | Starter (day 1-14) | 303.76 ± 15.73 | 340.94 ± 14.51 | 331.32 ± 38.28 | 336.92 ± 80.85 | ns |
| | Grower (day 15-28) | 719.09 ± 94.87 | 804.84 ± 134.08 | 778.31 ± 95.98 | 708.60 ± 45.03 | ns |
| | Finisher (day 29-42) | 1046.65 ± 189.69 | 1169.09 ± 157.89 | 1101.80 ± 178.30 | 1074.05 ± 174.00 | ns |
| Total BMG | | 2069.49 ± 167.83 | 2314.18 ± 187.90 | 2211.48 ± 246.92 | 2119.57 ± 165.92 | ns |
| Average daily gain [ADG] (g/d) | Starter (day 1-14) | 21.69 ± 1.12 | 24.35 ± 1.04 | 23.68 ± 2.73 | 24.07 ± 5.78 | ns |
| | Grower (day 15-28) | 51.36 ± 6.78 | 57.49 ± 9.58 | 55.59 ± 6.85 | 50.61 ± 3.21 | ns |
| | Finisher (day 29-42) | 74.76 ± 13.55 | 79.94 ± 11.28 | 78.70 ± 12.74 | 76.72 ± 12.43 | ns |
| ADG (Trial) | | 49.27 ± 3.99 | 55.10 ± 4.43 | 52.65 ± 5.88 | 50.47 ± 3.95 | ns |
| Feed intake [FI] (g) | Starter (day 1-14) | 830.07 ± 89.08 | 832.40 ± 89.88 | 836.79 ± 91.13 | 829.09 ± 79.48 | ns |
| | Grower (day 15-28) | 1577.80 ± 188.62 | 1698.39 ± 223.07 | 1621.18 ± 235.58 | 1585.49 ± 191.39 | ns |
| | Finisher (day 29-42) | 3027.40 ± 264.69 | 3058.88 ± 251.18 | 3050.66 ± 246.26 | 2979.30 ± 323.49 | ns |
| Total FI | | 5435.30 ± 542.30 | 5589.58 ± 562.80 | 5508.69 ± 569.75 | 5394.00 ± 592.70 | ns |
| Feed conversion ratio [FCR] | Starter (day 1-14) | 2.74 ± 0.33 | 2.44 ± 0.18 | 2.55 ± 0.42 | 2.59 ± 0.87 | ns |
| | Grower (day 15-28) | 2.23 ± 0.44 | 2.12 ± 0.19 | 2.08 ± 0.22 | 2.24 ± 0.31 | ns |
| | Finisher (day 29-42) | 2.93 ± 0.32 | 2.75 ± 0.19 | 2.79 ± 0.25 | 2.79 ± 0.19 | ns |
| FCR (Trial) | | 2.63 ± 0.08 | 2.41 ± 0.07 | 2.49 ± 0.09 | 2.54 ± 0.14 | ns |

ns = not significant, $p > 0.05$.
Diet 1: Starter/Grower/Finisher + zinc bacitracin at 500 mg/kg of feed (positive control), Diet 2: Starter/Grower/Finisher + zingerone at 40 mg/kg of feed, Diet 3: Starter/Grower/Finisher + zingerone at 80 mg/kg of feed and Diet 4: Starter/ Grower/Finisher + zingerone at 120 mg/kg of feed. Results expressed as mean ± standard deviation (SD), n = 3 replicates per dietary treatment with each replicate having 10 birds.

**Table 3:** Effect of supplemental zingerone on meat yield of Cobb 500 broiler chickens

| Parameter | Dietary treatments | | | | Significance level |
|---|---|---|---|---|---|
| | Diet 1 | Diet 2 | Diet 3 | Diet 4 | |
| Slaughter body mass (g) | 2189.71 ± 199.80 | 2417.27 ± 178.79 | 2322.52 ± 245.96 | 2214.83 ± 156.07 | ns |
| Empty carcass mass (g) | 1636.02 ± 222.69 | 1867.58 ± 168.87 | 1813.10 ± 187.82 | 1708.04 ± 113.24 | ns |
| Dressing percentage (%) | 77.59 ± 1.50 | 78.89 ± 2.25 | 78.40 ± 1.43 | 77.03 ± 0.82 | ns |

ns = not significant, $p > 0.05$.
Diet 1: Starter/Grower/Finisher + zinc bacitracin at 500 mg/kg of feed (positive control), Diet 2: Starter/Grower/Finisher + zingerone at 40 mg/kg of feed, Diet 3: Starter/Grower/Finisher + zingerone at 80 mg/kg of feed and Diet 4: Starter/ Grower/ Finisher + zingerone at 120 mg/kg of feed. Results expressed as mean ± standard deviation (SD), n = 3 replicates per dietary treatment with each replicate having 10 birds.


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**Table 4:** Effect of supplemental zingerone on viscera gastrointestinal organs of Cobb 500 broiler chickens

| Parameter | Dietary treatments | | | | Significance Level |
|---|---|---|---|---|---|
| | Diet 1 | Diet 2 | Diet 3 | Diet 4 | |
| Liver (g) | 37.19 ± 2.29 | 40.97 ± 2.12 | 42.25 ± 4.42 | 37.65 ± 3.83 | ns |
| (% body mass) | 1.73 ± 0.15 | 1.67 ± 0.08 | 1.80 ± 0.02 | 1.68 ± 0.15 | ns |
| Pancreas (g) | 4.10 ± 0.52 | 3.96 ± 0.22 | 4.02 ± 0.53 | 3.83 ± 0.10 | ns |
| (% body mass) | 0.18 ± 0.02 | 0.16 ± 0.01 | 0.17 ± 0.03 | 0.17 ± 0.02 | ns |
| Proventriculus (g) | 8.80 ± 0.67 | 9.45 ± 1.47 | 9.07 ± 0.36 | 8.70 ± 0.62 | ns |
| (% body mass) | 0.39 ± 0.03 | 0.41 ± 0.12 | 0.40 ± 0.06 | 0.39 ± 0.01 | ns |
| Ventriculus (g) | 36.78 ± 2.45 | 39.20 ± 3.35 | 39.74 ± 0.97 | 37.52 ± 1.85 | ns |
| (% body mass) | 1.65 ± 0.06 | 1.67 ± 0.09 | 1.74 ± 0.18 | 1.69 ± 0.05 | ns |
| Small intestines (g) | 42.87 ± 2.71 | 47.89 ± 2.67 | 46.47 ± 2.99 | 42.74 ± 3.86 | ns |
| (% body mass) | 1.95 ± 0.19 | 1.97 ± 0.13 | 2.02 ± 0.23 | 1.93 ± 0.21 | ns |
| Small intestines length (mm) | 1585.90 ± 140.87 | 1688.29 ± 130.06 | 1674.75 ± 71.75 | 1601.10 ± 99.73 | ns |
| Large intestines (g) | 3.45 ± 0.53 | 3.78 ± 0.41 | 3.49 ± 0.14 | 3.28 ± 0.07 | ns |
| (% body mass) | 0.15 ± 0.02 | 0.16 ± 0.03 | 0.15 ± 0.02 | 0.15 ± 0.01 | ns |
| Large intestines length (mm) | 111.13 ± 5.57 | 111.91 ± 4.11 | 113.52 ± 7.35 | 110.61 ± 1.15 | ns |
| Caecum (g) | 6.25 ± 0.58 | 7.44 ± 0.48 | 6.69 ± 0.58 | 0.58 ± 0.73 | ns |
| (% body mass) | 0.28 ± 0.01 | 0.32 ± 0.02 | 0.29 ± 0.04 | 0.31 ± 0.02 | ns |
| Visceral fat (g) | 35.88 ± 3.19 | 42.18 ± 5.22 | 45.73 ± 1.05 | 39.85 ± 5.98 | ns |
| (% body mass) | 1.62 ± 0.04 | 1.72 ± 0.09 | 1.95 ± 0.27 | 1.76 ± 0.15 | ns |

ns = not significant, $p > 0.05$.

Diet 1: Starter/Grower/Finisher + zinc bacitracin at 500 mg/kg of feed (positive control), Diet 2: Starter/Grower/Finisher + zingerone at 40 mg/kg of feed, Diet 3: Starter/Grower/Finisher + zingerone at 80 mg/kg of feed and Diet 4: Starter/ Grower/ Finisher + zingerone at 120 mg/kg of feed. Results expressed as mean ± standard deviation (SD), n = 3 replicates per dietary treatment with each replicate having 10 birds.

### Gastrointestinal organ and accessory organ masses and lengths

The effect of dietary zingerone on GIT organ and accessory organ masses and small and large intestine lengths are shown in Table 4. Zingerone had similar effects ($p > 0.05$) as ZnBcn on the absolute and relative masses of the ventriculus, proventriculus, small and large intestines, caeca, liver, pancreas, visceral fat as well as the length of the small and large intestines.

## DISCUSSION

We evaluated the effect of substituting zinc bacitracin, an antibiotic used as a growth promoter in broiler chicken feeds, with zingerone in the starter, grower, and finisher diets of broiler chicken and determined the effects of dietary zingerone on growth performance, feed intake, and feed utilisation efficiency, GIT organ, and accessory organ mass and small and large intestine length and meat yield. Growth performance is a function of body mass gain and the efficiency with which feed is converted to mass as measured by the feed conversion ratio (Nogueira et al., 2019; Zampiga et al., 2021). Findings from this study show that dietary zingerone used in place of ZnBcn had similar effects on terminal body mass, BMG, ADG, FI, and FCR by growth phase and combined trial performance (Table 2). It also similar impact on meat yield as control. The similarities in the terminal body mass, BMG, ADG, FI, and FCR by growth phase and trial across dietary treatments indicate that zingerone neither improved nor compromised growth performance and feed utilisation efficiency. In fact, the performance of the broiler chicken, across the three growth phases and combined trial performance, was similar to that achieved with zinc bacitracin as a growth promoter demonstrating that zingerone can be used as an alternative growth-promoting supplement in broiler chicken feeds. It has been shown that supplementing broiler chicken feeds with ginger, the source of zingerone, improved BMG, ADG, and FCR but had a similar effect on FI as the control (Zhang et al., 2009; Habibi et al., 2014; Qorbanpour et al., 2018). The reported improvement in BMG and ADG could have been due to the synergist effects of several (gingerol, shogaol, and paradol) phytochemicals in ginger (Ahmad et al., 2015; Raza et al., 2016) in addition to zingerone. We, therefore, contend that when administered alone zingerone might not stimulate enhanced growth performance. Although that could have been the case, it is important to note that zingerone in place of zinc bacitracin did not compromise growth performance and feed utilisation efficiency thus broiler chicken productivity and efficiency can be maintained with the use of zingerone as a growth promoter in place of zinc bacitracin, an antibiotic growth promoter. Based on our findings, we contend that zingerone can be used to replace antibiotics as growth promoters in broiler chicken production and thus offers a window of opportunity to mitigate the challenges and costs of antibiotic resistance and environmental pollution when antibiotics are used at sub-therapeutic doses as growth-stimulating supplements in broiler chicken production.

Meat yield is a critical production efficiency indicator for broiler chicken as well as in other poultry species. Proposed and potential dietary interventions, while perhaps providing a solution to the challenges of antibiotic resistance and environmental pollution must not negatively impact the product yield, in this case, meat yield. Barazesh et al. (2013) and Qorbanpour et al. (2018) showed that fortifying broiler chicken diets with graded inclusion levels of powdered ginger had a similar effect on empty carcass mass and dressing percentage. Similarly, Onu (2010) did not observe any significant effect on slaughter traits of broiler chicken from supplementing broiler chicken with ginger. We observed that supplemental zingerone had similar effects as ZnBcn on the slaughter and empty carcass mass and the dressing percent of the broiler chicken (Table 3). These findings suggest that in addition to its potential to be used as a growth promoter without loss in growth performance and feed utilisation efficiency by broiler chicken, zingerone can also be used to replace zinc bacitracin without risking a reduction in meat yield.

The GIT organs and GIT accessory organs are critical to nutrient digestion and absorption (Adedokun and Olojede, 2019). Feed composition has been shown to impact the growth and development of the GIT (Ravindran and Reza Abdollahi, 2021). In birds, for instance, phytochemicals have been shown to stimulate digestion (Kiarie & Mills, 2019). Additionally, fortifying broiler chicken feeds with cinnamaldehyde has been reported to enhance the growth of GIT organs and GIT accessory organs (Ali et al., 2021). Our findings show that zingerone had similar effects as ZnBcn on the masses of the proventriculi, ventriculi, small and large intestines, caeca, the lengths of the small, and intestines, and the masses of the pancreas and livers of the broiler chicken (Table 4). This finding is in tandem with the reported lack of effect on broiler chicken viscera reported by Onu (2010) when ginger was used to fortify broiler chicken feed. The fundamental message from our findings is that fortifying broiler chicken diets with zingerone do not compromise the growth and development and physiological function of GIT organs and the pancreas and livers of broiler chicken more so considering that zingerone did not compromise growth, feed intake, and utilisation efficiency and meat yield which suggest uncompromised GIT digestive and absorptive function.

## CONCLUSIONS

Findings from this study show that zingerone can be used to replace zinc bacitracin as a growth promoter in broiler chicken feeds without compromising growth performance, feed utilisation efficiency, and meat yield. Importantly and interestingly, even the lowest dietary inclusion level of zingerone, 40mg/kg of feed, is equally effective as a substitute to zinc bacitracin which possibly contributes to reduced costs of fortifying broiler chicken feeds.

## ACKNOWLEDGEMENTS

Professor Kennedy H. Erlwanger is acknowledged for technical input and staff members of the Wits Research Animal Facility for assistance with monitoring chicken health. We wish to thank the National Research Foundation of South Africa (grant number: 121415) and the Wits Faculty of Health Sciences Research Endowment Fund (grant number: 001 254 8521101 5121105 000000 0000000000 5254) for funding this research.

## CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

## NOVELTY STATEMENT

This study reports for the first time the potential of zingerone to substitute the zinc bacitracin in broiler chicken diets without compromising growth performance, feed utilisation efficiency, meat yield and gastrointestinal tract viscera.

## AUTHOR`S CONTRIBUTION

BM and EC designed the study. BM and FM conducted the experiment and analysed the data. EC and BWL supervised the project. BM and EC were equally involved in the write-up of the manuscript. All authors contributed to the article and approved the submitted version.

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