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# Dietary Garlic (*Allium sativum*) Powder Supplementation Enhances Growth Performance, Feed Efficiency, and Protein Utilization in Cobb-500 Broiler Chickens

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**Abstract**

The dose-dependent effect of garlic powder on growth performance, FCR and protein utilization efficiency of Cobb-500 broiler chickens was evaluated. Cobb-500 broiler chicks (one-week-old) were randomly assigned to three dietary treatments with four replicates per treatment (5 birds per replicate; 20 birds per treatment). The experiment was conducted for 28 days under standard husbandry conditions. Growth parameters such as body weight gain (BWG), feed intake (FI) and Feed conversion ratio(FCR) were measured every week. In vitro digestion assays to measure soluble protein (SP) and pellet protein (PP) concentrations, nitrogen retention (NR) and protein efficiency ratio (PER) were used to assess the protein utilization. The growth performance was significantly improved ($P<0.05$) in garlic supplementation, with the 1% garlic group having the highest BWG (1650±55.1 g) and the lowest FCR (1.75±0.05) when compared with the control (1450±52.3 g, FCR 1.95±0.08). The protein digestibility of garlic-supplemented groups was significantly increased ($P<0.001$) in both SP and PP. The 1% garlic group showed superior NR (71±3.2%) and PER (2.07±0.11 g/g) compared to control (58±2.8%; 1.75±0.09 g/g) ($P<0.01$). These findings indicate that dietary garlic powder at a 0.5-1% level is a natural, cost-effective alternative to synthetic growth promoter in broiler production that enhances growth performance, feed efficiency and protein utilization.

**Keywords: A. sativum, Broiler, Protein utilization, Growth performance**

**الملخص**

تم تقييم التأثير المتعلق بالجرعة لمسحوق الثوم على أداء النمو، ونسبة تحويل العلف**(FCR)** ، وكفاءة استفادة البروتين لدى دجاج التسمين من سلالة كوب-500. تم توزيع فراخ دجاج التسمين من سلالة كوب-500 (عمرها أسبوع واحد) عشوائياً على ثلاث معالجات غذائية، مع أربع مجموعات تكرار لكل معالجة (5 طيور لكل مجموعة تكرار؛ 20 طائراً لكل معالجة). أُجريت التجربة لمدة 28 يوماً في ظل ظروف تربية قياسية. تم قياس معلمات النمو مثل زيادة الوزن **(BWG)** واستهلاك العلف **(FI)** ونسبة تحويل العلف **(FCR)** كل أسبوع. تم استخدام اختبارات الهضم المختبري لقياس تركيزات البروتين القابل للذوبان **(SP)** والبروتين الحبيبي **(PP)** واحتباس النيتروجين **(NR)** ونسبة كفاءة البروتين **(PER)** لتقييم استخدام البروتين. تحسّن أداء النمو بشكل ملحوظ **(P<0.05)** في المجموعات التي تم إعطاؤها مكملات الثوم، حيث سجلت المجموعة التي تلقت 1% من الثوم أعلى زيادة في وزن الجسم (1650±55.1 غ) وأدنى نسبة تحويل علف (1.75±0.05) مقارنةً بالمجموعة الضابطة **(1450±52.3** غ، **FCR 1.95±0.08).** زادت قابلية هضم البروتين في المجموعات التي تم إعطاؤها مكملات الثوم بشكل ملحوظ **(P<0.001)** في كل من **SP** و **PP.** أظهرت المجموعة التي تناولت 1٪ من الثوم معدل استيعاب مغذيات **(71±3.2٪) (NR)** ومعدل استفادة من البروتين **(PER)** (2.07±0.11 جم/جم) أفضل مقارنة بالمجموعة الضابطة (58±2.8٪؛ 1.75±0.09 جم/جم) **(P<0.01).** تشير هذه النتائج إلى أن مسحوق الثوم الغذائي بنسبة 0.5-1٪ هو بديل طبيعي وفعال من حيث التكلفة لمحفزات النمو الاصطناعية في إنتاج الدجاج اللاحم، حيث يعزز أداء النمو وكفاءة التغذية واستخدام البروتين.

**الكلمات المفتاحية : A. Sativum , دجاج التسمين، استفادة البروتين، أداء النمو**

## Introduction

The poultry industry is among the rapidly developing industries in animal farming, which provides a source of high-quality protein in the form of meat and eggs [16]. Broiler chickens have become the preferred chickens in the world due to a number of factors, such as the high rate of growth, high feed weight ratio and the fact that they gain market weight within a very short time [1, 17]. The price of feed, particularly protein-based foods and items, occupies a major part of the total production costs [18]. The enhancement of efficiency of protein utilization in broiler chickens has become an urgent objective of poultry producers since it directly influences growth performance, feed efficiency and profitability [2, 19]. Historically, antibiotic growth promoters have been included in the food of chickens to improve growth, feed efficiency and resistance to diseases [20]. Overuse of antibiotics has raised a question of antimicrobial resistance, food safety, and unfavorable consequences to human health [3,

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22]. The administration of antibiotics in animal feeds has also been controlled. This has brought about the necessity to employ safe, natural, and cost-effective products so that maximum growth can be realized in poultry [22]. The use of medicinal plants, herbal extracts, and phytogenic feed additives enhances nutrient intake and overall health of broiler chickens, and has gained increased attention from researchers [4, 22].

Among others, Garlic (*A. sativum*) is a promising herbal supplement due to its varying bioactive molecules such as allicin, flavonoids and sulfur-bearing molecules [23]. Garlic has been known to possess antimicrobial, antioxidant, and immunomodulatory properties [5,24]. Garlic is beneficial for poultry nutrition; it maintains ~~a~~ healthy microflora, improves enzyme activity, and increases nutrient absorption [25]. These effects can be used to improve the ratio of food to growth and reduce the likelihood of digestive disorders and infections [6, 26].

Protein is a major broiler chicken nutrient, as it plays an important role in muscle development, tissue repair and growth [27]. It is a good utilization of nutritional protein, whose advantages include that it maximizes the ratio of the feed to body mass, reduces the amount of nitrogen discharged, and renders production of lean poultry sustainable (7). Despite different studies reporting the general benefits of garlic supplementation on growth and health parameters, not many studies have been conducted to ascertain the effects of the supplement on the use of proteins in broiler chickens [8]. Potential results of researching the influence of garlic on protein metabolism and efficiency of its conversion into energy can result in an improved understanding of poultry diet maximization and reduction in feed price [28]. The growing demand for organic and chemical-free poultry products, as well as the use of natural additive feeds like garlic in the poultry food, attracted interest [9, 29]. Consumers are growing more worried about the quality and safety of food, and this has established a market trend that poultry products produced with at least some synthetic food additives are more preferred by consumers. The efficiency in production and an increase in the market value of poultry products can be solved by the role of garlic supplementation in natural growth promotion [10, 30].

The objective of the current research was to study the growth performance of broiler chickens in response to the supplementation with garlic powder. The study will be useful in terms of making a recommendation on the use of garlic as a natural feed additive based on the assessment of parameters such as the intake of the feed, intake of the proteins, weight gain, and the ratio of the feed to the weight.

## Materials and Methods

### Garlic Powder Preparation

The fresh garlic bulbs (*A. sativum*) were purchased from the local market. Dirt and foreign materials were removed from the bulbs by washing them with distilled water. The garlic cloves were peeled and then sliced into thin pieces (2-3 mm thick) and dried in a forced air oven at 60°C until constant weight was reached after 48 hours. The dried garlic slices were finely ground in a laboratory mill (particle size <0.5 mm) and kept in a dark room at room temperature (20-25°C) until used in experimental diets.

### Experimental Design and Bird Management

Cobb-500 broiler chicks of mixed sex were purchased at a commercial hatchery and randomly assigned to three dietary treatment groups in a completely randomized design with 61-week-old chicks (145±8.5 g), obtained from

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a commercial hatchery. The birds were placed in 20 birds per treatment in 4 replicate pens of 5 birds each in floor pens (1.0 m × 1.5 m) with wood shavings as litter material. The experimental unit was the pen (5 birds/pen).

**Dietary Treatments**

Control (T0): Basal diet (no garlic supplementation)

Treatment 2 (T1): Basal diet + 1% garlic powder

Treatment 2 (T2): Basal diet + 1.0% garlic powder.

Birds were kept in a well-ventilated poultry house with controlled environmental conditions. During the first week, the ambient temperature was maintained at 32 °C and gradually reduced to 24 °C by the fourth week. Relative humidity was consistently maintained between 60–70% throughout the experimental period. Feed and water were available ad libitum. The experimental period was 28 days (from day 7 to day 35 of age). Vaccination procedures were carried out as usual, including Newcastle disease and infectious bursal disease vaccines. The health status was checked every day, and deaths were noted.

**Basal Diet Composition**

The basal diet was designed to satisfy or surpass the nutritional needs of Cobb-500 broilers as recommended by the broiler's recommendation. The nutrient composition and nutrient calculation of the basal diet are given in Table 1.

**Table 1. Ingredient Composition and Calculated Nutrient Content of Basal Diet**

| **Ingredients** | **Inclusion Level (% as-fed basis)** |
|---|---|
| Corn | 56.50 |
| Soybean meal (44% CP) | 35.20 |
| Wheat bran | 3.00 |
| Soybean oil | 2.00 |
| Dicalcium phosphate | 1.50 |
| Limestone | 1.00 |
| Salt (NaCl) | 0.30 |
| Vitamin-mineral premix* | 0.50 |

| | |
|---|---|
| **Total** | **100.00** |
| **Calculated Nutrient Content** | **Value** |
| Metabolizable Energy (kcal/kg) | 3050 |
| Crude Protein (%) | 21.50 |
| Crude Fiber (%) | 3.20 |
| Calcium (%) | 0.95 |
| Available Phosphorus (%) | 0.42 |
| Lysine (%) | 1.15 |
| Methionine (%) | 0.48 |
| Methionine + Cysteine (%) | 0.85 |

Vitamin-mineral premix provided per kg of diet: Vitamin A, 12,000 IU; Vitamin $D_3$, 2,500 IU; Vitamin E, 30 IU; Vitamin $K_3$, 3 mg; Vitamin $B_1$, 2 mg; Vitamin $B_2$, 6 mg; Vitamin $B_6$, 3 mg; Vitamin $B_{12}$, 0.015 mg; Niacin, 40 mg; Pantothenic acid, 12 mg; Folic acid, 1 mg; Biotin, 0.1 mg; Choline chloride, 500 mg; Mn, 100 mg; Zn, 80 mg; Fe, 60 mg; Cu, 10 mg; I, 1 mg; Se, 0.2 mg; Co, 0.5 mg.

Garlic powder was added to the basal diet by substituting an equivalent amount of corn. All diets were formulated weekly as mashes and thoroughly mixed to ensure even distribution of garlic powder.

**Growth Performance Measurements**

Feed intake was measured daily by weighing the feed offered and refused for each replicate pen. After 4 hours of withdrawal of food, the body weight of individual birds was measured weekly on a digital balance with a precision of 1g. Body weight gain (BWG) was determined as the change in body weight of each measurement period. FCR was determined as:

$$\mathrm{FCR} = \frac{\text{Feed Consumed (g)}}{\text{Weight gain (g)}}$$

Mortality was recorded daily, and FCR was adjusted for mortality if necessary.

### Protein Utilization Assessment

Protein digestibility was determined using a two-step in vitro digestion method, which mimics the digestion in the poultry stomach and intestine. Each experimental feed was weighed into a 50 mL centrifuge tube and placed in 50 mL of simulated gastric fluid (SGF) with pepsin (2 g/L; Sigma-Aldrich) to a pH of 2.5 using HCl. Tubes were incubated at 40°C in a shaking water bath for 3 hours. The pH was then brought to 6.8 with NaOH and pancreatin (5 g/L; Sigma-Aldrich) was added to mimic gastrointestinal digestion. The incubation was continued for another 9 hours at 40°C. Samples (2 mL) were taken at 1, 3, 6, 9, and 12 hours after the incubation was initiated and immediately centrifuged at 4°C at 10,000 rpm for 10 minutes. The supernatant (soluble protein fraction) was removed from the pellet (undigested protein fraction). The Bradford protein assay (Bradford, 1976) was used to determine the concentration of soluble protein (SP) in the supernatant and the concentration of pellet protein (PP) in the resuspended pellet, using bovine serum albumin as a standard.

### Nitrogen Retention and Protein Efficiency Ratio

Total excreta collection was used to determine NR during the last week of the experiment (days 28-35). Birds were kept in metabolic cages (n=4 birds per treatment) with wire mesh floors to collect the birds' excreta completely. The daily consumption of feed and output of excreta for 7 days in a row were measured. Samples of feed and excreta were collected, dried at 60°C for 48 hours and ground for nitrogen analysis. The total nitrogen in feed and excreta was measured by the Kjeldahl method (AOAC, 2019). Nitrogen retention was determined as:

$$\text{Nitrogen Retention (NR)} = \left(\frac{\text{Nitrogen intake} - \text{Nitrogen excreted}}{\text{Nitrogen intake}}\right) \times 100$$

Protein efficiency ratio (PER) was determined by the following equation:

$$\text{PER}\left(\frac{g}{g}\right) = \frac{\text{Total body weight gain(g)}}{\text{Total protein intake (g)}}$$

The total protein intake was determined as the product of feed intake and crude protein percentage of the feed.

### Statistical Analysis

The data were analyzed with SPSS software (version 25.0; IBM Corporation, Armonk, NY, USA) and SAS software (version 9.4; SAS Institute Inc., Cary, NC, USA). The normality of data was tested with the Shapiro-Wilk test and homogeneity of variance was tested with Levene's test. The effects of the treatments on growth performance parameters, protein digestibility indices, nitrogen retention and protein efficiency ratio were tested by one-way analysis of variance (ANOVA). When significant treatment effects were detected ($P<0.05$), means were separated using Duncan's multiple range test. Data are reported as mean ± SD. A P value of $<0.05$ was regarded as statistically significant and statistical trends were discussed at $0.05 \leq P < 0.10$.

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## Results

### Growth Performance Parameters

The results of dietary garlic powder supplementation on growth performance parameters are presented in Table 2. The body weight gain, feed intake and FCR were significantly affected by garlic supplementation in comparison to the control group (P<0.05).

**Table 2. Effects of Dietary Garlic Powder Supplementation on Overall Growth Performance in Broiler Chickens (Days 7–35)**

| Parameter | Control | 0.5% Garlic | 1.0% Garlic | P-value |
|---|---|---|---|---|
| Initial BW (g) | 145 ± 8.2[a] | 146 ± 7.9[a] | 145 ± 8.5[a] | 0.952 |
| Final BW (g) | 1595 ± 52.8[c] | 1726 ± 51.2[b] | 1795 ± 56.3[a] | <0.001 |
| Body Weight Gain (g) | 1450 ± 52.3[c] | 1580 ± 48.9[b] | 1650 ± 55.1[a] | <0.001 |
| Feed Intake (g) | 3200 ± 45.2[a] | 3150 ± 38.7[ab] | 3100 ± 42.1[b] | 0.032 |
| FCR | 1.95 ± 0.08[a] | 1.82 ± 0.06[b] | 1.75 ± 0.05[c] | <0.001 |

Values represent mean ± SD (n = 20 birds per treatment, 4 replicates of 5 birds).

[abc] Means within a row bearing different superscripts differ significantly (P < 0.05) according to Duncan's Multiple Range Test.

The garlic-supplemented groups had significantly higher body weight gain than the control group (P<0.001). The 1% garlic group had the best BWG (1650±55.1 g), which is 13.8% more than the control (1450±52.3 g). The 0.5% garlic group showed intermediate performance (1580±48.9 g) and showed an improvement of 9.0% when compared to the control. The garlic-supplemented groups had numerically lower feed intake, with the 1% garlic group having significantly lower feed intake (3100±42.1 g) than the control group (3200±45.2 g) (P=0.032), which is a 3.1% reduction. The FCR was significantly enhanced in a dose-dependent manner with garlic supplementation (P<0.001). The 1% garlic group had the most efficient FCR (1.75±0.05), which was 10.3% better than the control (1.95±0.08). The garlic group (0.5%) had intermediate FCR (1.82±0.06) with 6.7% better than the control.

### Weekly Growth Performance

Table 3 shows the body weight gain patterns weekly during the experimental period. Beginning in Week 2, treatment effects on BWG were significant and gradually increased in magnitude between the garlic-supplemented and control groups.

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**Table 3. Weekly Body Weight Gain (g) in Broiler Chickens Fed Garlic-Supplemented Diets**

| Week | Control | 0.5% Garlic | 1.0% Garlic | P-value |
|---|---|---|---|---|
| Week 1 (Days 7–14) | $350 \pm 15.2^{a}$ | $360 \pm 12.8^{a}$ | $370 \pm 14.1^{a}$ | 0.187 |
| Week 2 (Days 15–21) | $400 \pm 18.5^{b}$ | $430 \pm 16.2^{ab}$ | $440 \pm 17.8^{a}$ | 0.023 |
| Week 3 (Days 22–28) | $350 \pm 20.1^{c}$ | $390 \pm 18.9^{b}$ | $410 \pm 19.5^{a}$ | <0.001 |
| Week 4 (Days 29–35) | $350 \pm 22.3^{c}$ | $400 \pm 20.1^{b}$ | $430 \pm 21.7^{a}$ | <0.001 |

Values represent mean ± SD (n = 20 birds per treatment).[abc] Means within a row bearing different superscripts differ significantly ($P < 0.05$) according to Duncan's Multiple Range Test.

No significant difference in weekly BWG was found in week 1 (P=0.187), indicating an adaptation period for the dietary treatments. The garlic supplementation significantly increased weekly BWG (P<0.05) in week 2 and the effect became more pronounced in subsequent weeks (3 and 4). The trend of FCR in the experimental period is shown in Figure 1, which indicates that the FCR of the broiler improved progressively with garlic supplementation. The difference in the FCR between the treatments increased from week 2 and onwards, and the 1% garlic group always had the lowest (most efficient) FCR.

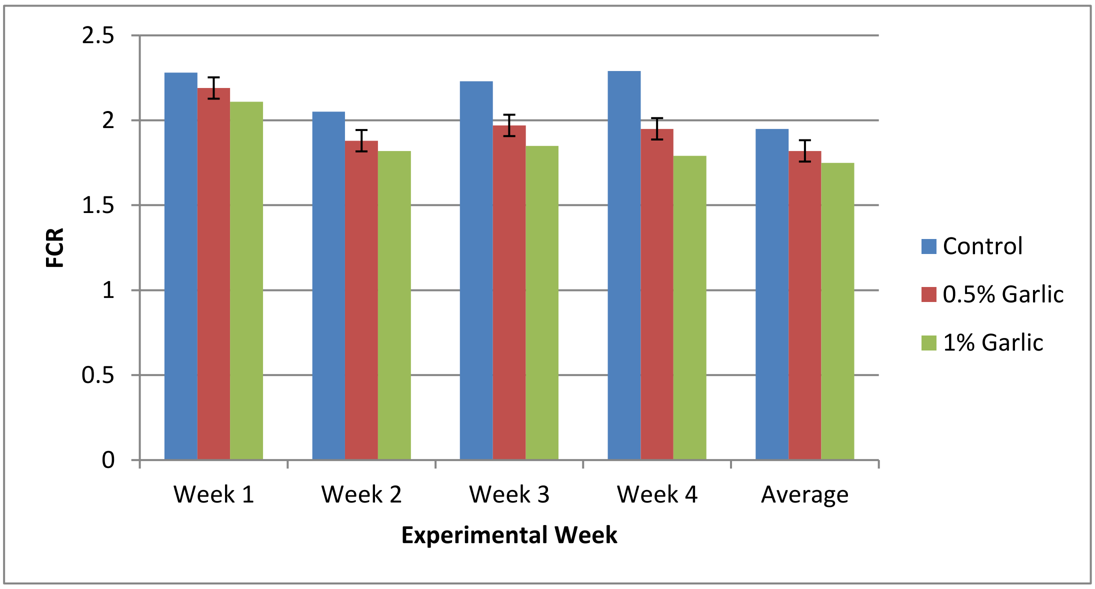


**Figure 1. Weekly FCR in Broiler Chickens Fed Garlic-Supplemented Diets**

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## Digestibility of Proteins

The release of soluble protein (SP) and pellet protein (PP) during in vitro digestion is shown in Figure 2 and summarized in Table 4.

**Table 4. SP and PP Concentrations Following 12-h In Vitro Digestion**

| Treatment | Soluble Protein (mg/g) | Pellet Protein (mg/g) |
|---|---|---|
| Control | $5.2 \pm 0.8^{c}$ | $6.5 \pm 0.5^{b}$ |
| 0.5% Garlic | $14.6 \pm 1.2^{b}$ | $7.5 \pm 0.6^{a}$ |
| 1.0% Garlic | $16.3 \pm 1.4^{a}$ | $8.2 \pm 0.7^{a}$ |
| P-value | <0.001 | 0.009 |

Values represent mean ± SD (n = 4 replicates per treatment). $^{abc}$ Means within a column bearing different superscripts differ significantly ($P < 0.05$) according to Duncan's Multiple Range Test.

The level of soluble protein was significantly raised by garlic supplementation ($P<0.001$). In the case of 0.5% garlic group, the concentration of SP at 12 hours of in vitro digestion was 14.6±1.2 mg/g, which is 2.8-fold higher (181% elevation) than that of control (5.2±0.8 mg/g). The 1% garlic group showed even higher SP release (16.3±1.4 mg/g) which is 3.1-fold higher (214% elevation) than the control. These findings suggest that protein solubilization and digestibility were improved in garlic-supplemented diets. There was also a significant increase in pellet protein concentration with garlic supplementation ($P=0.009$) which suggests a greater protein degradation by enzymes. The PP concentration was found to be 6.5±0.5 mg/g in control, 7.5±0.6 mg/g in 0.5% garlic and 8.2±0.7 mg/g in 1% garlic which is 15.4% and 26.2% increase respectively. The time-course analysis showed that the increase in SP concentration in the garlic-supplemented group compared to the control group was observed as early as 1 hour after incubation, and gradually increased over the 12-hour digestion time (Figure 2). This pattern indicates that the bioactive compounds of garlic are beneficial for both the onset and continued digestion of protein.

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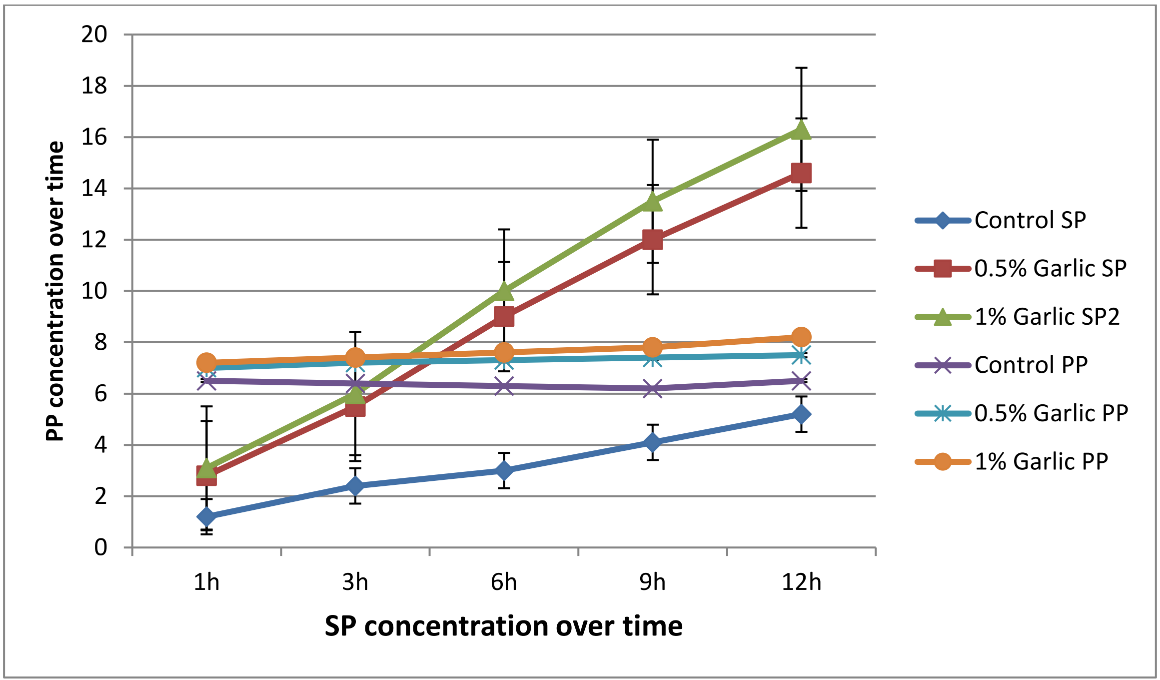


**Figure 2. In Vitro SP and PP Release Kinetics during 12h Digestion**

**Nitrogen Retention and Protein Efficiency Ratio**

The dietary effect of garlic supplementation on N retention and protein efficiency ratio are shown in Table 5.

**Table 5. Nitrogen Retention and Protein Efficiency Ratio in Broilers Fed Garlic-Supplemented Diets**

| Parameter | Control | 0.5% Garlic | 1.0% Garlic | P-value |
|---|---|---|---|---|
| Nitrogen Retention (%) | $58.0 \pm 2.8^{c}$ | $67.0 \pm 3.1^{b}$ | $71.0 \pm 3.2^{a}$ | <0.001 |
| Protein Efficiency Ratio (g/g) | $1.75 \pm 0.09^{c}$ | $1.95 \pm 0.10^{b}$ | $2.07 \pm 0.11^{a}$ | 0.002 |

Values represent mean ± SD (n = 4 replicates per treatment). $^{abc}$ Means within a row bearing different superscripts differ significantly (P < 0.05) according to Duncan's Multiple Range Test.

Garlic supplementation resulted in a significant improvement in N retention, which was dose dependent (P<0.001). The 0.5% garlic group

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demonstrated 67.0±3.1% NR, representing a 15.5% improvement over control (58.0±2.8%). The 1% garlic group had the highest NR (71.0±3.2%), which was 22.4% higher than the control group. The results suggest that garlic supplementation can improve NUE and decrease nitrogen excretion. There was a significant increase in protein efficiency ratio in the garlic supplementation group (P=0.002). The PER values for 0.5% and 1% garlic groups were 1.95±0.10 and 2.07±0.11 g/g, respectively, compared to 1.75±0.09 g/g in the control group. The protein conversion efficiency of the garlic supplementation at 0.5% and 1% were 11.4% and 18.3% better, respectively.

**Dose-Response Relationship**

For all the measured parameters (BWG, FCR, SP, PP, NR and PER), the improvement showed a dose-dependent relationship, and the 1% garlic supplementation group consistently exhibited better results than 0.5% garlic and control groups (P<0.05). The results indicate that the beneficial effect on growth performance and protein utilization of garlic is concentration dependent in the range tested (0-1%).

**Discussion**

The current study showed that the inclusion of garlic powder in the feed at 0.5% and 1% significantly enhanced the growth performance, feed utilization efficiency, and protein metabolism in Cobb-500 broiler chickens. The improvements were dependent on the dose and the 1% garlic group showed consistently better performance in all parameters measured. The overall results demonstrated the great potential of using garlic as an alternative to antibiotic growth promoters in poultry production systems. The positive effects observed on body weight gain and FCR are likely due to the various biological activities of the garlic bioactive compounds, including the allicin compound, organosulfur compounds, and flavonoids. These compounds are known to stimulate the secretion of digestive enzymes, optimize intestinal microbial balance and improve the efficiency of nutrient absorption [5,23,24]. The chief compound produced from alliin, allicin, has been extensively mentioned for its ability to activate pancreatic and intestinal enzymes including amylase, lipase, and proteases which enhance the digestion and assimilation of nutrients [23,25]. The significant rise in soluble protein level during in vitro digestion of the present study further supports the greater proteolytic activity of garlic-supplemented diets, which suggests increased protein breakdown and availability for absorption.

Garlic bioactives may also stimulate bile secretion and intestinal functionality, leading to better lipid digestion and nutrient utilization, in addition to digestive enhancement [11]. The superior FCR recorded for supplemented birds may be attributed to the physiological changes that occurred in these groups, which enabled the birds to better utilize feed nutrients to gain weight without additional wastage. Modulation of gut microbiota is another important mechanism involved in growth promotion. Garlic has a selective antimicrobial activity against pathogenic bacteria like Escherichia coli, Salmonella, and Clostridium spp., and promotes beneficial microbes like Lactobacillus spp. and Bifidobacterium spp. [25,26]. The microbial balance leads to decreased inflammation in the intestine, less competition for nutrients, and better gut health, which all leads to better growth performance and feed efficiency. A similar study was conducted by Elbaz et al. [11] and Abdullahi et al. [12] who also noted improved growth performance and gut health in broilers fed garlic-based diets. The most important results of this study were the marked improvements in protein utilization parameters such as protein efficiency ratio, nitrogen retention, soluble and pellet protein concentration. The results indicate a significant increase in dietary protein digestibility and metabolic utilization. The increased protein digestion to amino acids, which are the building blocks of muscle proteins, probably led to increased utilization of dietary protein for muscle protein synthesis, instead of as nitrogen waste. The increased nitrogen retention in the garlic supplemented groups (67-71% vs. 58% in the control) suggests better utilization of dietary protein for growth. This not only has economic importance because of the improved conversion of costly protein sources into meat production but also environmental importance because of the decreased nitrogen excretion that reduces ammonia emissions in poultry production systems. Alem [13] reported similar results with the use of herbal additives to increase nutrient retention and decrease the amount of waste produced in the environment. In addition, the increase in protein efficiency ratio indicates better utilisation of dietary protein for body weight gain. This may be attributed to increased levels of absorption of amino acids, decreased degradation of microbial protein in the gut and better post-absorptive metabolism. All of these effects suggest that garlic supplementation improves the digestibility and utilization of dietary protein.

The FCR is one of the most economically important parameters in poultry production and the observed increase of 6.7-10.3% in the FCR of the garlic treated groups is a great production advantage. The 1% garlic group also had a decreased feed intake, yet showed enhanced weight gain, indicating that the garlic may have enhanced the efficiency of feed use and/or increased the utilization of the nutrients. This could also be associated with better control of gut hormones and metabolic efficiency. The results are similar to Abd El-Ghany [14] who reported increased growth performance and feed efficiency in broilers fed garlic. In a similar study, Mustafa and Dikel [15] showed that growth performance was improved with moderate garlic supplementation without any negative physiological effects, which is in line with the optimal dose range found in the current study. All responses were dose dependent, suggesting that higher inclusion rates of garlic in the range tested yield greater physiological benefits. It should be noted, however, that the level of supplementation above optimal may not necessarily result in a proportional improvement, and may even result in reduced palatability or metabolic imbalance. Thus, more studies are required to determine the exact optimum level of inclusion over 1%. The application of garlic as a growth promoter has important implications to decrease the use of A.G.P. in poultry production. Garlic has several benefits: it is natural, accepted by consumers, inexpensive, has a wide range of biological activity and is not subject to withdrawal requirements. Furthermore, its antimicrobial, antioxidant and immunomodulatory properties render it an all-round feed additive with the potential to enhance productivity and animal health. The present results corroborate those of Ashour et al. [10] who found garlic diets to be beneficial for broilers' performance and health status. The improvement in FCR obtained in this study was however more than that reported by Hayat et al. [28] which could be explained due to the difference in preparation of the garlic, genetic of the birds, environmental conditions or diet composition. This variability points to the need for the standardization of garlic processing in future studies and experimental conditions. Although the results were encouraging, there are several caveats. The length of the study (28 days) may not be representative of long-term production performance or meat quality results. Furthermore, the intestinal morphology, digestive enzyme activity and gut microbiota composition were not directly measured, which prevented a more in-depth physiological interpretation. Additionally, quality characteristics of meat were not assessed, which is important for consumer acceptance and market value. Additionally, the study failed to quantify specific bioactive compounds in the garlic powder used, and this makes it difficult to make a direct correlation between the amount of compound and biological effects. The experiment was also performed under controlled conditions and results might differ under commercial or stress prone conditions. Finally, only Cobb-500 broilers were used and results may vary for other genetic strains.

Future studies should look into long-term trials with complete production cycles, thorough mechanistic studies including gut histological examination and profiling of gut microbiome, and meat quality attributes. In addition, research on the use of higher inclusion rates, various garlic preparations and synergistic combinations with probiotics and other phytogenic additives can further optimize performance results. Field validation is also required for commercial scale to validate the applicability of these results.

**Conclusion**

The present study shows that feeding broiler chickens Cobb-500 with garlic (*A. sativum*) powder at 0.5% and 1% levels significantly improves growth performance, feed efficiency and protein utilization. Garlic fed birds recorded a higher body weight gain (9.0–13.8%), higher FCR (6.7–10.3%) and better protein metabolism (higher soluble protein, higher pellet protein, higher nitrogen retention, better protein efficiency ratio). These effects were dose dependent, with the 1% inclusion rate showing the most consistent and optimal effects. The benefits observed may be attributed to the presence of bioactive compounds in garlic that stimulate the activity of digestive enzymes, promote a healthy balance of the gut flora, and boost the absorption of nutrients. On the applied side, garlic can be used as a natural alternative to antibiotic growth promoters (AGP), enhancing productivity and decreasing feed cost and environmental nitrogen losses. It's also in sync with the consumer demand for antibiotic-free poultry products. Garlic supplementation of 0.5–1.0% is recommended to enhance the performance of broilers and future studies should be conducted to determine the optimal dosage in commercial condition

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