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Evaluation of dietary supplementation of garlic powder (*Allium sativum*) on the growth performance, carcass traits and meat quality of Japanese quails (*Coturnix coturnix japonica*)

Hassan Jalal [*], Sibel Canoğullari Doğan [†], Melania Giammarco [*,1], Damiano Cavallini, [‡] Lydia Lanzoni [*], Paolo Pezzi, [*] Muhammad Zeeshan Akram [§], and Isa Fusaro [*]

[*]*Department of Veterinary Medicine, University of Teramo, 64100 Teramo, Italy;* [†]*Department of Animal Production and Technologies, Faculty of Agricultural Sciences and Technologies, Nigde Ömer Halisdemir University, 51240 Nigde, Turkey;* [‡]*Department of Veterinary Sciences, University of Bologna, 40064 Ozzano dell'Emilia, Italy; and* [§]*Department of Biosystems, Nutrition and Animal-Microbiota Ecosystems Lab, KU Leuven, 3001 Leuven, Belgium*

ABSTRACT Dietary supplementation with plant-based products may arise as part of an alternative strategy to using antibiotics as growth promoters in the poultry industry. Garlic powder (**GP**) possesses antimicrobial and antioxidant properties. The aim was to investigate the effect of dietary supplementation of GP on growth performance, carcass traits and meat quality of the Japanese quail. A total of 240, day-old mixed gender Japanese quail were assigned to 4 treatment groups, each group being replicated 4 times and containing 15 birds in each replication. Birds were provided with either a basal diet (control) or basal diet supplemented with 0.5%, 1% and 2% GP for 5 wk. At slaughter age, birds fed 1% GP had higher *($P < 0.05$)* live weight and body weight gain when compared to the control. Supplementation with different levels of GP had no influence ($P > 0.05$) on feed intake, feed conversion ratio except 3rd wk, carcass traits and abdominal fat. Thiobarbituric acid, peroxide and pH values in breast meat of birds receiving GP (1% or 2%) after storage (0, 1, 3, 5, and 7 d) were lower *($P < 0.05$)* than the birds in control. Furthermore, total psychrophilic bacteria count was lower in breast meat of birds supplemented with GP at any dose compared to the birds of control. Sensory characteristics such as color, aroma, juiciness and tenderness were observed significantly better *($P < 0.05$)* in GP supplemented groups especially when fed 1% GP. In conclusion, supplementing the diet with 1% to 2% GP demonstrated growth-promoting effects and positively impacted meat quality, including sensory characteristics.

Key words: quail, garlic, antibiotic, meat quality, carcass trait

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INTRODUCTION

The unprecedented growth of the human population and its projected increase to over 10 billion individuals by 2050 (Jalal et al., 2023) pose significant challenges, particularly in the domain of food production. The poultry industry has grown to be an essential factor in fulfilling the increasing demand for food, providing consumers across the globe with high-quality animal protein (Asghar et al., 2022). The Japanese quail (JQ, Coturnix coturnix japonica) has garnered significant interest in the egg and meat production industries due to its high production capacity and cost-effective maintenance (Ray et al., 2014). Notably, in a free-range rearing system, JQ can acquire a live weight of 100-160g, whereas their commercially-raised counterparts can achieve 200 g in just 4 wk after hatching (Arunrao et al., 2023). The appealing features associated with quail production have made it a progressively desirable choice among poultry producers. While the intensification of poultry production has historically involved antibiotic use to mitigate morbidity and mortality (Akram et al., 2021), concerns about antimicrobial resistance have led to changes in practices. It is important to note that antibiotic use varies globally, with some regions, such as Europe, having already implemented strict regulations on antibiotic use in animal feed (Van Boeckel et al., 2015; Lekagul et al., 2019). The search for alternatives to antibiotics as growth promoters has been an ongoing trend in the poultry industry for well over a decade

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[1]Corresponding author: mgiammarco@unite.it

(Gadde et al., 2017; Lillehoj et al., 2018). Recent developments in food production have increased interest in natural preservatives that can maintain meat quality and safety (Akram et al., 2019). While poultry meat fatty acid profile makes it susceptible to oxidation (Domínguez et al., 2019), modern processing and storage techniques have largely mitigated these concerns in industrial settings (Petracci, 2017). However, in contexts where cold chain management is challenging, strategies to enhance meat stability remain relevant (Kumar et al., 2015; Jiang and Xiong, 2016).

To address these challenges, researchers have explored various alternatives, including plant-derived compounds, phytobiotics, and essential oils. These compounds have shown potential in different species for maintaining growth performance, carcass quality, and meat safety (Jalal et al., 2019; Sevim et al., 2020; Ali et al., 2022). Among these alternatives, garlic (Allium sativum) has garnered significant attention due to its reported antimicrobial, antioxidant, and immunomodulatory properties (Navidshad et al., 2018). Historically valued for its medicinal and aromatic qualities, garlic offers numerous potential benefits (El-Ghany and A, 2024). Garlic has been shown to offer multiple benefits in livestock and poultry nutrition, including the potential to improve growth performance, feed efficiency, and meat quality (Ogbuewu et al., 2019). Over the past 3 decades, allium-based feed additives, particularly garlic, have extensively been studied in poultry diets (Kothari et al., 2019). Garlic contains at least 33 sulfur compounds, various enzymes, minerals, vitamins, amino acids, and dietary fibers (Gebreyohannes and Gebreyohannes, 2013; Aarti and Khusro, 2020). Allicin, the most studied primary bioactive component, has demonstrated significant antimicrobial, antioxidant, and growth-promoting effects (Kirkpinar et al., 2014; El-Ghany and A, 2024). Previous studies have shown that garlic can positively affect broiler growth, digestion, immune function and carcass quality (Swain et al., 2017; Bhavani et al., 2020; Elbaz et al., 2021). Additionally, antimicrobial properties of garlic have been found to lower bacterial infections in poultry, reducing the need for antibiotics (Sheoran et al., 2017; Ogbuewu et al., 2019; Alagawany et al., 2021). Ogbuewu et al. (2019) suggested that garlic's broad spectrum of beneficial properties makes it a promising natural alternative to synthetic additives in poultry production. Incorporating garlic into animal diets may offer a strategy for introducing natural antimicrobial and antioxidant agents into the animal's body. These bioactive compounds could potentially circulate throughout the body and accumulate in tissues, thereby impacting lipid oxidation and microbial activity (Akram et al., 2021).

However, the available research on the impact of garlic in poultry feeding has produced inconsistent results, possibly due to variations in garlic preparations, species selection, dosages, study duration, and other factors. For instance, Elbaz et al. (2021) and Sangilimadan et al. (2019) found that feeding garlic to broilers improved their growth performance, while Elsagheer et al. (2020) did not see any significant effects on growth. Similarly, (Elbaz et al., 2021; Noruzi and Aziz-Aliabadi, 2024), observed enhanced immune responses in garlic-supplemented broilers, whereas Toghyani et al. (2011) reported no significant impact on immune function. This inconsistency indicates a need to further investigate and establish clear guidelines for garlic's role in poultry nutrition.

Despite the growing body of research on garlic in poultry nutrition, limited studies exist specifically on dietary supplementation of GP in JQ diets and its influence on growth performance and meat quality. Therefore, this study aimed to evaluate the effects of dietary supplementation of GP on growth performance, carcass traits, meat quality, and sensory properties in JQ meat.

MATERIALS AND METHODS

The animal study protocol was approved by the Niğde Governorship, Provincial Directorate of Agriculture and Forestry Turkey (protocol code: E-15018773-050.01.04-75931) for studies involving animals.

Animals, Housing and Diets

A total of 240 day-old mixed-gender JQ quail chicks with an average weight of 9.6 ± 0.09 g were obtained from the Ayhan Şahenk Agricultural Research Center at Niğde Ömer Halisdemir University in Turkey. The chicks were randomly assigned to 4 treatment groups, with 60 birds per group and divided into 4 replicates of 15 birds each, using a complete randomized design. The groups were as follows: Control (no garlic powder), 0.5% GP (0.5% garlic powder), 1% GP (1% garlic powder), and 2% GP (2% garlic powder). All birds were fed an iso-caloric and iso-nitrogenous broiler chick starter feed for 5 wk, as per NRC guidelines (Table 1). The temperature was initially set at 33°C on d 1 and gradually reduced by 2°C to 3°C per wk until reaching 24°C to 25°C. Birds had free access to feed and water throughout the study.

Table 1. Composition of the basal experimental diet provided to the JQ during the entire trial.

Raw materials	Percentage	Calculated nutrients (%)	
Corn	43.31	ME (kcal / kg)	3100
Soybean	38.06	Crude Protein	22.92
Wheat bran	12.00	Dry Matter	89.33
Vegetable oil	3.50	Raw oil	6.78
$CaCO_3$	0.82	Ash	5.52
DCP	0.78	Crude fiber	5.37
Salt	0.30	Lysine	1.44
Lysine	0.52	Methionine	0.68
Methionine	0.39	Methionine + Cystine	1.08
Threonine	0.13	Calcium	0.90
Vitamin mix *	0.10	Phosphorus	0.44
Mineral mix **	0.10		
Total	100		

Vitamin-mineral premix for 1 kg feed includes 12.000 IU Vitamin A, 5000 IU vitamin D3, 50 mg vitamin E, 10 mg vitamin K3, 5 mg vitamin B2, 20 mg vitamin B12, 6 mg vitamin B1, 5 mg vitamin B6, 50 mg niacin, 25 mg folic acid, 30 mg biotin, 75 mg pantothenic acid, 175 mg choline chloride, 100 mg manganese, 80 mg iron, 60 mg zinc, 150 mg cobalt, 12 mg copper, 200 mg selenium.

Phenolic Extraction of Garlic Powder

For extraction of GP, 10 g of GP dissolved in 100 mL of 80% ethanol then stirred by ultrasonic water bath for 30 min. After that GP was dissolved by keeping it in the shaking machine for 24 h at a temperature of 40°C and 500 resolution per minute (RPM) agitation speed. The dissolved mixture was then filtered with coarse filter paper and then ethanol was evaporated at 50°C in a rotary evaporator (IKA, HB-10 digital, Germany) to obtain GP extract (Ucak et al., 2020).

Determination of the Total Phenolic Content of Garlic Powder

The total phenolic content (**TPC**) was evaluated through colorimetric analysis using the Folin−Ciocalteu reagent (FC), which was modified according to the methodology proposed by (Chuah et al., 2008). For this purpose, 900 μl of distilled water, 5 mL of 0.2 N Folin-Ciocalteu reagent and 4ml of saturated sodium carbonate ($\mathbf{Na2CO_3}$) solution (7.5 g/L) were added to 100 μl of the solution diluted from the GP extract. Samples were kept at room temperature in the dark for 2 h. Finally, a spectrophotometer (Spectronic 20 Genesys M131, Illinois) was used to measure the samples' absorbance at 725 nm and compared them to a calibration curve for gallic acid (Merck KGaA, Darmstadt, Germany). The outcomes were presented in milligrams of gallic acid per grams of dry matter.

Determination of the Antioxidant Activity of Garlic Powder

Trolox Equivalent Antioxidant Capacity (**TEAC**) analysis is an analysis based on inhibition of the absorbance of the 2,2′-azinobis 3-ethyl-bezothiazoline 6 sulfonate (**ABTS**) radical cation by antioxidants (Nazmati et al., 2022). To determine the antioxidant activity in GP, ABTS solution was prepared first. For this, a 7 mM ABTS solution containing 2.45 mM potassium persulfate ($\mathbf{K_2S_2O_8}$) was prepared and a radical solution (ABTS + •) was obtained by storing at room temperature for 12 to 16 h in the dark. In order to find the antioxidant activity of GP extract as trolox response, a series of concentrations of extract and trolox have been prepared. 10 μL of the sample was added on 1 mL ABTS + and a decrease in absorbance was observed in spectrometry for 6 min. The slope was calculated from the graphs where per cent inhibition was drawn against the concentrations. The antioxidant activity of the antioxidant substance as a 1 mM trolox response was determined as a result of the proportion of the slope of garlic powder to the slope of trolox concentrations (Re et al., 1999). While determining the antioxidant activity, 3 parallels were made for each concentration level and the measurements in the spectrometer were determined at 30°C with micro cuvettes.

$$TEAC\ value\ \mu M\ trolox = \frac{slope\ of\ sample}{slope\ of\ trolox} \times dilution\ factor$$

TEAC: Trolox Equivalent Antioxidant Capacity

Growth Performance and Carcass Characteristics

Individual live body weight (**LBW**) of birds, and feed consumption per pen were measured weekly. Subsequently, body weight gain (**BWG**), feed intake (**FI**), and feed conversion ratio (FCR = g feed/gain) were calculated. Birds were decapitated with a shear knife to ensure swift bleeding of the carcass. To obtain representative samples from each dietary treatment, all quails within each treatment group were initially weighed to determine the average body weight. At 35 d, 2 quails from each replicate pen, whose body weights were closest to the mean body weight of their respective treatment group, were then selected for sampling. The hot carcass weight was measured, along with the weight of the abdominal fat and internal organs including the heart, liver, and gizzard. To study the cold carcass weight, the carcasses were maintained at +4°C for 24 h. The left side of breast and thigh meat as well as skin samples were obtained and stored at 4°C for 0, 3, 5, and 7 d to assess the meat quality traits.

Meat Quality Evaluations

Oxidation Analysis of Meat Oxidation analysis of stored breast meat consisted of 2 parts: lipid oxidation status and peroxide value (**PV**) analysis. The lipid oxidation status of stored breast meat samples was determined by the thiobarbituric acid number analysis using AOCS (American Oil Chemists' Society) Cd 19-90 technique ("AOCS: Official method Cd 19−90. 2−Thiobarbituric... - Google Scholar,") . Briefly, 10 g of minced breast meat samples were extracted using a chloroform-methanol mixture (2:1, v/v) for 2 h with continuous shaking at room temperature. The mixture was filtered through Whatman No. 1 paper, and the solvent was evaporated using a rotary evaporator to obtain the oil. About 1 mL of this oil was transferred to a 25 ml flask and diluted to 25 ml with a Butylated hydroxytoluene (**BHT**) solution. The mixture was then homogenized with an ultra-thorax homogenizer. Next, 5 ml of this homogenized mixture was placed in tubes, and 5 ml of thiobarbituric acid was added to each tube. The tubes were incubated in a boiling water bath at 95°C for 2 h. Finally, the samples were analyzed using a spectrophotometer at 530 nm. PV analysis was performed using the AOAC (Association of Official Analytical Chemists) 965.33 technique (Feldsine et al., 2002). For this analysis, 1 mL of the extracted oil was transferred to a 250 mL flask and mixed with 30 mL of chloroform-acetic

acid solution. Subsequently, 1 mL of saturated potassium iodide solution was added and mixed well. The mixture was then kept in darkness for 5 min. After the dark incubation, 30 mL of distilled water and 4 drops of starch solution were added to the flask. The resulting solution was titrated with sodium thiosulfate solution until a light color was achieved. The volume of sodium thiosulfate used in the titration was recorded.

Microbiological Analysis of Meat Total psychrophilic counts were measured for breast meat samples stored at 4°C for 0, 3, 5, and 7 d using the method described by (Mech et al., 2021). In brief, 10 g of each meat sample was homogenized with 90 mL of 0.1% peptone water for 1 min. Serial dilutions were made with 0.1% peptone water and Ringer solution. The diluted samples were plated on plate count agar (**PCA**) and incubated at 7°C for 7 d. The results were expressed as log CFU/g, representing the number of bacteria.

Determination of pH in Meat The pH of breast meat samples stored at 4°C for 0, 3, 5, and 7 d was measured using the method described by Yang et al. (2019). On the day of slaughter, a Testo 205 pH meter was used to check the pH directly from 3 different areas of the breast meat, and the average pH was calculated. For the other storage days, a 5 g breast meat sample was blended with purified water, filtered, and the pH was measured using the pH meter with a probe.

Color Measurement of Meat The color of breast and thigh meat, as well as skin samples, was measured using a Konica Minolta CR-300 colorimeter, following the method described by Eltazi et al. (2014) with minor modifications. Meat color values were assessed using a chronometer (L* measures comparative lightness, a* measures comparative redness, and b* measures comparative yellowness). The colorimeter was calibrated with black and white plates before measuring the meat samples.

Sensory Evaluation of the Meat On day of slaughter, sensory attributes of the quail thigh and breast meat were undertaken according to the method described by Amerine et al. (1965) with minor modifications. Each sample was covered in aluminum foil and cooked for 75 min at 175°C. Cooked meat samples were cut into uniform size and served to panelists in covered serving dishes coded with 4 digit random numbers. The waiting period between sample tastings was 10 min. The 10 food technology specialist panel members, which included the faculty staff and students, were assigned to score the consumer preference test including, color, flavor, tenderness and juiciness. That was done on rating a scale from 1 to 9 (1: extremely desirable; 2: desirable; 3: desirable moderately; 4: slightly desirable; 5: neither desirable nor undesirable; 6: slightly undesirable; 7: moderately undesirable; 8: undesirable; 9 extremely undesirable).

Statistical Analysis

For body weight measurements, individual animal was used as the experimental unit, while for other performance parameters, pen was the experimental unit. For meat quality parameters, 2 birds per pen in each treatment group were slaughtered, and sampled birds were used as the experimental unit. Data normality was checked using the Shapiro-Wilk test in SPSS (Chicago, IL). We analyzed normally distributed data with 1-way ANOVA and used the Kruskal-Wallis test for non-normally distributed data. Data regarding sensory evaluation of the meat was assessed using Kruskal-Wallis tests. Significant differences between groups were determined using Duncan's multiple range test, with P values less than 0.05 ($P < 0.05$) considered significant.

RESULTS AND DISCUSSION

Phenolic Content of Garlic Powder

The value of antioxidant activity of GP was found to be 83.80 μmol trolox/g while the TPC ranges from 97.80 mg gallic acid equivalent (**GAE**)/g. The extract of GP can be acquired through distillation of water, ethanol, and chloroform. Jang et al. (2018) determined the TPC as 43.02 mg (GAE)/g and the antioxidant activity as 83.47 μmol trolox/g from the ethanol-extracted portion. Bhandari et al. (2014) investigated the range of TPC in GP, which varied from 70 to 120 mg GAE/100 g dry weight. They also evaluated the antioxidant activity, which was found to be 27.5%. However, the TPC found in the current study exhibited somewhat comparatively higher values than those reported by Chen et al. (2013). The study revealed that the garlic phenolic contents varied among various cultivars, with values ranging from 21.28 to 33.95 mg GAE/g. The disparities in the TPC and antioxidant activity observed between the current study and previous literature could be attributed to variances in garlic cultivar genotypes, agricultural practices, and seasonal fluctuations. These factors can significantly impact the chemical composition and bioactive properties of garlic, leading to variations in TPC and antioxidant activity measurements across different studies. The extraction techniques can also add some variability in phenolic content. Although the study provides data on total phenolic content and antioxidant activity, it has a limitation regarding the absence of a detailed phenolic profile that would offer a more comprehensive understanding of the specific bioactive compounds in garlic extract.

Growth Performance

All birds remained healthy with no mortality reported in any group. LBW was similar across all groups during the first and second wk ($P > 0.05$, Table 2). However, from the third to the fifth wk, LBW differed significantly ($P < 0.05$) between groups, with those receiving either 1% or 2% GP showing higher values. BWG was significantly higher ($P < 0.05$) in the groups supplemented with 1% GP during the third, fourth, and fifth wk, while feed intake remained unaffected by any level of GP supplementation ($P > 0.05$, Table 3). During the third wk,

Table 2. Effect of garlic powder (GP) supplementation in different levels on weekly live body weight (LBW).

LBW (Week)	Groups				SEM	*P*-value
	Control	0.5% GP	1% GP	2% GP		
DOC	9.6 ± 0.08	9.6 ± 0.09	9.7 ± 0.10	9.8 ± 0.10	0.048	0.698
1	40.71 ± 0.45	41.48 ± 0.49	40.24 ± 0.48	40.58 ± 0.40	0.230	0.276
2	104.35 ± 0.98	105.29 ± 1.08	103.63 ± 1.85	105.23 ± 0.93	0.630	0.764
3	174.96 ± 1.40^{b}	177.52 ± 1.65^{b}	187.01 ± 1.00^{a}	183.75 ± 1.17^{a}	1.732	0.007
4	232.84 ± 1.95^{b}	232.69 ± 2.27^{b}	239.50 ± 1.23^{a}	238.72 ± 1.74^{a}	0.940	0.009
5	272.96 ± 2.67b^{c}	270.96 ± 2.95^{c}	281.63 ± 2.27^{a}	279.15 ± 2.89^{ab}	1.379	0.018

The means with different superscripts in the same rows are significantly different from each other *(P < 0.05)*. SEM: Standard Mean Error, P: Significance Control: chicks that received no GP, 0.5% GP: the chicks that received 0.5% GP, 1% GP: the chicks that received 1% GP, 2% GP: the chicks that received 2% GP, DOC: day old chick.

groups receiving 1% and 2% GP had improved FCR compared to the control and 0.5% GP groups (*P < 0.05*). The results demonstrated that the group supplemented with 1% GP showed significant improvements in BWG, aligning with previous studies by Khalil et al. (2007) and Premavalli and Omprakash (2020), which also reported enhanced BWG in poultry supplemented with GP. This improvement is likely due to allicin, a potent antimicrobial compound in garlic, which has been shown to inhibit harmful bacteria and aflatoxin-producing fungi (Sivam, 2001). Additionally, allicin may positively influence the intestinal epithelium, improving nutrient absorption (Oladele et al. 2012; Premavalli and Omprakash, 2020), and could enhance salivary and gastric secretions, further improving BW (Kirubakaran et al., 2016). In contrast to the previous findings (Elsagheer et al., 2020; Olayinka et al., 2022), our studies revealed contradictory results as they observed no significant effects on BWG in broiler chickens with the dietary addition of GP. Nevertheless, the present study's results revealed that there were no significant differences in FI among the different groups, which aligns with the findings of previous studies (Raya et al., 2014; Olayinka et al., 2022). In contrast to these results, (H and N, 2019) reported that incorporating dietary GP at concentrations ranging from 1% to 3% resulted in significantly improved FI, in comparison to the control. These discrepancies in FI responses to GP supplementation across studies may be attributed to variations in poultry species, environmental conditions (including temperature, humidity, and lighting regimens), garlic powder composition and supplementation, and basal diet formulation. The findings of this study demonstrated a significant difference in FCR among the groups during the third wk, which is consistent with findings from previous studies (Lukanov et al., 2015; Karangiya et al., 2016; Elsagheer et al., 2020; Elbaz et al., 2021). This improvement in FCR is likely attributed to garlic's antimicrobial properties, which enhance nutrient absorption in the gastrointestinal tract. Contrary to this, Olayinka et al. (2022) reported that GP supplementation did not have an impact on FCR in broiler chickens.

Carcass Traits

Table 4 illustrates the effects of GP supplementation on quail carcass traits. GP supplementation did not significantly affect *(P > 0.05)* live weight, hot and cold carcass weights, carcass yield, or most carcass proportions. However, wing percentage was significantly influenced

Table 3. The effect of garlic powder (GP) supplementation at different levels on the weekly body weight gain (BWG, g), feed intake (FI, g) and feed conversion ratio (FCR, g/g).

Week	Control	0.5% GP	1% GP	2% GP	SEM	*P*-value
BWG						
1	31.11 ± 0.71	31.88 ± 0.89	30.56 ± 0.58	30.82 ± 0.31	0.322	0.549
2	63.64 ± 1.28	63.78 ± 1.04	63.41 ± 2.03	64.65 ± 0.13	0.599	0.915
3	70.60 ± 0.85^{c}	72.23 ± 1.20^{c}	83.25 ± 2.28^{a}	78.71 ± 0.63^{b}	1.452	0.000
4	56.62 ± 1.41^{b}	55.16 ± 0.81^{b}	59.32 ± 1.05^{a}	59.93 ± 1.01^{a}	0.701	0.029
5	37.83 ± 2.52^{b}	38.27 ± 1.64^{b}	44.36 ± 0.45^{a}	43.39 ± 1.48^{a}	1.071	0.035
FI						
1	46.10 ± 1.91	46.57 ± 1.39	44.34 ± 1.56	45.05 ± 1.73	0.777	0.777
2	109.66 ± 2.57	110.56 ± 1.37	113.92 ± 2.47	110.41 ± 1.72	1.029	0.508
3	157.47 ± 1.99	156.51 ± 2.32	163.79 ± 2.07	158.65 ± 2.12	1.198	0.128
4	188.58 ± 4.46	181.41 ± 4.42	184.53 ± 1.85	181.71 ± 0.67	1.650	0.419
5	234.12 ± 5.06	212.40 ± 4.39	235.44 ± 6.10	234.23 ± 1.70	2.540	0.195
FCR						
1	1.48 ± 0.04	1.46 ± 0.03	1.45 ± 0.03	1.46 ± 0.05	0.019	0.958
2	1.72 ± 0.01	1.73 ± 0.01	1.80 ± 0.05	1.70 ± 0.02	0.017	0.253
3	2.23 ± 0.04^{a}	2.16 ± 0.01^{a}	1.97 ± 0.06^{b}	2.01 ± 0.01^{b}	0.033	0.003
4	3.34 ± 0.14	3.29 ± 0.08	3.11 ± 0.08	3.03 ± 0.06	0.054	0.156
5	6.3 ± 0.56	5.81 ± 0.28	5.41 ± 0.16	5.41 ± 0.16	0.177	0.254

The means with different superscripts in the same rows are significantly different from each other *(P < 0.05)*. SEM: Standard Mean Error, P: Significance Control: chicks that received no GP, 0.5% GP: the chicks that received 0.5% GP, 1% GP: the chicks that received 1% GP, 2% GP: the chicks that received 2% GP.

Table 4. Effect of garlic powder (GP) supplementation in different levels on carcass traits.

	Control	0.5% GP	1 % GP	2 % GP	SEM	*P*-value
Live weight (g)	275.93 ± 4.08	281.98 ± 4.12	281.83 ± 4.01	280.51 ± 3.20	1.917	0.660
Hot carcass weight (g)	208.38 ± 2.36	211.16 ± 2.82	213.67 ± 2.32	213.14 ± 2.05	1.202	0.393
Cold carcass weight (g)	210.33 ± 2.66	210.28 ± 2.69	211.26 ± 2.32	210.66 ± 1.94	1.187	0.991
Carcass yield (%)	75.59±0.47	75.03±0.74	75.90±0.65	76.09±0.57	0.306	0.657
Thigh (%)	33.46 ± 0.66	34.65 ± 0.29	34.95 ± 0.25	34.18 ± 0.24	0.214	0.066
Breast (%)	34.42 ± 0.56	34.99 ± 0.47	34.45 ± 0.34	34.81 ± 0.33	0.217	0.759
Back (%)	14.13 ± 0.28	14.15 ± 0.33	13.87 ± 0.28	13.97 ± 0.27	0.143	0.891
Wings (%)	9.91 ± 0.16^{a}	8.99 ± 0.15^{b}	9.77 ± 0.18^{a}	9.65 ± 0.11^{a}	0.088	0.001
Neck (%)	7.66 ± 0.66	6.13 ± 0.28	6.62 ± 0.22	7.08 ± 0.20	0.208	0.055
Heart (%)	1.27 ± 0.04	1.28 ± 0.04	1.17 ± 0.05	1.27 ± 0.03	0.023	0.597
Liver (%)	3.34 ± 0.21	3.35 ± 0.22	3.32 ± 0.30	3.31 ± 0.16	0.112	0.932
Gizard (%)	2.68 ± 0.08	2.68 ± 0.09	2.72 ± 0.07	2.69 ± 0.07	0.041	0.584
Abdominal fat (%)	1.87 ± 0.18	1.65 ± 0.12	1.57 ± 0.17	1.81 ± 0.14	0.080	0.229

The means with different superscripts in the same rows are significantly different from each other *(P<0.05)*. SEM: Standard Mean Error, P: Significance Control: chicks that received no GP, 0.5% GP: the chicks that received 0.5% GP, 1% GP: the chicks that received 1% GP, 2% GP: the chicks that received 2% GP.

by GP supplementation *(P < 0.05)*, with the 0.5% GP group showing a lower percentage compared to other groups. Internal organs and abdominal fat were not significantly affected by GP supplementation *(P > 0.05)*. The results of the current study regarding quail carcass yield were consistent with previous research (Onibi et al., 2009; Issa and Omar, 2012; Raya et al., 2014). They concluded that GP supplementation did not significantly influence the dressing percentage values of both quails and broilers. However, (Saghi and Zarghi, 2022) found broilers fed a diet enriched with GP exhibited a higher dressing percentage compared to the control group. The findings related to hot and cold dressing percentages align with the observations made by (Fadlalla et al., 2010), who reported a nonsignificant effect of GP supplementation on these measures. However, Eltazi et al. (2014) reported a significant increase in both cold and hot dressing percentages in birds fed a diet containing 3% dietary GP, our study using lower concentrations did not replicate these effects. This suggests that the impact of GP on carcass traits may be dose-dependent, with higher concentrations potentially exerting more pronounced effects (Sheoran et al., 2017). The experimental diet employed in this study did not exert any significant effect on the proportion ratio of organs. Previous studies also reported that there were no notable variations observed among the groups concerning carcass cuts, including breast, thigh, back, and neck (Amouzmehr et al., 2012; Sangilimadan et al., 2019). The current findings align with previous findings (Swain et al., 2017) that observed nonsignificant differences in edible organ characteristics and abdominal fat in response to a diet supplemented with GP. Additionally, (Lukanov et al., 2015) reported similar results regarding the proportion of edible offal and meat cuts. While our study did not show significant effects on abdominal fat, some researchers have reported that garlic supplementation can reduce fat deposition. For instance, Issa and Omar, (2012) observed decreased abdominal fat in broilers supplemented with GP, attributing this to

Table 5. Effect of garlic powder (GP) supplementation in different levels on breast meat peroxide value (meq/kg), Thiobarbituric acid (mg MDA/kg), pH value, total psychrophilic bacteria count (log cfu g-1).

Day	Control	0.5% GP	1% GP	2% GP	SEM	*P*- value
Breast meat peroxide value (meq/kg)						
0	4.00 ± 0.00^{Ca}	3.66 ± 0.33^{Ca}	2.32 ± 0.33^{b}	1.00 ± 0.00^{Cc}	0.371	<0.001
3	5.33 ± 0.33^{Ba}	4.33 ± 0.33^{Bbc}	2.99 ± 0.00^{c}	1.66 ± 0.33^{BCd}	0.434	<0.001
5	5.66 ± 0.33^{Aba}	5.06 ± 0.16^{Aba}	3.66 ± 0.33^{b}	2.00 ± 0.00^{ABc}	0.433	<0.001
7	6.33 ± 0.33^{Aa}	5.66 ± 0.33^{Aa}	3.99 ± 0.57^{c}	2.66 ± 0.33^{Ab}	0.465	0.001
Breast meat thiobarbituric acid (TBA) value (mg MDA/kg)						
0	0.182 ± 0.08^{Ca}	0.167 ± 0.002^{Cab}	0.160 ± 0.00^{Db}	0.137 ± 0.00^{Dc}	0.00	0.001
3	0.270 ± 0.03^{Ba}	0.217 ± 0.01^{Bab}	0.195 ± 0.00^{Cb}	0.172 ± 0.00^{Bc}	0.00	0.014
5	0.363 ± 0.00^{Aa}	0.328 ± 0.00^{Ab}	0.313 ± 0.00^{Bc}	0.303 ± 0.00^{Bc}	0.00	<0.001
7	0.411 ± 0.00^{Aa}	0.356 ± 0.00^{Ab}	0.345 ± 0.00^{Ab}	0.339 ± 0.00^{Ab}	0.00	<0.001
Breast meat pH values						
0	5.94 ± 0.015^{Ba}	5.90 ± 0.009^{a}	5.78 ± 0.030^{Cb}	5.61 ± 0.005^{Cc}	0.039	<0.001
3	6.01 ± 0.00^{Ba}	5.90 ± 0.02^{Bb}	5.81 ± 0.01^{BCc}	5.71 ± 0.0^{Bd}	0.034	<0.001
5	6.14 ± 0.05^{Aa}	5.78 ± 0.08^{b}	5.86 ± 0.00^{ABb}	5.72 ± 0.00^{Bb}	0.052	0.002
7	6.13 ± 0.00^{Aa}	5.88 ± 0.01^{b}	5.88 ± 0.00^{Ab}	5.74 ± 0.00^{Ac}	0.042	<0.001
Breast meat total psychrophilic bacteria count (log cfu g-1)						
3	2.10 ± 0.023^{Ca}	1.18 ± 0.029^{Cb}	0.80 ± 0.102^{Cbc}	0.50 ± 0.198^{Bc}	0.232	0.002
5	2.34 ± 0.014^{Ba}	2.15 ± 0.04^{Bb}	2.08 ± 0.01^{Bbc}	2.05 ± 0.00^{Ac}	0.044	0.004
7	2.65 ± 0.00^{Aa}	2.51 ± 0.06^{Ab}	2.43 ± 0.05^{Ab}	2.40 ± 0.03^{Ab}	0.040	0.046

Means with different superscripts (capital letters) in the same column significantly different from each other *(P < 0.05)*. Means with different superscripts (lowercase) letters in the same rows differ significantly ($P < 0.05$), SEM: Standard Mean Error, P: Significance, Control: chicks that received no GP, 0.5% GP: the chicks that received 0.5% GP, 1% GP: the chicks that received 1% GP, 2% GP: the chicks that received 2% GP.

garlic's potential to inhibit lipogenesis and promote lipolysis. The discrepancy in our results might be due to differences in species, or dietary composition.

Antioxidant Effect of Garlic Powder

Antioxidant capacity of GP effectively prevented oxidation in the breast meat of quails. During the storage period, the peroxide value of the quail's breast meat decreased with increasing GP levels (Table 5). The 2% GP supplemented group exhibited the lowest peroxide value *($P < 0.05$)* of breast meat in comparison to the other groups. After 7 d of storage, the peroxide values in the control group were found highest when compared to the garlic supplemented groups. The TBA value of the control group exhibited the highest numbers and addition of 2% GP to the diet resulted in the lowest TBA value *($P < 0.001$)* in the breast meat. As the dietary level of GP increased, the TBA value of the breast meat decreased. Similar trend was also observed in the case of psychrophilic bacteria as their number decreased as GP supplementation increased. The pH of breast meat increased as the storage time increased while the groups supplemented with increased GP showed decreased pH levels. The lowest pH was observed in the 2% GP supplemented group as compared to other groups. The findings demonstrated that the antioxidant capacity of GP was effective in preventing oxidation in quail breast meat. This study presents new data indicating that GP may have a protective effect against oxidative damage in quail meat. Furthermore, this study emphasizes the potential usefulness of peroxide value as a quick and sensitive technique for detecting alterations in the oxidative stability of quail meat. A similar study for chicken meat was reported by Choi et al. (2010) who found that lipid oxidation represented by TBA values was reduced with higher concentrations of GP. These results are in agreement with the previous studies where (Dosoky et al., 2020; Onibi et al., 2009) found GP a good antioxidant source. The literature has shown that the presence of GP can prolong the shelf life of refrigerated meat. This effect may be attributed to the presence of antioxidant compounds such as flavonoids and organosulfur compounds, which contribute to a decrease in pH and aid in inhibiting lipid oxidation (Ao et al., 2011; Kothari et al., 2019). Moreover, as the storage time increased, the total count of psychrophilic bacteria increased in all groups, while higher levels of GP inclusion resulted in a reduction of these bacteria. These findings align with the results reported by (H and N, 2019), supporting the assumption that GP supplementation can effectively inhibit the growth of psychrophilic bacteria. The antimicrobial effect of GP, evidenced by reduced psychrophilic bacterial counts, can be primarily attributed to allicin and other thiosulfinates. These compounds disrupt bacterial cell membranes and inhibit crucial enzymatic systems, particularly those containing thiol groups (Reiter et al., 2017). Furthermore, garlic's antimicrobial activity extends to both Gram-positive and Gram-negative

Table 6. Effect of garlic powder (GP) supplementation on meat calorimetric characteristics.

	Thigh meat			Thigh skin			Breast meat			Breast skin		
Groups	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
Control	55.85 ± 0.44	2.18 ± 0.13	6.79 ± 0.40^{a}	60.60 ± 1.16	1.57 ± 0.19	6.35 ± 0.73	62.31 ± 0.67	4.01 ± 0.38	10.74 ± 0.34	68.06 ± 0.42^{a}	3.75 ± 0.30	9.79 ± 0.46^{b}
0.5% GP	56.09 ± 0.45	2.51 ± 0.31	5.57 ± 0.39^{b}	59.79 ± 0.45	1.63 ± 0.12	5.51 ± 0.33	60.35 ± 0.80	3.67 ± 0.37	10.21 ± 0.30	68.69 ± 0.66^{a}	3.83 ± 0.54	12.46 ± 1.20^{a}
1 % GP	56.25 ± 0.53	2.24 ± 0.13	7.46 ± 0.33^{a}	60.26 ± 0.77	1.76 ± 0.27	6.19 ± 0.51	62.11 ± 1.10	3.65 ± 0.31	10.68 ± 0.22	68.59 ± 0.55^{a}	3.34 ± 0.23	9.86 ± 0.25^{b}
2 % GP	55.49 ± 0.38	2.76 ± 0.28	7.09 ± 0.38^{a}	58.79 ± 0.95	2.01 ± 0.20	6.40 ± 0.46	60.60 ± 0.77	3.75 ± 0.29	10.55 ± 0.29	65.51 ± 0.83^{b}	3.80 ± 3.33	9.60 ± 0.48^{b}
SEM	0.223	0.122	0.207	0.431	0.097	0.261	0.422	0.169	0.146	0.350	0.187	0.395
P-value	0.680	0.322	0.05	0.493	0.392	0.591	0.237	0.873	0.576	0.002	0.801	0.020

Means with different superscripts in the same column differ significantly *($P < 0.05$)*, SEM: Standard Mean Error, P: Significance, L*: brightness, a*: redness, b*: yellowness, Control: chicks that received no GP, 0.5% GP: the chicks that received 0.5% GP, 1% GP: the chicks that received 1% GP, 2% GP: the chicks that received 2% GP.

Table 7. Sensory characteristics of cooked meat of Japanese quail as influenced by dietary garlic powder (GP).

Parameters	Control	0.5% GP	1% GP	2% GP	SEM	*P*-value
Colour						
Thigh	6.68 ± 0.32^{c}	7.31 ± 0.19^{b}	8.43 ± 0.15^{a}	7.81 ± 0.13^{b}	0.133	<0.001
Breast	6.75 ± 0.41^{b}	7.12 ± 0.39^{b}	8.37 ± 0.18^{a}	7.50 ± 0.18^{ab}	0.184	0.007
Juiciness						
Thigh	6.87 ± 0.35^{c}	7.43 ± 0.24^{bc}	8.50 ± 0.12^{a}	8.00 ± 0.18^{ab}	0.140	<0.001
Breast	6.25 ± 0.25^{b}	6.75 ± 0.52^{ab}	7.87 ± 0.35^{a}	6.50 ± 0.50^{b}	0.229	0.053
Tenderness						
Thigh	6.93 ± 0.30^{c}	7.43 ± 0.20^{bc}	8.18 ± 0.18^{a}	8.06 ± 0.17^{ab}	0.126	<0.001
Breast	6.75 ± 0.45	6.75 ± 0.49	7.87 ± 0.29	7.50 ± 0.26	0.204	0.124
Flavour						
Thigh	6.81 ± 0.27^{b}	7.50 ± 0.27^{a}	8.06 ± 0.14^{a}	7.50 ± 0.15^{a}	0.121	0.003
Breast	6.12 ± 0.29^{b}	6.37 ± 0.53^{b}	8.50 ± 0.26^{a}	6.80 ± 0.35^{b}	0.243	<0.001

The means with different superscripts in the same rows are significantly different from each other *($P < 0.05$)*, SEM: Standard Mean Error, P: Significance, Control: chicks that received no GP, 0.5% GP: the chicks that received 0.5% GP, 1% GP: the chicks that received 1% GP, 2% GP: the chicks that received 2% GP.

bacteria, making it a broad-spectrum natural preservative (El-Azzouny et al., 2018). The synergistic action of GP's antioxidant and antimicrobial properties likely contributes to its overall preservative effect on quail meat. This dual-action mechanism not only retards lipid oxidation but also inhibits microbial growth, thereby extending the shelf life and maintaining the quality of the meat during storage (Puvača et al., 2013).

Meat Color Measurements

Significant differences ($P < 0.05$) were observed in the b* of thigh meat among the treatments, with the 0.5% GP group exhibiting the lowest b* values and the 1% GP group displaying the highest b* values (Table 6). Breast skin exhibited significant differences in L* and b* *($P < 0.05$)*, with the 2% GP group displaying the lowest L* value while the 0.5% GP group had the highest b* value. No significant differences were observed in other colour parameters for thigh skin, thigh meat (L* and a*), or breast meat *($P > 0.05$)*. These findings align partially with Choi et al. (2010), who observed increased yellowness in thigh muscles with higher levels of GP. They attributed this effect to reduced metmyoglobin formation and oxidation, likely due to garlic's antioxidant properties, particularly its organosulfur compounds such as allicin and diallyl sulfides. These compounds may inhibit lipid oxidation and help preserve meat color in metabolically active muscles. However, the results differ from those of Kirkpinar et al. (2014), who found variations in breast meat L* and a* values in broiler chickens fed a combination of oregano and garlic essential oils. This discrepancy could be due to differences in garlic supplementation forms (powder versus essential oil), the potential synergistic effects of combined supplements, species-specific metabolic variations, or differences in dosages affecting the concentration of active compounds in muscle tissues. The significant differences observed in breast skin color, especially the increased b* in the 0.5% GP group, may be due to the deposition of garlic-derived pigments such as flavonoids and other phenolic compounds (Lanzotti, 2006). The varying effects between thigh and breast meat could be attributed to their distinct fiber compositions and metabolic characteristics. Breast muscle, being predominantly white with fewer mitochondria, might be less responsive to garlic's antioxidant effects compared to the more oxidative thigh muscles (Listrat et al., 2016).

Sensory Characteristics

The scores for color, juiciness, tenderness, and flavor of thigh meat were significantly higher in the treatment groups compared to the control group ($P < 0.05$, Table 7). The sensory values of thigh meat in the control group were lower than those in the experimental groups. However, the tenderness values of breast meat did not show significant differences ($P > 0.05$) among the experimental groups. Conversely, significant differences ($P < 0.05$) were observed in the color, juiciness, and flavor of breast meat between the control group and the other garlic-supplemented groups. Numerically, the values of color, juiciness, and flavor were lowered in the control group. It was hypothesized that including spices like garlic in a quail or broiler diet would affect the flavor and softness of the meat. The current findings are in line with the results reported by Kim et al. (2009) who also observed a positive impact of GP supplementation on the flavor characteristics of poultry meat. These research findings are in agreement with previous studies (Kırkpınar et al., 2011; Bobko and ร *f* ยก ria Angelovi, 2012) which also reported a statistically significant effect of GP supplementation and various other phytobiotics on the sensory quality of chicken meat. These studies have demonstrated that the incorporation of GP in chicken diets can positively influence the sensory attributes of the meat, enhancing its flavor, aroma, texture and overall palatability of meat.

CONCLUSION

Dietary supplementation of 1% GP had superior effects on all the parameters studied compared to the other concentrations of GP. Moreover, it is not

necessary to add garlic in high amounts as a feed additive in animal diets. Excessive supplementation of garlic may cause a reduction in FI and potentially have negative effects on growth performance parameters. Furthermore, GP had a significant impact on the performance of quail and the shelf life of the meat, and it can be used in poultry feed as a natural antioxidant to avert or delay the lipid oxidation of meat. Animal diet can play an important role to inhibit the free radical production in organisms and their derived products at their localized sites. The addition of garlic in the diet of animals is a simple and efficient approach to incorporate natural antioxidant compounds into lipidic layers of membrane. In this way, they can inhibit lipid oxidation more effectively and prevent oxidative losses of animal products compared to *postmortem* addition.

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DISCLOSURES

The authors declare no conflicts of interest.

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