# PROCESSING, PRODUCTS, AND FOOD SAFETY

# Effects of dietary garlic powder and α-tocopherol supplementation on performance, serum cholesterol levels, and meat quality of chicken

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**ABSTRACT** This study was carried out to evaluate the effects of supplementing diets with garlic powder and α-tocopherol on performance, serum cholesterol levels, and meat quality of chickens. Three hundred 1-d-old male broiler chicks were assigned to 5 diet treatments (0, 1, 3, and 5% garlic powder and 3% garlic powder + 200 IU of α-tocopherol/kg) with 3 replications of 20 birds for 35 d. There were no significant differences in broiler performance among the treatments. Moisture and crude ash contents of chicken thigh muscle were not different among all treatments, but dietary garlic powder and α-tocopherol supplementation resulted in significantly higher CP and lower crude fat contents in comparison with control ($P < 0.05$). Increasing the levels of garlic powder and applying garlic powder plus α-tocopherol significantly decreased total and low-density lipoprotein cholesterol and increased high-density lipoprotein cholesterol in broiler blood ($P < 0.05$). The pH and TBA reactive substances values were significantly reduced ($P < 0.05$) by the inclusion of garlic powder and α-tocopherol. However, no significant differences in water-holding capacity or shear force values were observed among the treatments. For broiler thigh muscle color, L* (lightness) values were decreased ($P < 0.05$), and a* (redness) and b* (yellowness) values were increased ($P < 0.05$) with the increased garlic powder levels and the combination of garlic powder and α-tocopherol. In terms of fatty acid composition in thigh muscle, unlike saturated fatty acid and total saturated fatty acid, dietary garlic powder or garlic powder plus α-tocopherol supplementation increased unsaturated fatty acid, total unsaturated fatty acid, and total unsaturated fatty acid:total saturated fatty acid ratios. These results suggest that 5% garlic powder or 3% garlic powder plus 200 IU of α-tocopherol antioxidant properties were effective for enhancing lipid and color stability.

**Key words:** garlic powder, α-tocopherol, broiler performance, serum cholesterol, meat quality

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## INTRODUCTION

A major problem in the meat industry is a reduction in the acceptability and nutritional quality of meat as well as changes in flavor due to the process of lipid oxidation. Therefore, changes and improvements in eating habits of people have led to an interest in natural health and functional foods, including the development of new convenience meat products with natural flavor and taste. As a result, an approach to overcoming the lipid oxidation problem of the meat industry is to use dietary garlic and α-tocopherol supplementation in animals, which can reduce cholesterol levels and increase lipid stability (Cannon et al., 1995; Kim et al., 2005).

Garlic (*Allium sativum*) is widely used as either a flavoring agent for food or as a medicinal agent for the treatment of a variety of diseases (Essman, 1984; Konjufca et al., 1997; Sallam et al., 2004). According to Lawson and Wang (2001), the increased benefits associated with garlic consumption can be attributed to the thiosulfinates, the single most abundant class of organosulfur compounds. Allicin, typically accounting for 70% of the total thiosulfinates (approximately 0.4% by fresh mass), is produced when fresh and raw garlic is chopped or crushed, rupturing the intercellular compartments that keep alliin and alliinase physically separated from each other (Lawson, 1998; Rybak et al., 2004). Substantial evidence suggests that the active component of garlic has some beneficial effects for livestock, having hypocholesterolemic effects and growth-promoting and antioxidant activities (Kim et al., 1997;


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Konjufca et al., 1997; Lewis et al., 2003). Additionally, several components of garlic and garlic extracts have been shown to have antioxidant properties in both meat-type and egg-type chicken (Chowdhury et al., 2002; Sallam et al., 2004). In several other studies conducted with chickens, Qureshi et al. (1983a) showed the reduction of the activities of hydroxymethylglutaryl-coenzyme A reductase, cholesterol 7 α-hydroxylase, and fatty acid synthetase when chickens were supplemented with polar fractions of garlic powder (garlic equivalent to 1, 2, 4, 6, and 8% fresh garlic paste) for 3 wk. Konjufca et al. (1997) reported that feeding 3% garlic powder resulted in a decrease of plasma cholesterol and breast and thigh muscle cholesterol in broilers. In the study of Yalçin et al. (2006), the supplementation of diets with 5 and 10 g/kg of garlic powder increased egg weight and decreased egg yolk cholesterol and serum triglyceride without adverse effects on performance and egg traits of laying hens. However, decreased yolk and serum cholesterol levels in laying hens fed 3% garlic powder for 8 mo were not observed by Birrenkott et al. (2000). In terms of the use of by-products as a nutritional value (phenolic compounds), garlic husk had higher total phenolics than garlic bulb, as reported by Nuutila et al. (2003).

Vitamin E, mainly α-tocopherol, is well known as a lipid-soluble antioxidant that can effectively protect polyunsaturated fatty acids from oxidation by free radicals and control color deterioration (Morrissey et al., 1994; Faustman and Wang, 2000). It has already been reported that supplementation of animal diets with vitamin E improves vitamin E concentration in tissue or muscle and the overall quality of meat products by inhibiting fatty acid oxidation and loss of desirable color and flavor during both refrigerated and frozen storage (Morrissey et al., 1998). Galvin et al. (1998) demonstrated that supplementation with 800 mg of α-tocopheryl acetate/kg of feed reduces the formation of cholesterol oxidation products in chicken muscles during refrigerated storage.

In recent years, the use of antioxidant blends has also been of particular interest to potential economic advantages for the meat industry because using a single compound will require higher production costs than a combination of antioxidants (Shahidi, 1996; Nanari et al., 2004). Nanari et al. (2004) suggested that a blend of dietary tocopherols and tocotrienols might have stronger antioxidant effects than tocopherols alone. Therefore, determining the antioxidant properties of a dietary mixture of garlic and α-tocopherol in meat will provide fundamental knowledge that will enable an effective utilization for improving meat quality (Nanari et al., 2004). Unfortunately, there is little information available on the influence of supplementation of garlic or α-tocopherol, or both, on performance and meat quality of chickens. Thus, we have attempted to evaluate the effect of supplementing broiler diets with garlic powder or α-tocopherol, or both, on performance, serum cholesterol levels, and meat quality.

## MATERIALS AND METHODS

### Experimental Designs, Birds, and Diets

The experimental procedures used in this study were carried out under the guidelines of the animal policy at the farm of Daegu University (Gyong San, South Korea). A total of 300 male broiler chicks (Arbor Acres; 1 d old) were obtained from a commercial hatchery and transferred to the experimental farm of Daegu University. The birds were randomly allocated to 5 groups (3 replicate pens of 20 birds per group) for 35 d and each group was assigned 1 of 5 dietary treatments: control, 1% garlic powder (**GP1**), 3% garlic powder (**GP3**), 5% garlic powder (**GP5**), and 3% garlic powder + 200 IU of α-tocopherol/kg (**GP3 + AT**). Experimental diets were formulated to meet broiler nutrient requirements (NRC, 1994) for starter (1 to 21 d) and finisher (22 to 35 d) growth periods (Table 1). The chicks were raised on rice hull litter and maintained on a 24-h constant-light schedule and ambient temperature. Heat was provided with a heating lamp per pen for the first 2 wk. Each pen (2 × 1 m) was equipped with 1 tube feeder and an automatic bell drinker. Throughout the experimental period, diets and water were available ad libitum. Levels of α-tocopherol (Sigma Chemical Co, St. Louis, MO) in the diets were determined according to applicable recommendation of Ryu et al. (2006). Feed intake, weight gain, and feed conversion were determined as described by Borges et al. (2003). Briefly, feed intake was calculated by the difference between supplied feed and feed left in each pen. Weight gain was determined as the difference between initial weight and weight at 35 d of age. Feed conversion was calculated from the ratio between total feed intake and weight gain in the period for each pen.

### Preparation of Garlic Powder Samples

Fresh garlic bulbs harvested in May or June were purchased from a local market (Eui-Sung Local National Agriculture Cooperation Federation, Korea). Fresh garlic bulbs with husks were peeled, cut into slices, and dried under sunlight at 30 to 35°C for 1 d (Chowdhury et al., 2002; Lim et al., 2006). The air-dried garlic was further dried under 50°C in an oven, finely ground to a powder, and stored immediately at 4°C until used (Chowdhury et al., 2002). The dried garlic powder used in this study contained 905 g of DM/kg, 128 g of CP/kg, 38 g of crude fat/kg, and 57 g of crude ash/kg.

### Slaughter Procedure

At the end of the experimental period (5 wk), birds were fasted for 6 h. There were 20 birds per pen, and 10 birds, randomly collected from each pen, were transferred to the slaughterhouse and treated with conventional procedures. Broilers were stunned electrically and slaughtered by neck-cutting and exsanguination (Suk-

sombat et al., 2007). After slaughter, each carcass was then plucked and eviscerated to produce thigh muscles. All skin (s.c. fat and visible connective tissues) was removed from the thigh muscles before evaluation for different quality parameters. The thigh muscles were packed in sealable plastic bags and stored for 1 d at 4°C (Ryu et al., 2005; Kim et al., 2009).

## Blood Collection and Cholesterol Analysis

Ten remaining birds from each pen were used for collecting blood samples. Blood was collected between 1400 and 1600 h from the wing vein using a sterilized syringe and needles. Next, samples were transferred into vacuum tubes (Becton Dickinson Vacutainer Systems, Franklin Lakes, NJ) immediately and stored at −20°C until analysis. Samples were then centrifuged at 2,000 × *g* for 30 min and serum was separated. Serum were collected and stored at −20°C (for up to 2 d) for determination of serum cholesterol concentration. The concentrations of total cholesterol, low-density lipoprotein cholesterol, and high-density lipoprotein cholesterol in serum were estimated according to the colorimetric method using an automatic analyzer (Hitachi 747, Hitachi Co., Tokyo, Japan) and direct enzymatic kits (Boehringer Mannheim, Germany).

## Proximate Composition

Moisture, CP, crude fat, and crude ash contents of thigh muscle were analyzed according to the AOAC (1998). For determination of meat pH, approximately 10 g of sample was homogenized with 90 mL of distilled water and pH value was measured using a digital pH meter (model 520A, Orion, Beverly, MA). The TBA reactive substances (**TBARS**) were carried out by the method of Witte et al. (1970) and were expressed as milligrams of malonaldehyde per kilogram of meat. Twenty grams of samples was mixed in 50 mL of 20% trichloroacetic acid (in 2 *M* phosphate solution) and homogenized in a blender. After adding 50 mL of distilled water, the solution was filtered through No. 1 filter paper (Whatman Inc., Clifton, NJ). A 5-mL aliquot of the filtered solution was added to 5 mL of 2-TBA (0.005 *M* in water) in a test tube. The test tubes were incubated at room temperature in the dark for 15 h. The absorbance was measured in a UV-visible spectrophotometer [UV-24D1(PC) 5, Shimadzu, Kyoto, Japan] at 532 nm. To determine the water-holding capacity (**WHC**), 10 g of ground chicken meat was introduced to a centrifugal pipe and heated for 30 min at 70°C in a water bath. Then, it was cooled to room temperature and centrifuged at 4°C and low speed (1,000 × *g* for 10 min) to measure the amount of gravy (Kim et al., 2009). Shear force samples were cut parallel to muscle fibers, heated at 75°C using water baths, and measured with a rheometer (CR-300, Sun Scientific Co., Tokyo, Japan) under room temperature after cooling. Before the color measurement, thigh muscle samples were cut and exposed to air for 30 min. The color of the thigh muscle (CIE L*, a*, and b*) was measured using a Minolta chromameter (Minolta CR-300, Osaka, Japan) and the results were expressed as lightness (L*), redness (a*), and yellowness (b*).

**Table 1.** Composition of experimental diets

| Item | Starter (1 to 21 d) | Finisher (22 to 35 d) |
|---|---|---|
| Ingredients (%) | | |
| Corn | 59.66 | 63.55 |
| Soybean meal | 27.02 | 30.11 |
| Wheat bran | 10.00 | 3.50 |
| Dicalcium phosphate | 1.19 | 1.12 |
| Limestone | 1.40 | 1.07 |
| Salt | 0.40 | 0.40 |
| DL-Methionine | 0.13 | 0.05 |
| Vitamin premix[1] | 0.10 | 0.10 |
| Mineral premix[2] | 0.10 | 0.10 |
| Total | 100 | 100 |
| Calculated values | | |
| ME (kcal/kg) | 3,100 | 3,100 |
| CP (%) | 21.50 | 19.00 |
| Methionine (%) | 0.50 | 0.38 |
| Lysine (%) | 1.10 | 1.00 |
| Ca (%) | 1.00 | 0.90 |
| Available P (%) | 0.45 | 0.35 |

[1]Vitamin premix provides the following (per kg of diet): vitamin A, 5,500 IU; vitamin $D_3$, 1,100 IU; vitamin E, 10 IU; riboflavin, 4.4 mg; vitamin $B_{12}$, 12 mg; nicotimic acid, 44 mg; menadione, 1.1 mg; biotin, 0.11 mg; thiamine, 2.2 mg; and ethoxyquin, 125 mg.

[2]Mineral premix provides the following (per kg of diet): Mn, 120 mg; Zn, 100 mg; Fe, 60 mg; Cu, 10 mg; Se, 0.17 mg; I, 0.46 mg; Ca, minimum: 150 mg, maximum: 180 mg.

## Fatty Acid Analysis

Lipid was extracted from thigh muscle samples with chloroform:methanol (2:1, vol:vol) as described previously by Folch et al. (1957). Briefly, 80 mg of extracted fat and 0.4 mg of tricosanoic acid methyl esters (0.4 mg/mL of hexane, internal standard) were placed into a glass tube with a screw cap and solvent and the pooled extracts were evaporated under $N_2$ at 30°C. Then, 1 mL of 0.5 *N* NaOH (in methanol) was added, and they were heated at 90°C for 7 min. After cooling to room temperature over 5 min, free fatty acid was methylated with 1 mL of 4% $H_2SO_4$ solution for 10 min at 90°C and cooled at room temperature for 30 min again. Two milliliters of hexane and 4 mL of distilled water were added to the sample, and 1 mL of supernatant was collected and stored in a −20°C freezer until analysis. Samples were analyzed for the contents of conjugated linoleic acid esters and total fatty acid. Fatty acid methyl esters were separated using a CP-Sil88 column (100 m × 0.25 mm × 0.2 μm; Chrompack, Middelburg, the Netherlands). The gas chromatography (GA-17A, Shimadzu, Tokyo, Japan) conditions were operated at 180°C for initial temperature of a column and heated to 230°C with 1.5°C/min. Temperature of the injector and detector was 240 and 260°C, respectively. Collected sample (0.5 μL) was injected into the column in the split mode. Each fatty acid was identified by comparing

relative retention time, corresponding with standards acquired from Sigma (St. Louis, MO). Identification of the peak included fatty acids between 14:0 and 20:4. We adopted the weight percentage of each fatty acid in all detected fatty acids as a measurement value.

### Statistical Analysis

Pen means were considered as the experimental unit for statistical analysis. Data were evaluated by ANOVA using the GLM procedure of the SAS package program (SAS Institute, 2002) according to a randomized complete block design. Significant differences between treatment means were determined by using Duncan's new multiple range test (Duncan, 1955). Statements of significance were based on $P < 0.05$.

## RESULTS AND DISCUSSION

### Broiler Performance

The effects of dietary garlic powder and α-tocopherol supplementation on broiler performance are presented in Table 2. No significant effects of garlic powder and α-tocopherol on growth performance were observed during the experimental period. Overall weight gain, feed intake, and feed conversion in the control were similar to treatments with different levels of garlic powder (GP1, GP3, and GP5). These results suggested that there were no beneficial effects of a combination of antioxidants (GP3 + AT) on the growth performance as compared with a single one (GP1, GP3, and GP5). In agreement with the current study, some authors (Reddy et al., 1991; Chowdhury et al., 2002) reported that the addition of sun-dried garlic powder and garlic oil did not affect growth performance. Qureshi et al. (1983b) reported no differences in growth performance in poultry fed diets with various garlic products at levels equal to about 50 kg/ton of garlic bulb. Ryu et al. (2006) also observed that the supplementation of α-tocopherol with 50, 100, 200, and 400 IU/kg had no effect on chicken growth. In the study of Guo et al. (2001), the growth performance of broiler was not influenced by supplementation with vitamin E of 50 or 100 mg/kg from 4 to 6 wk of age or from 0 to 6 wk of age. The exact mechanism of this is uncertain. In another study involving performance of laying quails, Yalçin et al. (2007) reported that BW, feed consumption, and feed efficiency were unaffected by the dietary garlic powder. They explained that the strong odor of garlic does not act as a deterrent of feeding.

### Proximate Composition

Proximate composition of chicken thigh muscle obtained from garlic powder and α-tocopherol after 5 wk is shown in Table 3. Consequently, there were no significant differences among treatments in moisture and crude ash contents. Crude protein content was significantly increased ($P < 0.05$), and crude fat content was significantly decreased ($P < 0.05$) in all treatments with garlic powder and α-tocopherol (GP1, GP3, GP5, and GP3 + AT) as compared with that of the control group. The reason for this may be due to both the reduction of fatty acid synthesis by garlic powder, which would decrease fat accumulation in the liver (Chang and Johnson, 1980), and the protection of chicken meat from unsaturated fat sources by α-tocopherol against oxidation (Grau et al., 2001). This observation is in accordance with that of Kim et al. (2009), who reported that garlic bulb (2 and 4%) and garlic husk (2 and 4%) supplementation resulted in a higher protein content and lower fat content in thigh muscle of chicks compared with muscle from birds fed nonsupplemented diets. In the present study, these results suggest that when compared with supplementation with different levels of garlic powder (GP1, GP3, and GP5), a dietary mixture of garlic powder and α-tocopherol (GP3 + AT) had no particular effects on proximate composition.

### Serum Cholesterol

The effects of dietary garlic powder and α-tocopherol supplementation on serum cholesterol levels after 5 wk are presented in Table 4. The dietary supplementation of different levels of garlic powder (GP1, GP3, and GP5) and the addition of 3% garlic powder and α-tocopherol (GP3 + AT) had a significant ($P < 0.05$) effect on serum cholesterol levels. In our study, the supplementation with 5% garlic powder (GP5) or 3% garlic powder plus α-tocopherol (GP3 + AT) resulted in significantly lower total and low-density lipoprotein cholesterol levels and greater high-density lipoprotein cholesterol levels compared with the control. This could be explained by the reduction of synthetic enzyme activity because 5% garlic powder (GP5) or 3% garlic powder plus α-tocopherol (GP3 + AT) would be expected to have a much higher antioxidant capacity or biological

**Table 2.** Effects of dietary garlic powder and α-tocopherol supplementation on broiler performance during 5 wk[1]

| Item | Control | GP1 | GP3 | GP5 | GP3 + AT |
|---|---|---|---|---|---|
| Initial BW (at 1 d, g) | 40.69 ± 0.17 | 40.69 ± 0.04 | 40.72 ± 0.04 | 40.65 ± 0.18 | 40.60 ± 0.06 |
| Final BW (at 35 d, g) | 1,845.85 ± 17.61 | 1,847.24 ± 34.91 | 1,848.09 ± 17.67 | 1,847.84 ± 35.41 | 1,839.53 ± 5.91 |
| Weight gain (1 to 35 d, g) | 1,805.16 ± 17.44 | 1,806.55 ± 34.88 | 1,807.37 ± 13.34 | 1,807.19 ± 10.62 | 1,798.93 ± 5.97 |
| Feed intake (1 to 35 d, g) | 3,116.16 ± 22.54 | 3,134.78 ± 52.35 | 3,139.59 ± 22.87 | 3,139.41 ± 53.00 | 3,082.55 ± 40.08 |
| Feed conversion (1 to 35 d) | 1.73 ± 0.01 | 1.74 ± 0.01 | 1.74 ± 0.01 | 1.74 ± 0.02 | 1.71 ± 0.03 |

[1]GP1 = 1% garlic powder; GP3 = 3% garlic powder; GP5 = 5% garlic powder; GP3 + AT = 3% garlic powder + 200 IU/kg of α-tocopherol.

**Table 3.** Proximate composition of chicken meat obtained from dietary garlic powder and α-tocopherol supplementation after 5 wk[1]

| Item (%) | Control | GP1 | GP3 | GP5 | GP3 + AT |
|---|---|---|---|---|---|
| Moisture | 73.97 ± 0.23 | 73.51 ± 0.42 | 73.87 ± 0.50 | 74.21 ± 0.49 | 73.96 ± 0.11 |
| CP | 21.09 ± 0.13[c] | 22.66 ± 0.21[a] | 22.84 ± 0.12[a] | 22.38 ± 0.04[b] | 22.41 ± 0.06[b] |
| Crude fat | 3.86 ± 0.09[a] | 2.65 ± 0.18[b] | 2.21 ± 0.44[c] | 2.32 ± 0.20[b] | 2.50 ± 0.18[b] |
| Crude ash | 1.11 ± 0.02 | 1.11 ± 0.03 | 1.09 ± 0.07 | 1.10 ± 0.05 | 1.08 ± 0.01 |

[a–c]Means within the same row without common superscripts are significantly different ($P < 0.05$).

[1]GP1 = 1% garlic powder; GP3 = 3% garlic powder; GP5 = 5% garlic powder; GP3 + AT = 3% garlic powder + 200 IU/kg of α-tocopherol.

effects than other treatments, among which are suppressing the formation of free radicals (Chowdhury et al., 2002). Similar results have been observed in laying hens and broiler chicks, in which dietary 2, 4, 6, 8, or 10% garlic paste and supplementation with 200 or 400 IU of α-tocopherol reduced serum cholesterol concentration or total cholesterol oxidation products (Chowdhury et al., 2002; Kim et al., 2006). Konjufca et al. (1997) reported that feeding 3% garlic powder (GP3) resulted in reduced levels of plasma, liver, breast, and thigh muscle cholesterol. In contrast, other studies have shown that 0.02% garlic oil did not have any significant effect on serum cholesterol (Reddy et al., 1991). Lim et al. (2006) also reported that the level of high-density lipoprotein cholesterol was not influenced by feeding of garlic powder (0, 1, 3, and 5%) in laying hens.

## Physical and Chemical Analysis

The effects of garlic powder and α-tocopherol supplementation on pH, TBARS, WHC, and shear force in chicken are given in Table 5. There were significant differences in pH and TBARS values among all treatments ($P < 0.05$). The pH values decreased with increase of dietary garlic powder and combination of garlic powder and α-tocopherol (GP1, GP3, GP5, and GP3 + AT). The treatments with the lowest pH values were obtained from 5% garlic powder (GP5) and 3% garlic powder plus α-tocopherol (GP3 + AT). The decrease in pH in thigh muscle of chicks may partially be explained by the fact that the effectiveness of an antioxidant such as garlic powder (polyphenols and flavonoids) and α-tocopherol is dependant on pH (Xiong et al., 1993). These results are in agreement with those of Kim et al. (2009), which showed a linear decrease in pH with increasing levels of dietary garlic bulb and husk as compared with control.

The TBARS values observed in this study followed similar patterns to pH, with increase in dietary garlic powder (GP1, GP3, and GP5) and the addition of 3% garlic powder plus α-tocopherol (GP3 + AT) to diets. Dietary supplementations of 5% garlic powder (GP5) and 3% garlic powder plus α-tocopherol (GP3 + AT) resulted in a lower TBARS value in thigh muscle when compared with the control. As mentioned earlier, these data show that thigh muscle with 5% garlic powder (GP5) at high rates and 3% garlic powder plus α-tocopherol (GP3 + AT) as a combination of antioxidants were greater in activities to inhibit the synthesis of fatty acid in the liver and lipid oxidation than other treatments (Yeh and Liu, 2001; Guo et al., 2006). A similar study for chicken sausages was reported by Sallam et al. (2004), who found that lipid oxidation represented by TBA values was reduced with the higher concentrations of each of the 3 forms of garlic (fresh garlic, garlic power, and garlic oil).

It was observed in the current study that there were no ($P > 0.05$) significant differences among all treatments in WHC and shear force in thigh muscle. This finding suggested that treatment with different levels of garlic powder or 3% garlic powder plus α-tocopherol (GP3 + AT, a combination of antioxidants) did not act as physiochemical properties or obtain the expected tenderization effect. Recent work by Kim et al. (2009) also reported that the shear force values of thigh muscle on broiler fed the garlic bulb and garlic husk were significantly lower than the control ($P < 0.05$); however, WHC in thigh muscle did not show any differences between garlic bulb and garlic husk.

In particular, WHC and shear force values can be used to determine if meat products vary in color, texture, and firmness or texture by measuring the variability in total cutting force (Kim et al., 2009). In a study examining the effectiveness of ginger extract

**Table 4.** Effects of dietary garlic powder and α-tocopherol supplementation on blood cholesterol levels in broiler chickens after 5 wk[1]

| Item[2] (mg/dL) | Control | GP1 | GP3 | GP5 | GP3 + AT |
|---|---|---|---|---|---|
| Total serum cholesterol | 127.30 ± 0.87[a] | 124.35 ± 1.14[b] | 120.16 ± 1.04[c] | 116.30 ± 0.42[d] | 121.13 ± 0.64[c] |
| HDL cholesterol | 53.45 ± 0.03[c] | 53.40 ± 0.19[c] | 56.18 ± 0.30[b] | 57.09 ± 0.15[a] | 56.38 ± 0.35[b] |
| LDL cholesterol | 37.86 ± 0.24[a] | 37.58 ± 0.32[a] | 35.64 ± 0.17[b] | 33.39 ± 0.38[c] | 34.18 ± 0.07[b] |

[a–d]Means within the same row without common superscripts are significantly different ($P < 0.05$).

[1]GP1 = 1% garlic powder; GP3 = 3% garlic powder; GP5 = 5% garlic powder; GP3 + AT = 3% garlic powder + 200 IU/kg of α-tocopherol.

[2]HDL = high-density lipoprotein; LDL = low-density lipoprotein.

**Table 5.** Effects of dietary garlic powder and α-tocopherol supplementation on pH, TBA reactive substances (TBARS), water-holding capacity (WHC), and shear force in chicken meats after 5 wk[1]

| Item | Control | GP1 | GP3 | GP5 | GP3 + AT |
|---|---|---|---|---|---|
| pH | 6.04 ± 0.06[a] | 6.00 ± 0.05[a] | 5.90 ± 0.02[b] | 5.81 ± 0.07[bc] | 5.79 ± 0.07[c] |
| TBARS (mg of malonaldehyde/kg) | 0.046 ± 0.002[a] | 0.043 ± 0.002[a] | 0.039 ± 0.001[b] | 0.033 ± 0.002[c] | 0.026 ± 0.002[d] |
| WHC (%) | 55.78 ± 0.44 | 56.37 ± 0.48 | 57.05 ± 0.84 | 57.77 ± 0.65 | 56.65 ± 0.82 |
| Shear force (kg/cm$^2$) | 3.71 ± 0.17 | 3.80 ± 0.14 | 3.46 ± 0.07 | 3.66 ± 0.14 | 3.60 ± 0.23 |

[a–d]Means within the same row without common superscripts are significantly different ($P < 0.05$).

[1]GP1 = 1% garlic powder; GP3 = 3% garlic powder; GP5 = 5% garlic powder; GP3 + AT = 3% garlic powder + 200 IU/kg of α-tocopherol.

as a tenderizing agent in spent hen and buffalo meat, Naveena and Mendiratta (2001, 2004) reported a decrease in shear force values with increasing amount of ginger extract.

## Meat Color

The effects of dietary garlic powder and α-tocopherol on meat color in thigh muscle of broiler chicks are presented in Table 6. Overall, the meat color in thigh muscle of broilers, as expressed by L* (lightness), a* (redness), and b* (yellowness), was significantly influenced ($P < 0.05$) by different dietary supplementations with garlic powder and α-tocopherol. The highest L* values and the lowest a* and b* values were obtained in the control groups, but treatments with 5% garlic powder (GP5) and 3% garlic powder plus α-tocopherol (GP3 + AT) showed the lowest L* values and the highest a* and b* values. This is not surprising because garlic powder and α-tocopherol containing antioxidant compounds could retard metmyoglobin formation and oxidation in thigh muscle of chicks. Some authors reported that lightness increase and redness decrease might be associated with the increase in metmyoglobin formation and the oxidation process (Higgins et al., 1998; Fernández-López et al., 2005). Similar findings were reported by Fernández-López et al. (2005) for meatballs with natural extracts. They suggested that the presence of antioxidant compounds in the natural extracts could retard metmyoglobin formation in meatballs and so L* values decreased. Aksu and Kaya (2005) also found the unadded antioxidant kavurma had lower b* values than those produced with antioxidant. However, the exact mechanism of this is not well understood.

Considering the current results, it was observed that dietary supplementation with 3% garlic powder plus α-tocopherol (GP3 + AT) in comparison with the different levels of garlic powder (GP1, GP3, and GP5) did bring about color stability in thigh muscle due to the presence of antioxidant compounds (Aksu and Kaya, 2005; Fernández-López et al., 2005).

## Changes in Fatty Acid Composition

Fatty acid compositions of broiler thigh muscle produced from dietary garlic powder and α-tocopherol supplementation are presented in Table 7. There were some differences in the percentages of palmitoleic acid (C16:1) among all treatments, and percentages of palmitoleic acids were similar to those of each treatment. However, no significant differences were observed in the percentages of myristic acid (C14:0), stearic acid (C18:0), and arachidonic acid (C20:4) among all treatments. Overall percentages of oleic (C18:1), linoleic (C18:2), and linolenic acid (C18:3) significantly increased ($P < 0.05$). Furthermore, there was a numeric decrease in the percentages of palmitic acid (C16:0) with incremental levels of garlic powder (GP1, GP3, and GP5) or the addition of 3% garlic powder plus α-tocopherol (GP3 + AT), and this result was significant ($P < 0.05$) in the treatment with 1% garlic powder (GP1) relative to the control. In this study, percentages of total unsaturated fatty acid are the most abundant (66.21 to 68.26%), followed by total saturated fatty acid. Other than total saturated fatty acid, percentages of total unsaturated fatty acid and total unsaturated fatty acid:total saturated fatty acid ratios were increased by feeding incremental levels of garlic powder or adding 3% garlic powder plus α-tocopherol (GP3 + AT, $P < 0.05$). Our results are similar to other studies of supplementation with different types of garlic (garlic powder, garlic bulb, and husk) in broiler diets (Kim et al., 2005, 2009). Cherian et al. (1996) found that dietary vitamin E supplementation increased long-chain n-3 polyunsaturated fatty acid and decreased saturated fatty acid. However, Hsieh et al. (2002) reported no observation on increasing tissue polyunsaturated fatty acid and decreasing saturated fatty acid contents by increasing dietary vi-

**Table 6.** Effects of dietary garlic powder and α-tocopherol supplementation on meat color of chicken after 5 wk[1]

| Item | Control | GP1 | GP3 | GP5 | GP3 + AT |
|---|---|---|---|---|---|
| L* (lightness) | 57.06 ± 0.82[a] | 56.16 ± 0.59[b] | 55.45 ± 0.27[c] | 55.28 ± 0.16[c] | 55.83 ± 0.05[bc] |
| a* (redness) | 5.29 ± 0.08[c] | 5.65 ± 0.07[b] | 5.70 ± 0.08[ab] | 5.72 ± 0.13[ab] | 5.82 ± 0.06[a] |
| b* (yellowness) | 3.40 ± 0.15[c] | 3.44 ± 0.06[bc] | 3.59 ± 0.14[bc] | 3.66 ± 0.18[b] | 3.95 ± 0.03[a] |

[a–c]Means within the same row without common superscripts are significantly different ($P < 0.05$).

[1]GP1 = 1% garlic powder; GP3 = 3% garlic powder; GP5 = 5% garlic powder; GP3 + AT = 3% garlic powder + 200 IU/kg of α-tocopherol.

**Table 7.** Effects of dietary garlic powder and α-tocopherol supplementation on fatty acid composition in broiler chickens after 5 wk[1]

| Fatty acid (%) | Control | GP1 | GP3 | GP5 | GP3 + AT |
|---|---|---|---|---|---|
| Myristic acid (C14:0) | 0.73 ± 0.02 | 0.72 ± 0.03 | 0.73 ± 0.03 | 0.72 ± 0.01 | 0.73 ± 0.01 |
| Palmitic acid (C16:0) | 24.55 ± 0.03[a] | 23.53 ± 0.16[b] | 22.72 ± 0.21[c] | 22.63 ± 0.18[c] | 22.53 ± 0.46[c] |
| Palmitoleic acid (C16:1) | 6.12 ± 0.02[a] | 6.04 ± 0.06[b] | 6.14 ± 0.04[a] | 6.12 ± 0.03[a] | 6.07 ± 0.03[ab] |
| Stearic acid (C18:0) | 8.52 ± 0.24 | 8.53 ± 0.19 | 8.35 ± 0.23 | 8.44 ± 0.32 | 8.48 ± 0.09 |
| Oleic acid (C18:1) | 40.27 ± 0.56[c] | 40.82 ± 0.16[b] | 41.69 ± 0.04[a] | 41.40 ± 0.15[a] | 41.39 ± 0.01[a] |
| Linoleic acid (C18:2) | 17.67 ± 0.34[b] | 18.21 ± 0.20[a] | 18.16 ± 0.09[a] | 18.47 ± 0.04[a] | 18.50 ± 0.08[a] |
| Linolenic acid (C18:3) | 1.13 ± 0.01[d] | 1.15 ± 0.01[d] | 1.19 ± 0.01[c] | 1.22 ± 0.02[b] | 1.27 ± 0.03[a] |
| Arachidonic acid (C20:4) | 1.04 ± 0.03 | 1.03 ± 0.02 | 1.05 ± 0.02 | 1.03 ± 0.02 | 1.03 ± 0.01 |
| Total saturated fatty acid (TS) | 33.79 ± 0.19[a] | 32.62 ± 0.18[ab] | 31.79 ± 0.04[c] | 31.78 ± 0.14[c] | 31.74 ± 1.73[c] |
| Total unsaturated fatty acid (TU) | 66.21 ± 0.19[c] | 67.39 ± 0.18[b] | 68.21 ± 0.04[a] | 68.23 ± 0.14[a] | 68.26 ± 0.06[a] |
| TU:TS | 1.96 ± 0.02[c] | 2.07 ± 0.02[b] | 2.15 ± 0.01[a] | 2.15 ± 0.01[a] | 2.15 ± 0.01[a] |

[a–d]Means within the same row without common superscripts are significantly different ($P < 0.05$).

[1]GP1 = 1% garlic powder; GP3 = 3% garlic powder; GP5 = 5% garlic powder; GP3 + AT = 3% garlic powder + 200 IU/kg of α-tocopherol.

tamin E. In the current study, these results show that 3 and 5% garlic powder (GP3 and GP5, respectively) or 3% garlic powder plus α-tocopherol (GP3 + AT) supplementation to diets can effectively change the fatty acid composition by increasing or protecting the oxidation of unsaturated fatty acid and total unsaturated fatty acid because palmitic and oleic acids are the main fatty acids of the thigh muscle. There are 2 possible reasons for this phenomenon in the effectiveness of this product: 1) reduction in unsaturated fatty acid and total unsaturated fatty acid using garlic powder and α-tocopherol is related to peroxide-scavenging enzyme activity, which could reduce unsaturated fatty acid and total unsaturated fatty acid oxidation and 2) some active components in the garlic powder and α-tocopherol may involve desaturase and elongase activities (Kim et al., 2005; Guo et al., 2006). Thus, in terms of beneficial health-related biological properties, it is evident that increasing unsaturated fatty acid and total unsaturated fatty acid contents through dietary manipulation (garlic powder and α-tocopherol) could hold promise for the health of consumers (Shahidi, 1996; Belury, 2002).

## *Conclusion*

In the current study, increasing the levels of garlic powder or providing a combination of garlic powder and α-tocopherol led to decreased serum cholesterol levels, TBARS values, saturated fatty acid, and total saturated fatty acid and increased unsaturated fatty acid, total unsaturated fatty acid, total unsaturated fatty acid:total saturated fatty acid ratios, indicating that synthetic enzyme activity or lipid oxidation should be reduced or delayed. In addition, the different levels of garlic powder or a combination of garlic powder and α-tocopherol did bring about color stability in thigh muscle. However, broiler growth, WHC, and shear force were not significantly affected by the levels of garlic powder and α-tocopherol, which were important for practical application or could act as physiochemical properties. Thus, we concluded that applying 5% garlic powder (GP5) or 3% garlic powder plus α-tocopherol (GP3 + AT) to diets has the potential to improve the ability of the poultry industry to provide several benefits in meat quality of chickens. Because we could not report the organoleptic properties of garlic powder plus α-tocopherol in the present study, further studies are needed to evaluate sensory characteristics such as juiciness and flavor and to confirm the active components of garlic powder plus α-tocopherol.

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