Effect of oregano oil and tannic acid combinations on the quality and sensory characteristics of cooked chicken meat

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ABSTRACT The antioxidant effects of oregano essential oil and tannic acid combinations on ground chicken breast and thigh meats were studied. Six treatments, including: 1) control (none added), 2) 100 ppm oregano essential oil + 5 ppm tannic acid, 3) 100 ppm oregano essential oil + 10 ppm tannic acid, 4) 200 ppm oregano essential oil + 5 ppm tannic acid, 5) 200 ppm oregano essential oil + 10 ppm tannic acid, and 6) 5 ppm butylated hydroxyanisole (BHA) for breast or 14 ppm for thigh meat, were prepared. Cooked meat samples were individually vacuum-packaged in oxygen-impermeable vacuum bags and then cooked in-bag to an internal temperature of 75°C. After cooling to room temperature, the cooked meat was re-packaged in new oxygen-permeable bags and stored at 4°C for 7 days. Cooked ground chicken meats were analyzed for lipid and protein oxidation and volatiles at 0, 3, and 7 d of storage. The significant differences among the treatments were very clear in cooked meat samples: Thigh meat patties showed higher 2-thiobarbituric acid reactive substances (TBARS), total carbonyl, and volatiles content compared to the breast meat during storage. A combination of 200 ppm oregano oil with 10 ppm tannic acid showed the most significant effects ($P < 0.05$) on TBARS, total carbonyl, and off-odor volatile formation for both breast and thigh meats. Oregano oil (200 ppm) and 10 ppm tannic acid combination also showed positive effects on the sensory scores of chicken thigh meat. In conclusion, the combination of 200 ppm oregano oil and 10 ppm tannic acid could be a good replacement for the synthetic antioxidants in ground cooked chicken meat.

Key words: oregano essential oil, tannic acid, cooked chicken meat, quality, sensory scores

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INTRODUCTION

Recently the food industry showed very strong interests in replacing synthetic antioxidants with the natural ones (Solomakos et al., 2008; Karre et al., 2013). Synthetic antioxidants, such as butylated hydroxytoulene (**BHT**), butylated hydroxyanisole (**BHA**), and tertiary butyl hydroquinone (**TBHQ**), are allowed at concentrations up to 0.02% of the fat content in meat products. Natural antioxidants, particularly those from plant sources, have less limitation on their use in food or meat products. Several herbs and plant extracts were used in poultry meat to maintain product stability and extend shelf life (Fasseas et al., 2007; Brannan, 2008; Abdel-Hamied et al., 2009). Lipid and protein oxidations are the major problems due to their effect on poultry meat quality, including color, flavor, and nutritive value (Nam et al., 2007). Natural antioxidants from plant origins are a safe and healthful replacement for the synthetic ones that can prevent oxidation in meat (Solomakos et al., 2008; Gulcin et al., 2010).

Oregano essential oil (**EO**) and tannins are extracted from plants and have strong antioxidant properties (Goulas and Kontominas, 2007; Scramlin et al., 2010). The antioxidant effect of oregano EO is due to its high polyphenol content, such as carvacrol and thymol (Kosar et al., 2003; Capecka et al., 2005; Al-Bandak, 2007). However, little work has been done to determine the effect of oregano EO directly added to meat on meat quality.

Tannins are secondary poly-phenol compounds produced by plants to protect themselves from diseases and being eaten by herbivores (Salminen et al., 2011). These compounds have biological, metal ion chelating, antioxidant (Hagerman, 2010; Okuda and Ito, 2011), and protein precipitating activities (Hagerman et al., 1998). In addition, tannins showed a positive effect on the color stability of meat (Luciano et al., 2009; Maqsood and Benjakul, 2010a). These properties of tannins are due to their chemical structure, which has two or three phenolic hydroxyl groups on phenyl ring. Hydrolysable tannins are more popular for use as a food preservative than the condensed type (Okuda and Ito, 2011). The

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hydrolysable type of tannins contains polyhydric alcohol and hydroxyl groups, which are esterified with gallic acid (Gallotannins) or hexahydroxydiphenic acid (Ellagitannins) (Haslam, 1989; Okuda, 2005; Okuda and Ito, 2011).

In most cases, use of one natural antioxidant to replace synthetic antioxidant is not enough to produce satisfactory results. Therefore, combinations of antioxidants with different antioxidant mechanisms are considered to improve their effectiveness (Brewer, 2011). Smet et al. (2008) reported that combining a dietary synthetic antioxidant with vitamin E was more effective in preventing lipid and protein oxidation in fresh frozen chicken patties than using one natural antioxidant. The antioxidant activity of phenolic compounds and the ability of acid compounds to bind metal ions generate synergistic effects. Lee et al. (2005) found that the combination of a chelator (sodium triphosphate or sodium citrate) with a reductant (e.g., erythrobate and rosemary extract) was more effective than using them alone in decreasing lipid oxidation and maintaining the color of ground beef.

The antioxidant effects of plant extracts such as green tea, fruit juices, and chestnut wood, which contain high levels of tannins (Liu et al., 2009; Staszewski et al., 2011), were tested in meat systems. Naveena et al. (2008) studied the effect of adding pomegranate juice or pomegranate rind powder extract containing high levels of tannins in chicken patties and found that 10 mg equivalent phenolics/100 g meat were sufficient to protect chicken patties from oxidative rancidity for a longer period than most of the synthetic antioxidants. Oregano oil or tannic acid can be added in animal diets (Botsoglou et al., 2002) or added directly to meat during processing to protect the meat from oxidation. Oregano EO is reported as one of the most prospective (ranked the highest) herbal extracts that have been tested to improve the storage stability of meat (Zheng and Wang, 2001). In addition, little work has been done to use tannic acid, especially hydrolysable tannins, in meat preservation, even though it is known to have a strong antioxidant effect because of its strong metal-chelating and hydroxyl radical scavenging activities (Lopes et al., 1999; Gulcin et al., 2010). Tannic acid also has shown positive effects on color stability and extension of shelf life of meat (Hagerman, 2010; Maqsood and Benjakul, 2010a). To the best of our knowledge, this study is the first study examining the effect of tannic acid and oregano EO combination on the storage stability of meat.

The objectives of this study were: 1) to evaluate the combination effect of tannic acid and oregano oil on the quality and storage stability of cooked ground chicken thigh or breast meat, and 2) to select the best levels of tannic acid-oregano oil combinations to control lipid oxidation, protein oxidation, and off-odor of cooked ground chicken meat.

MATERIAL AND METHODS

Sample Preparation

One-hundred-twenty, 6-week-old broilers raised on a corn-soybean meal diet were slaughtered using the USDA guidelines (USDA, 1982). The chicken carcasses were chilled in ice water for 2 h and drained in a cold room, and the breast and thigh muscles were separated from the carcasses at 24 h after slaughter. Boneless muscles (breast and thigh) were cleaned, skins removed, external fats trimmed off, and stored in a −20°C freezer until use.

The frozen meats were thawed in a walk-in cooler (4°C), ground twice through a 10-mm and a 3-mm plate (Kitchen Aid, Inc., St. Joseph, MI) before use. Six different treatments, including: 1) (none added), 2) 100 ppm oregano EO + 5 tannic acid, 3) 100 oregano EO + 10 tannic acid, 4) 200 ppm oregano EO + 5 tannic acid, 5) 200 oregano EO + 10 tannic acid, and 6) 5 ppm BHA for breast or 14 ppm for thigh meat (based on fat content), were prepared.

The oregano EO was obtained from a certified company in New York (Healthy-Health, Staten Island, NY). The GC/MS analysis of the oregano EO indicated that 80.12% of the EO was carvacrol. BHA powder (0.1 g) and oregano EO (1.25 g) were dissolved in 10 mL of 100% ethanol and then mixed with 50 mL mineral oil to make their stock solutions. The ethanol added was removed using a rotary evaporator (BUCH Rotavapor, Model R-200) at (70°C, 175 mbar vacuum pressure) before adding the stock solution to meat samples.

Tannic acid powder containing 90% tannin was obtained from Sigma-Aldrich (St. Louis, MO). The product's name is hydrolyzable tannin obtained from oak gallnuts from *Quercus infectoria*. Tannic acid (0.1 g) was dissolved in 50 mL of de-ionized distilled water (**DDW**) and stored in a dark area to prevent exposure to air and light. Each additive treatment was added to the ground meat (breast or thigh) and then mixed for 2 min in a bowl mixer (Model KSM 90; Kitchen Aid Inc., St. Joseph, MI). All treatments were added with the same amount of mineral oil to provide the same conditions.

The raw meat samples were packaged in oxygen-impermeable vacuum bags (O_2 permeability, 9.3 mL $O_2/m^2/24$ h at 0°C, Koch, Koch, Kansas City, MO), and the meats were cooked in-bag in a 90°C water bath (Isotemp®, Fisher Scientific Inc., Pittsburgh, PA) until the internal temperature of the meat reached 75°C. After cooling to room temperature, the cooked meat was transferred to a new oxygen-permeable bag (polyethylene, 4 × 6.2 mil, Associated Bag Co., Milwaukee, WI), and stored at 4°C for up to 7 d, and analyzed for lipid and protein oxidation and volatiles at 0, 3, and 7 d of storage.

2-thiobarbituric Acid-reactive Substances Measurement

Lipid oxidation was determined using a 2-thiobarbituric acid reactive substances (**TBARS**) method (Ahn et al., 1998). Five grams of ground chicken meat were weighed into a 50-mL test tube and homogenized with 50 μL BHT (7.2%) and 15 mL of DDW using a Polytron homogenizer (Type PT 10/35, Brinkman Instruments Inc., Westbury, NY) for 15 s at high speed. One mL of the meat homogenate was transferred to a disposable test tube (13 × 100 mm), and 2-thiobarbituric acid (15 mM TBA/15% Trichloroacetic acid (**TCA**), 2 mL) was added. The mixture was vortex-mixed and incubated in a boiling water bath for 15 min to develop color. Then samples were cooled in the ice water for 10 min, mixed again, and centrifuged for 15 min at 2,500 x g at 4°C. The absorbance of the resulting supernatant solution was determined at 532 nm against a blank containing 1 mL of DDW and 2 mL of TBA/TCA solution. The amounts of TBARS were expressed as mg of malondialdehyde (**MDA**) per kg of meat.

Volatile Analysis

Volatiles of samples were analyzed using a Solatek 72 Multimatrix-Vial Auto-sampler/Sample Concentrator 3100 (Tekmar-Dohrmann, Cincinnati, OH) connected to a GC/MS (Model 6890/5973; Hewlett-Packard Co., Wilmington, DE) according to the method of Ahn et al. (2001). A sample (2 g) was placed in a 40-mL sample vial, flushed with helium gas (40 psi) for 3 s, and then capped airtight with a Teflon*fluorocarbon resin/silicone septum (I-Chem Co., New Castle, DE). Samples from different treatments were randomly organized on the refrigerated (4°C) holding tray to minimize the variation of the oxidative changes in samples during analyses. The meat sample was purged with helium (40 mL/min) for 14 min at 20°C. Volatiles were trapped using a Tenax/charcoal/silica column (Tekmar-Dohrmann) and desorbed for 2 min at 225°C, focused in a cryofocusing module (−70°C), and then thermally desorbed into a capillary column for 2 min at 225°C. An HP-624 column (7.5 m, 0.25 mm i.d., 1.4 μm nominal), an HP-1 column (52.5 m, 0.25 mm i.d., 0.25 μm nominal), and an HP-Wax column (7.5 m, 0.25 mm i.d., 0.25 μm nominal) were connected using zero dead-volume column connectors (J &W Scientific, Folsom, CA). Ramped oven temperature was used to improve volatile separation. The initial oven temperature of 25°C was held for 5 minutes. After that, the oven temperature was increased to 85°C at 40°C per min, increased to 165°C at 20°C per min, and then increased to 230°C at 5°C per min and held for 2.5 min at that temperature. Constant column pressure at 22.5 psi was maintained. The ionization potential of MS was 70 eV, and the scan range was 20.1 to 350 m/z. The identification of volatiles was achieved by the Wiley Library (Hewlett-Packard Co.). The area of each peak was integrated using ChemStation^{TM} software (Hewlett-Packard Co.), and the total peak area (total ion counts x 10^4) was reported as an indicator of volatiles generated from the samples.

Protein Oxidation (Total Carbonyl)

Protein oxidation was determined by the method of Lund et al. (2008) with minor modifications. One gram of meat sample was homogenized with a Brinkman Polytron (Type PT 10/35) (Brinkman Instrument Inc., Westbury, NY) in 10 mL of pyrophosphate buffer (2.0 mM $Na_4P_2O_7$, 10 mM trizma-maleate) containing 100 mM KCL, 2.0 mM $MgCl_2$, and 2.0 mM ethylene glycol tetraacetic acid, pH 7.4. Two equal amounts of meat homogenate (2 mL) were taken from a sample, precipitated with 2 mL of 20% trichloroacetic acid, and centrifuged at 12,000 × g for 5 min at room temperature. After centrifugation, the pellet from one sample was treated with 2 mL of 10 mM 2,4-dinitrophenylhydrazine dissolved in 2 M HCL, and the pellet from the other was incubated with 2 M HCL as a blank. During 30 min of incubation in the dark, samples were vortex-mixed for 10 s every 3 minutes. The protein was further precipitated with 2 mL of 20% trichloroacetic acid and centrifuged at 12,000 x g for 5 min. The 2,4-dinitrophenylhydrazine was removed by washing 3 times with 4 mL of 10 mM HCL in 1:1 (vol/vol) ethanol: ethyl acetate, followed by centrifuging at 12,000 × g for 5 min. The pellets were finally solubilized in 2 mL of 6.0 mM guanidine hydrochloride dissolved in 20 mM potassium dihydrogen phosphate (pH = 2.3). The samples were kept at 5°C overnight. The next d, the samples were centrifuged to remove insoluble materials. The absorbance of the supernatant was read at 370 nm. The absorbance values for blank samples were subtracted from their corresponding sample values. Protein concentration was measured using a Protein Assay Kit (Bio-Rad Laboratories, Hercules, CA) following Microplate Assay protocol at 280 nm absorbance (BioTek-Gen5 Microplate data collection and analysis software/BioTek Instruments, Inc., Model S4MLFPTA, Winooski, VT). The carbonyl content was calculated as nmol/mg protein using absorption coefficient of 22,000/M/cm.

Sensory Evaluation

Trained sensory panels were used to evaluate the sensory characteristics of ground chicken thigh meat using the method described by Sebranek et al. (2001). Sensory panels evaluated the aroma (chicken, oxidative, oregano) and overall acceptability of the cooked meat. Six treatments were prepared, cooked, packaged, and stored as described above. The cooked meat samples were refrigerated at 4°C for 3 d before each evaluation

Table 1. TBARS value of cooked ground chicken meat with different oregano oil and tannic acid combinations during storage at 4°C under aerobic packaging conditions.

Time	Control	CM1	CM2	CM3	CM4	5 ppm BHA	SEM
Breast meat				TBARS (mg MDA/kg meat)			
Day 0	$0.21^{a,z}$	$0.18^{a,z}$	$0.19^{a,y}$	$0.21^{a,z}$	$0.19^{a,y}$	$0.21^{a,z}$	0.02
Day 3	$1.36^{a,y}$	$0.87^{b,y}$	$0.77^{b,c,x}$	$0.74^{b,c,y}$	$0.57^{c,x}$	$0.96^{b,y}$	0.07
Day 7	$2.03^{a,x}$	$1.32^{b,c,x}$	$0.97^{c,d,x}$	$0.88^{d,x}$	$0.75^{d,x}$	$1.50^{b,x}$	0.08
SEM	0.08	0.04	0.08	0.01	0.06	0.06	
Thigh meat				TBARS (mg MDA/kg meat)			
Time	Control	CM1	CM2	CM3	CM4	14 ppm BHA	SEM
Day 0	$1.23^{a,y}$	$1.10^{a,z}$	$1.09^{a,z}$	$0.97^{a,z}$	$0.94^{a,y}$	$1.27^{a,z}$	0.07
Day 3	$3.40^{a,x}$	$1.64^{c,y}$	$1.36^{d,y}$	$1.11^{e,y}$	$1.01^{e,y}$	$1.88^{b,y}$	0.04
Day 7	$3.48^{a,x}$	$2.58^{b,c,x}$	$2.32^{c,d,x}$	$2.07^{d,x}$	$1.75^{e,x}$	$2.82^{b,x}$	0.06
SEM	0.06	0.04	0.05	0.03	0.07	0.08	

$^{a–e}$Values with different letters within a row differ significantly ($P < 0.05$), n = 4.
$^{x–z}$Values with different letters within a column are significantly different ($P < 0.05$).
Treatment: control; CM1: 5 ppm tannic acid + 100 ppm oregano oil; CM2: 10 ppm tannic acid + 100 ppm oregano oil; CM3: 5 ppm tannic acid + 200 ppm oregano oil; CM4: 10 ppm tannic acid + 200 ppm oregano oil; BHA: buthylated hydroxyanisole.

session. Ten trained panelists participated for each session. The evaluations were done twice after 3 d of storage at 4°C. For training, 3 one-hour sessions were held using commercial and experimental products to develop descriptive terms for chicken flavor, oxidative odor, spice odor or oregano odor, and overall acceptability.

All attributes were measured using a line scale without numbers (numerical value 9 units) with graduation from 0 to 9—e.g., overall acceptability, where 9 represented extremely desirable and 0 represented extremely undesirable (9-extremely desirable, 8-very, 7-moderate, 6-slightly, 5-neutral, 4-slightly undesirable, 3-moderately undesirable, 2-very undesirable, and 1-extremely undesirable). Similar terminology (e.g., detectable or undetectable) was used for the odor attributes. The samples (4 g each) were placed in glass vials (20 mL volume), and sample vials were labeled with 3-digit numbers selected randomly. Panelists were asked to smell samples in random order and record the intensity of odor or overall acceptability on the scale line.

Statistical Analysis

Data were analyzed using the procedures of Generalized Linear Model (Proc. GLM, version 9.3, SAS Institute, Inc., 2012). Mean values and standard error of the means (**SEM**) were reported. The significance was defined at $P < 0.05$, and the Tukey test or Tukey's Multiple Range test was used to determine whether there was a significant difference between the mean values. The Pearson correlation coefficient was used to determine the relationships among TBARS, total carbonyl, and hexanal content in meat.

RESULTS AND DISCUSSION

Lipid and Protein Oxidation

TBARS values of meats with all antioxidant treatments were significantly lower than that of the control ($P < 0.05$) at d 3 and 7. The highest combination effect was found when 200 ppm oregano oil and + 10 ppm of tannic acid combination was used (Table 1). Cooked meat is more susceptible to lipid oxidation than raw meat because of the denaturation of antioxidant enzymes and the structural damages in membranes, which can expose phospholipids to a pro-oxidant environment in cooked meat (Ahn et al., 1992; Gray et al., 1996). The TBARS values of cooked ground thigh meat were higher than those of the cooked breast meat, but the antioxidant effects were very similar in both breast and thigh meats (Du et al., 2000; Ahn et al., 2009).

The highest total carbonyl value was found in cooked thigh meat control, which reached 4.58 nmol/mg protein (Table 2). The amounts of total carbonyl in this study are similar to those of other researchers who found that total estimated carbonyl contents were in the range of 1 to 3 nmol/mg protein for raw meat and up to 5 nmol/mg protein for cooked meat products (Estevez et al., 2005; Sun et al., 2010). Again, the combination of 200 ppm oregano oil + 10 ppm tannic acid had the highest effect in preventing carbonyl formation in cooked meat. Generally positive relationships between TBARS value and total carbonyl formation were found in both breast and thigh meats during storage. It is known that the antioxidant activity of oregano oil and tannic acid was due to their polyphenols, which work to prevent oxidation in the foods (Goulas and Kontominas, 2007; Okuda and Ito, 2011).

Volatiles Production

The volatiles compounds tables of d 0 and 3 (both breast and thigh meat) were not shown in this paper because 7-day data are enough to explain the changes. Generally, the amounts and number of volatile compounds increased during storage time in both breast and thigh cooked meat patties. Among the carbonyl compounds, hexanal increased by 5- to 6-fold of control meat during the 7-day storage period. This was

Table 2. Effect of adding different levels of oregano oil and tannic acid combinations on protein oxidation of cooked chicken patties during storage at 4°C under aerobic acid conditions.

Time	Control	CM1	CM2	CM3	CM4	5 ppm BHA	SEM
Breast meat			Carbonyl content (nmole/mg protein)				
Day 0	1.00^{a,z}	1.05^{a,y}	0.99^{a,y}	0.98^{a,y}	0.98^{a,z}	1.01^{a,z}	0.06
Day 3	1.69^{a,y}	1.45^{a,b,x,y}	1.31^{b,x}	1.26^{b,x,y}	1.15^{b,y}	1.42^{a,b,y}	0.07
Day 7	2.15^{a,x}	1.75^{a,b,x}	1.41^{b,x}	1.34^{b,x}	1.30^{b,x}	1.76^{a,b,x}	0.11
SEM	0.04	0.16	0.04	0.08	0.03	0.07	
Thigh meat			Carbonyl content (nmole/mg protein)				
Time	Control	CM1	CM2	CM3	CM4	14 ppm BHA	SEM
Day 0	1.55^{a,z}	1.45^{a,y}	1.42^{a,z}	1.42^{a,z}	1.37^{a,y}	1.48^{a,z}	0.05
Day 3	3.10^{a,y}	2.63^{b,x}	2.16^{c,y}	1.75^{d,y}	1.51d^{x,y}	2.67^{b,y}	0.09
Day 7	4.58^{a,x}	3.03^{b,x}	2.52^{c,x}	2.06^{d,x}	1.70^{d,x}	3.21^{b,x}	0.09
SEM	0.08	0.12	0.07	0.08	0.05	0.03	

$^{a–d}$Values with different letters within a row differ significantly ($P < 0.05$), n = 4.
$^{x–z}$Values with different letters within a column are significantly different ($P < 0.05$).
Treatment: control; CM1: 5 ppm tannic acid + 100 ppm oregano oil; CM2: 10 ppm tannic acid + 100 ppm oregano oil; CM3: 5 ppm tannic acid + 200 ppm oregano oil; CM4: 10 ppm tannic acid + 200 ppm oregano oil; BHA: buthylated hydroxyanisole.

Table 3. Volatiles profile of cooked chicken thigh meat with different levels of oregano oil and tannic acid after 7 d of storage under aerobic packaging conditions.

Compound	Control	CM1	CM2	CM3	CM4	BHA	SEM
			Total ion counts x 10^4				
Pentane	697^{a}	0^{c}	0^{c}	0^{c}	0^{c}	195^{b}	25
Propanal	2156^{a}	127^{b}	0^{b}	0^{b}	0^{b}	0^{b}	38
2-propanone	1899^{a}	2412^{a}	2766^{a}	2672^{a}	2676^{a}	2441^{a}	198
2-propanol	274^{a,b}	172^{b}	149^{b}	394^{a}	426^{a}	152^{b}	38
Heptane	137^{a}	0^{c}	0^{c}	0^{c}	0^{c}	52^{b}	10
Butanal	198^{a}	0^{b}	0^{b}	0^{b}	0^{b}	0^{b}	9
Pentanal	10241^{a}	244^{b,c}	81^{c}	91^{c}	81^{c}	994^{b}	171
Octane	405^{a}	348^{a}	101^{c}	98^{c}	92^{c}	227^{b}	24
Hexanal	84538^{a}	3741^{b,c}	1269^{c}	1165^{c}	1014^{c}	9363^{b}	1451
Heptanal	449^{a}	0^{b}	0^{b}	0^{b}	0^{b}	0^{b}	17
Nonanal	63^{a}	0^{b}	0^{b}	0^{b}	0^{b}	0^{b}	2
α-Pinene	0^{b}	241^{a}	216^{a}	278^{a}	282^{a}	0^{b}	29
Camphene	0^{d}	243^{b,c}	165^{c}	280^{a,b}	369^{a}	0^{d}	20
Limonene	0^{b}	52^{b}	55^{b}	146^{a}	196^{a}	0^{b}	14
β-Myrcene	0^{b}	70^{b}	57^{b}	517^{a}	433^{a}	0^{b}	35
γ-Terpinene	0^{b}	203^{b}	208^{b}	1362^{a}	1156^{a}	0^{b}	101
Sabinene	0^{b}	0^{b}	0^{b}	140^{a}	154^{a}	0^{b}	7

$^{a–d}$Values with different letters within a row differ significantly ($P < 0.05$), n = 4.
Treatment: control; CM1: 5 ppm tannic acid + 100 ppm oregano oil; CM2: 10 ppm tannic acid + 100 ppm oregano oil; CM3: 5 ppm tannic acid + 200 ppm oregano oil; CM4: 10 ppm tannic acid + 200 ppm oregano oil; BHA: buthylated hydroxyanisole.

in agreement with Du et al. (2000) who found that the amount of total volatiles in aerobically packaged chicken meat increased by 5- to 6-fold during 7 d of refrigerated storage under aerobic conditions. However, in this study, cooked thigh meat (Tables 3 and 4) had higher volatile values than the cooked breast meat, as indicated by Ahn et al. (1998) and Kosowska (2017). The higher volatile values in thigh meat were due to their different chemical composition, such as fat content, water-holding capacity, and fatty acid composition. Control samples showed the highest aldehyde values among the treatments. A combination of 200 ppm oregano oil with 10 ppm of tannic acid showed the highest effects in inhibiting the volatile formation in both cooked breast and thigh meats during storage. Other antioxidant treatments also decreased the volatile formation during storage and showed significant effect ($P < 0.05$) on aldehydes, which are responsible for the off-flavor in cooked chicken meat after storage (Fasseas et al., 2007; Maqsood and Benjakul, 2010b). Lee et al. (2003) found that the aldehyde-lowering activity of antioxidants was consistent with the result of TBARS values in cooked turkey breast. A similar relationship was found between the TBARS values and aldehydes formation in both cooked breast and thigh meats. In addition, very high correlation coefficients among TBARS, total carbonyl, and hexanal values were found in meat with storage (Table 5). This explains the positive relationships among these three variables during storage periods. Among aldehydes, hexanal and pentanal were the most predominant aldehydes affected by the combination of 200 ppm oregano oil and 10 ppm tannic acid. Jo et al. (2006) found that hexanal contents of cooked control chicken breast meat increased by about 2.7 times at d 1 compared with d 0. Hexanal and pentanal are considered good indicators for lipid oxidation

Table 4. Volatiles profile of cooked chicken thigh meat with different levels of oregano oil and tannic acid after 7 d of storage under aerobic packaging conditions.

Compound	Control	CM1	CM2	CM3	CM4	BHA	SEM
			Total ion counts*10^4				
Pentane	474^{a}	0^{c}	0^{c}	0^{c}	0^{c}	176^{b}	26
2-Propanone	4064^{a,b}	4622^{a}	2824^{b,c}	2807^{b,c}	2465^{c}	3714$^{a–c}$	301
2-Propanol	2983^{a}	1620^{b}	938^{b}	809^{b}	742^{b}	629^{b}	222
Hexane	243^{a}	173^{a,b}	139^{b,c}	0^{d}	0^{d}	83^{c}	17
Cyclohexane	152^{a}	106^{b}	0^{c}	0^{c}	0^{c}	143^{a}	7
Pentanal	2477^{a}	375^{c}	150^{c}	44^{c}	76^{c}	1154^{b}	89
Heptane	347^{a}	0^{b}	0^{b}	0^{b}	0^{b}	57^{b}	18
Octane	1337^{a}	627^{b,c}	494^{c}	478^{c}	458^{c}	850^{b}	56
Hexanal	88685^{a}	5573^{c}	1871^{c}	1652^{c}	832^{c}	25172^{b}	1175
Heptanal	395^{a}	0^{c}	0^{c}	0^{c}	0^{c}	135^{b}	14
Octanal	70^{a}	0^{b}	0^{b}	0^{b}	0^{b}	0^{b}	4
α-Pinene	0^{d}	434^{b,c}	333^{c}	517^{a,b}	669^{a}	0^{d}	37
Camphene	0^{d}	246^{c}	283^{b,c}	449^{b}	638^{a}	0^{d}	38
Limonene	0^{c}	43^{b}	53^{b}	140^{a}	144^{a}	0^{c}	5
β-Myrcene	0^{c}	129^{b}	100^{b}	245^{a}	280^{a}	0^{c}	9
γ-Terpinene	0^{c}	319^{b}	309^{b}	638^{a}	792^{a}	0^{c}	58
Sabinene	0^{c}	0^{c}	0^{c}	41^{b}	59^{a}	0^{c}	4

$^{a–d}$Values with different letters within a row differ significantly different ($P < 0.05$), n = 4.

Treatment: control; CM1: 5 ppm tannic acid + 100 ppm oregano oil; CM2: 10 ppm tannic acid + 100 ppm oregano oil; CM3: 5 ppm tannic acid + 200 ppm oregano oil; CM4: 10 ppm tannic acid + 200 ppm oregano oil; BHA: buthylated hydroxyanisole.

Table 5. Correlation coefficients of TBARS, total carbonyl, and hexanal values during storage time.

	Cooked breast				Cooked thigh		
Var	TBARS	CAR	HEX	Var	TBARS	CAR	HEX
			Pearson's Correlation Coefficients				
TBARS	1	0.983*	0.949*	TBA	1	0.981*	0.960*
CAR	0.983*	1	0.971*	CAR	0.981*	1	0.991*
HEX	0.949*	0.971*	1	HEX	0.960*	0.991*	1

*$P < 0.01$, n = 12.

Abbreviations: Var: variables; TBARS: 2-thobarbituric acid reactive substances; CAR: carbonyl; Hex: hexane.

(Ahn et al., 2000) during storage. The volatile profile also showed some terpenoids, such as camphene and limonene, when ground chicken meats were mixed with oregano oil, and their amounts increased as the amount of oregano oil increased (data not shown). These compounds are responsible for the spice odor of meat with added oregano oil. The content of sulfur compounds (dimethyl trisulfide and dimethyl disulfide) was very low because of the high volatility of those compounds and susceptibility to escape from the oxygen-permeable bags (Nam et al., 2002; Lee et al., 2003). Meats (both breast and thigh) with 200 ppm oregano oil and 10 ppm tannic acid combination showed lower volatile formation than the BHA treatment during storage.

Sensory Evaluation

Sensory panels could distinguish the differences in oregano odor between 200 ppm oregano-added and no oregano-added treatments (Table 6). A combination of 5 or 10 ppm of tannic acid plus 200 ppm oregano oil had significantly ($P < 0.05$) lower oxidation odor score than the control. In addition, a combination of 10 ppm of tannic acid and 200 ppm oregano oil showed the highest score on the overall acceptability of the cooked chicken meats.

Table 6. Sensory attributes means of ground cooked thigh chicken meat patties.

	Sensory attributes			
TRT	Cooked chicken	Oregano odor	Oxidation odor	Overall acceptability
Control	4.6^{b}	0.7^{d}	5.3^{a}	4.1^{c}
CM1	5.9^{a,b}	2.1^{c,d}	4.7^{a,b}	4.6^{c}
CM2	6.4^{a,b}	2.9^{b,c}	3.5^{a,b}	5.7^{b,c}
CM3	6.7^{a,b}	4.7^{a}	2.3^{b}	7.5^{a,b}
CM4	7.9^{a}	4.3^{a,b}	2.6^{b}	7.9^{a}
BHA	6.6^{a,b}	1.1^{d}	3.1^{a,b}	7.3^{a,b}
SEM^{c}	0.5	0.4	0.6	0.4

$^{a–d}$Values with different letters within a column differ significantly ($P < 0.05$), n = 10.

Treatment: control; CM1: 5 ppm tannic acid + 100 ppm oregano oil; CM2: 10 ppm tannic acid + 100 ppm oregano oil; CM3: 5 ppm tannic acid + 200 ppm oregano oil; CM4: 10 ppm tannic acid + 200 ppm oregano oil; BHA: buthylated hydroxyanisole.

CONCLUSION

Oregano EO and tannic acid at levels 200 ppm and 10 ppm, respectively, showed a positive effect on the decreasing TBARS values, total carbonyl, and

deteriorate off-odor volatile formation, but the combination of 200 ppm oregano oil and 10 ppm tannic acid showed the best results. This indicated that a combination of 200 ppm oregano oil and 10 ppm tannic acid could be a good replacement for the synthetic antioxidant (BHA) in cooked ground chicken meat products.

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