Thiobarbituric Acid Reactive Substances and Volatile Compounds in Chicken Breast Meat Infused with Plant Extracts and Subjected to Electron Beam Irradiation

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ABSTRACT The effect of irradiation on thiobarbituric acid reactive substances (TBARS) and volatile compounds in raw and cooked nonirradiated and irradiated chicken breast meat infused with green tea and grape seed extracts was investigated. Chicken breast meat was vacuum infused with green tea extract (3,000 ppm), grape seed extract (3,000 ppm), or their combination (at a total of 6,000 ppm), irradiated with an electron beam, and stored at 5°C for 12 d. The targeted irradiation dosage was 3.0 kGy and the average absorbed dosage was 3.12 kGy. Values of TBARS and volatile compound contents of raw and cooked chicken meat were determined during the 12-d storage period. Thiobarbituric acid reactive substances values ranged from 15.5 to 71.4 mg of malondialdehyde/kg for nonirradiated raw chicken and 17.3 to 80.1 mg of malondialdehyde/kg for irradiated raw chicken. Values for cooked chicken ranged from 31.4 to 386.2 and 38.4 to 504.1 mg of malondialdehyde/kg for nonirradiated and irradiated chicken, respectively. Irradiation increased TBARS and hexanal values of controls and meat infused with plant extracts. Hexanal had the highest intensity of volatiles followed by pentanal and other volatiles. Cooking the samples significantly ($P < 0.05$) increased the amounts of TBARS and volatiles. Addition of plant extracts decreased the amount of TBARS as well as hexanal and pentanal values. Although irradiation increases lipid oxidation, infusion of chicken meat with plant extracts could reduce lipid oxidation caused by irradiation.

Key words: irradiation, antioxidant, volatile, thiobarbituric acid reactive substances

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INTRODUCTION

Irradiation is one of the most effective ways to minimize pathogenic contaminants in food products (Diehl, 1994). In May 1990, The Food and Drug Administration of the United States approved the use of 1.5 to 3.0 kGy of irradiation to reduce pathogenic microorganisms in poultry products (Food and Drug Administration, 2000). However, based on some recent studies, electron beam irradiation causes some negative effects (lipid oxidation and off-odors and flavors) on the quality of foods (Ahn et al., 1998; Nam et al., 2002).

The level of malondialdehyde generated in meat can be determined using the thiobarbituric acid-reactive substances (**TBARS**) assay (Jo and Ahn, 1998). Electron beam irradiation increased TBARS values in meat and meat products due to lipid oxidation (Ahn et al., 1998; Nam et al., 2001). Sweetie et al. (1998) showed that TBARS values for nonirradiated samples of ground chicken meat were lower than those of low-dose γ-irradiated samples. Irradiated poultry may have an off-odor because of aldehydes and sulfur volatiles that develop during gamma irradiation (Patterson and Stevenson, 1995). The amount of volatile compounds including 1-octene, hexanal, and nonanal in irradiated chicken increased after gamma irradiation (Hansen et al., 1987). Hexanal was the major lipid oxidation-related volatile in cooked meat, but the contribution of other aldehydes such as heptanal, octanal, and nonanal to off-flavor of cooked meat would be significant because of their high flavor-d ilution factors (Ramarathnam et al., 1993; Specht and Baltes, 1994). Electron beam irradiation has been shown to have very little detrimental effect on the flavor of preheated or sous-vide–treated (sealed under vacuum) chicken breast meat (Shamsuzzaman et al., 1992).

To delay lipid oxidation, synthetic antioxidants have been applied extensively in food products (Ahmad, 1996). However, due to consumer preferences for natural ingredients over synthetic compounds (Ahn et al., 2002), there is a demand for discovering new plant extracts that can reduce lipid oxidation in lipid-containing food products. Grape seed and green tea extracts contain large amounts of antioxidant compounds (Yen and Chen, 1995; Fadhel

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Table 1. Effect of storage time on thiobarbituric acid reactive substances (mg of malondialdehyde/kg of chicken) values of raw nonirradiated and irradiated chicken breast meat infused with plant extracts and stored at 5°C for 0 to 12 d

Treatment	Level (ppm)	Nonirradiated days			Irradiated days		
		0	6	12	0	6	12
Noninfused control	—	16.4^{az}	42.4^{bx}	67.8^{bw}	28.6^{by}	72.1^{bv}	76.6^{bu}
Water control	—	16.0^{az}	45.2^{ax}	71.4^{aw}	29.9^{ay}	75.2^{av}	80.1^{au}
Green tea extract	3,000	16.1^{az}	19.8^{cx}	38.0^{cw}	18.0^{cdy}	40.3^{cv}	49.0^{cu}
Grape seed extract	3,000	15.8^{ay}	18.9^{dx}	36.0^{dv}	18.7^{cx}	33.1^{dw}	45.0^{du}
Grape seed + green tea	6,000	15.5^{ay}	15.9^{ey}	31.0^{ev}	17.3^{dx}	24.8^{ew}	38.6^{eu}

$^{a–e}$Values within a column with different letters are significantly different ($P < 0.05$).

$^{u–z}$Values within a row with different letters are significantly different ($P < 0.05$).

and Amran, 2002). Rababah et al. (2004) investigated antioxidant activities of some plant extracts and found that grape seed and green tea extracts showed the highest antioxidant activities.

Natural antioxidants such as sesamol, quercetin, rutin, and rosemary have been shown to reduce TBARS values in irradiated raw meat during storage (Chen et al., 1999). Ahn et al. (2002) found that selected natural antioxidants reduced development of warmed-over flavor and TBARS values in cooked ground beef. The effect of green tea and grape seed extracts (alone or in combination) to prevent or minimize the lipid oxidation and volatile development that occur during irradiation of raw and cooked chicken breast meat warrants investigation.

Research information is limited on comparing the effect of plant extracts on raw and cooked irradiated chicken breast meat at 3.0 kGy dosage on lipid oxidation. The objective of this study was to evaluate the effects of green tea extract, commercial grape seed extract, and their combination on 1) lipid oxidation of nonirradiated and irradiated, raw and cooked chicken breast meat, and 2) volatile compound development in raw and cooked irradiated chicken breast meat during storage at 5°C for 12 d.

MATERIALS AND METHODS

Materials

Fresh boneless and skinless chicken breast meat (approximately 24 h postslaughter, stored at 4°C during transportation) was donated by a local poultry company. Green tea (Celestial Seasoning, Inc., Boulder, CO) and ziplock plastic bags were obtained from a local supermarket. Commercial grape seed extract powder (Mega Natural Inc., Madera, CA) was used in this study. Cryovac B640 packaging bags (a polyolefin-based barrier bag, 20 × 50 cm, Sealed Air Corp., Duncan, SC) were provided by the Department of Microbiology at Iowa State University (Ames).

Preparation of Green Tea Extracts

After grinding in a coffee grinder (Braun Aromatic KSM2, Braun Canada Div., Gillette Canada Co., Mississauga, ON, Canada) for 1 min, the ground green tea powder was boiled with water (1:10) for 10 min. The mixture was then filtered through a vacuum filtration unit using Whatman filter paper no. 4. The water extract was frozen to −20°C and freeze-dried at <13 Pa vacuum. The dried extract was kept at 4°C before use.

Chicken Breast Infusion with Plant Extracts

A vacuum tumbling method was used to infuse chicken breasts with green tea extract, grape seed extract, or combined extracts. For each treatment, chicken breast meat (4 kg) was infused with 320 mL of antioxidant solution (8% for 4 kg of chicken) for 20 min at 25 rpm under a pressure of 63.5 cm Hg using a vacuum tumbler (model LT-40, LyCo, Janesville, WI) in a temperature-controlled room at 5°C. This infusion resulted in 3,000 ppm of green tea or grape seed extract, or their combination at a total

Table 2. Effect of storage time on thiobarbituric acid reactive substances (mg of malondialdehyde/kg of chicken) of cooked nonirradiated and irradiated chicken breast meat infused with plant extracts and stored at 5°C for 0 to 12 d

Treatment	Level (ppm)	Nonirradiated days			Irradiated days		
		0	6	12	0	6	12
Noninfused control	—	50.2^{az}	201.8^{bx}	366.1^{bw}	81.2^{ay}	391.1^{bv}	474.1^{bu}
Water control	—	53.2^{az}	212.1^{ax}	386.2^{aw}	83.5^{ay}	415.4^{av}	504.1^{au}
Green tea extract	3,000	36.1^{bz}	66.5^{cx}	77.1^{cw}	48.2^{by}	100.8^{cv}	150.5^{cu}
Grape seed extract	3,000	34.0^{bcz}	63.5^{cx}	74.0^{cw}	41.5^{cy}	92.7^{dv}	131.9^{du}
Grape seed + green tea	6,000	31.4^{dy}	39.8^{dx}	50.8^{dw}	38.4^{cy}	65.2^{ev}	77.9^{eu}

$^{a–e}$Values within a column with different letters are significantly different ($P < 0.05$).

$^{u–z}$Values within a row with different letters are significantly different ($P < 0.05$).

Table 3. Volatile compound contents (ppb) of nonirradiated and irradiated raw chicken breast meat infused with plant extracts and stored for 0 d at 5°C[1]

Volatile compound	Nonirradiated					Irradiated				
	CA	WC	GTE	GSE	GSE+GTE	CA	WC	GTE	GSE	GSE+GTE
Acetylaldehyde	222.0^{abc}	262.8^{abc}	186.4^{c}	328.7^{a}	234.6^{abc}	194.5^{bc}	304.4^{ab}	249.1^{abc}	245.6^{abc}	183.2^{c}
Propanol	11.7^{bc}	14.7^{ab}	16.8^{a}	15.3^{a}	16.4^{a}	11.6^{c}	14.7^{ab}	14.5^{abc}	15.5^{a}	16.4^{a}
Propanal	156.0^{a}	112.7^{c}	92.7^{i}	87.1^{j}	95.8^{h}	110.1^{d}	120.4^{b}	101.9^{e}	98.9^{f}	97.7^{fg}
Butanal	121.8^{a}	100.6^{ab}	66.9^{c}	78.8^{bc}	65.7^{c}	107.9^{ab}	91.2^{abc}	63.5^{c}	79.6^{bc}	59.9^{c}
Butanol	20.5^{a}	20.4^{a}	18.5^{ab}	15.8^{b}	19.7^{ab}	20.9^{a}	21.7^{a}	18.8^{ab}	17.4^{ab}	19.6^{ab}
Pentanol	11.2^{a}	8.9^{abc}	5.4^{de}	7.2^{bcde}	6.0^{cde}	8.7^{abc}	9.3^{ab}	4.5^{e}	7.8^{bcd}	6.3^{bcde}
1-Octene	14.0^{ab}	13.1^{ab}	7.9^{c}	7.8^{c}	8.0^{c}	12.8^{ab}	16.3^{a}	9.9^{bc}	7.7^{c}	7.8^{c}
Heptanal	19.3^{ab}	20.0^{a}	16.7^{bc}	16.0^{c}	18.7^{abc}	18.5^{abc}	19.0^{abc}	17.4^{abc}	16.7^{bc}	18.2^{abc}
1-Octen-3-ol	37.0^{ab}	37.3^{ab}	29.0^{b}	32.0^{ab}	32.0^{ab}	36.1^{ab}	38.6^{a}	31.8^{ab}	34.2^{ab}	34.2^{ab}
Nonanal	24.7^{a}	18.5^{abc}	13.0^{bc}	16.0^{abc}	9.4^{c}	21.2^{ab}	20.6^{ab}	19.3^{ab}	21.3^{ab}	17.0^{abc}

$^{a–j}$Values within a row with different letters are significantly different ($P < 0.05$).

[1]CA = noninfused control; WC = water control; GTE = green tea extract; GSE = grape seed extract.

of 6,000 ppm calculated based on 2.5% chicken fat. For comparison, chicken breasts infused with deionized water and chicken breasts without infusion were included as water control and noninfused control, respectively. After infusion, 4 pieces of the chicken breast samples were packaged in a Cryovac bags and sealed using a vacuum impulse sealer (model PVS-GA18, Packaging Aids Corp., San Rafael, CA) with a sealing time of 4 s and a cooling time of 9 s. Packaging and sealing were conducted at atmospheric conditions. After sealing, the samples were double bagged in zip-lock plastic bags; then each treatment was separated equally (for irradiation and nonirradiation), and stored in boxes at 5°C.

Irradiation and Storage

For the irradiation process, the chicken samples under refrigeration were immediately transported to Texas A& M University (College Station) for electron beam irradiation using dual 10-MeV pulsed-electron accelerators (Titan Scan Technologies, San Diego, CA). The targeted irradiation dosage was 3.0 kGy and the average absorbed dosage was 3.12 kGy. The samples were stored at 5°C and transported to our facility immediately after irradiation. For every sampling time (0, 6, and 12 d), 3 pieces of chicken breasts of each treatment and control were taken randomly for analyses and the remaining samples were kept in storage at 5°C.

TBARS Analysis for Raw and Cooked Meat Samples

The TBARS values of the raw and cooked chicken samples were determined using a modified method described by Jo and Ahn (1998). To a 1-mL sample of homogenized chicken [2 to 10 g of the chicken meat samples with 40 to 80 mL of deionized water in a blender (Osterizer Galaxie Dual Range 14, Oster Corp., Milwaukee, WI) for 1.5 min] was added 200 μL of 8.1% SDS, 1.5 mL of 2 *M* HCl, 1.5 mL of 20 m*M* TBA, and 50 μL of 7.2% butylated hydroxytoluene, and the mixture was vortexed. For a blank, 1.0 mL of deionized water was used in the place of the liquefied samples. The solutions were then heated to 90°C in a water bath for 15 min, and cooled in cold water for 10 min. After adding 1.0 mL of deionized water and 5.0 mL of n-butanol:pyridine (15:1), the solutions were centrifuged (J2-21 centrifuge, Beckman Instruments, Fullerton, CA) at 3,000 × *g* at 20°C for 15 min. The intensity of fluorescence of the clear upper-layer solution was read using a spectrofluorophotometer (model RF-1501, Shi-

Table 4. Volatile compound contents (ppb) of nonirradiated and irradiated raw chicken breast meat infused with plant extracts and stored for 6 d at 5°C[1]

Volatile compound	Nonirradiated					Irradiated				
	CA	WC	GTE	GSE	GSE+GTE	CA	WC	GTE	GSE	GSE+GTE
Acetylaldehyde	269.2^{ab}	309.7^{ab}	256.1^{ab}	331.9^{a}	245.9^{b}	296.7^{ab}	251.2^{ab}	258.6^{ab}	230.8^{b}	236.1^{b}
Propanol	11.3^{e}	14.9^{c}	19.2^{ab}	15.5^{bc}	17.4^{ab}	12.1^{de}	15.2^{bc}	13.5^{cde}	14.9^{c}	14.1^{cd}
Propanal	142.9^{a}	102.5^{bc}	93.5^{bc}	93.9^{bc}	92.3^{c}	97.6^{bc}	105.9^{b}	98.5^{bc}	102.7^{bc}	101.5^{bc}
Butanal	121.0^{a}	95.0^{b}	67.3^{cd}	83.7^{bc}	68.1^{cd}	93.7^{b}	89.1^{b}	65.0^{d}	94.2^{b}	60.3^{d}
Butanol	21.9^{a}	21.2^{a}	18.5^{ab}	16.6^{b}	19.9^{ab}	21.2^{a}	21.8^{a}	20.3^{ab}	19.6^{ab}	18.6^{ab}
Pentanol	10.8^{a}	9.1^{abc}	6.2^{de}	7.7^{bcd}	7.6^{cde}	7.8^{bcd}	9.7^{ab}	5.6^{e}	9.7^{ab}	7.2^{cde}
Heptanal	19.5^{a}	20.7^{a}	27.1^{a}	16.1^{a}	26.6^{a}	27.1^{a}	27.3^{a}	23.1^{a}	20.5^{a}	25.2^{a}
1-Octen-3-ol	38.1^{ab}	36.1^{abc}	30.0^{c}	34.4^{abc}	32.0^{bc}	37.1^{ab}	39.4^{a}	35.9^{abc}	33.9^{abc}	36.4^{abc}
Nonanal	27.4^{a}	22.6^{ab}	19.2^{b}	19.6^{b}	19.7^{b}	21.7^{ab}	21.4^{ab}	21.8^{ab}	24.2^{ab}	25.2^{ab}

$^{a–e}$Values within a row with different letters are significantly different ($P < 0.05$).

[1]CA = noninfused control; WC = water control; GTE = green tea extract; GSE = grape seed extract.

Table 5. Volatile compound contents (ppb) of nonirradiated and irradiated raw chicken breast meat infused with plant extracts and stored for 12 d at 5°C[1]

Volatile compound	Nonirradiated					Irradiated				
	CA	WC	GTE	GSE	GSE+GTE	CA	WC	GTE	GSE	GSE+GTE
Acetylaldehyde	261.1^{b}	328.4^{ab}	280.8^{ab}	359.0^{a}	266.0^{b}	279.7^{ab}	288.6^{ab}	294.2^{ab}	273.1^{ab}	279.0^{ab}
Propanol	11.8^{b}	14.3^{b}	20.1^{ab}	13.7^{b}	18.5^{ab}	11.8^{b}	52.2^{a}	15.0^{b}	13.4^{b}	13.0^{b}
Propanal	123.3^{a}	107.3^{b}	97.1^{b}	97.2^{b}	97.3^{b}	94.4^{b}	96.8^{b}	100.6^{b}	95.7^{b}	95.1^{b}
Butanal	106.9^{a}	90.7^{ab}	64.0^{cd}	79.2^{bc}	70.3^{cd}	89.4^{b}	91.5^{ab}	58.8^{d}	86.7^{b}	63.9^{cd}
Butanol	20.6^{a}	17.3^{a}	19.6^{a}	18.0^{a}	21.8^{a}	21.0^{a}	20.7^{a}	21.0^{a}	20.6^{a}	19.5^{a}
Pentanol	9.7^{a}	9.5^{a}	6.7^{c}	8.2^{abc}	7.0^{bc}	8.2^{abc}	9.1^{ab}	6.2^{c}	9.2^{ab}	8.2^{abc}
Heptanal	17.8^{cd}	18.5^{bcd}	30.5^{abc}	15.5^{d}	30.6^{abc}	31.8^{ab}	33.2^{a}	28.4^{abcd}	26.1^{abcd}	30.7^{abc}
1-Octen-3-ol	38.4^{a}	38.1^{a}	34.3^{ab}	37.2^{ab}	36.2^{ab}	34.9^{ab}	36.3^{ab}	33.2^{b}	36.8^{ab}	35.5^{ab}
Nonanal	31.2^{a}	29.1^{abc}	21.9^{bc}	25.5^{abc}	22.6^{abc}	26.9^{abc}	24.3^{abc}	25.1^{abc}	21.0^{c}	29.5^{ab}

$^{a–d}$Values within a row with different letters are significantly different ($P < 0.05$).

[1]CA = noninfused control; WC = water control; GTE = green tea extract; GSE = grape seed extract.

madzu, Kyoto, Japan) at 520 nm (excitation) and 550 nm (emission). The level of the TBARS was quantified from the observed fluorescent intensity of the samples using an equation of a standard curve ($R^2 = 0.998$) of malondialdehyde (MDA) as follows: TBARS (in mg of MDA/kg of chicken) = $[(0.0331 \times F - 0.1836) \times 50 \times 72]$, where F = fluorescent intensity. The concentrations of MDA used to determine the standard curve were 0.01 to 2.0 m*M*.

Volatiles Determination

In preparation for volatile compound analysis, 100 g of the raw sample meat was ground using a blender for 10 s and 7 g of this ground meat was weighed into a sample vial (16 mL), capped tightly with a polytetrafluoroethylene/silicone open-mouth cap, and placed in a refrigerator (4°C) until analysis. For cooked meat treatments, capped samples of raw meat were cooked at 85°C in a water bath for 15 min and placed in a refrigerator (4°C) until analysis. The stored vials (not more than 6 h) were used for headspace analysis.

Headspace volatile compounds were analyzed by using a Varian 3800 gas chromatograph (Varian Analytical Instrument, Walnut Creek, CA) equipped with a flame-ionization detector using carboxen/polydimethylsiloxane (PDMS) fiber (75 μm film thickness, Supelco, Inc., Bellefonte, PA). The sample in a vial was placed in a CMS Equatherm oven (Curtin Matheson Scientific, Inc., Houston, TX) at 40°C for 45 min with agitation. Volatile components in the samples were adsorbed by inserting the carboxen/polydimethylsiloxane fiber into the headspace of the vial at 40°C for 45 min. The adsorbed volatile components in the fiber were desorbed in an injector port at 270°C for 2 min, and then separated on a DB-5 column (30 m × 0.32 mm i.d. × 0.25 μm, J&W Scientific Inc., Folsom, CA). A linear gradient was used to increase the gas chromatograph oven temperature from 50 to 150°C at a rate of 3°C/min with ultrahigh-purity helium as the carrier gas. The holding time for initial and final temperatures was 5 min.

The identification and concentration of volatiles were evaluated by an external calibration method using volatile standards. Standard mixtures were prepared over the range of concentrations expected in the sample. Each standard mixture was exposed to the solid-phase microextraction fiber carboxen/polydimethylsiloxane and analyzed. Absorption conditions for the solid-phase microextraction fiber were the same as for the samples. A calibration curve for each analyte was prepared and the linear equation was obtained to determine the amount of each volatile compound in the chicken samples. The volatile contents were expressed as micrograms per gram of meat (ppb).

Table 6. Effect of storage time on pentanal and hexanal contents (ppb) of nonirradiated and irradiated raw chicken breast meat infused with plant extracts and stored for up to 12 at 5°C[1]

Volatile compound	Storage time (d)	Nonirradiated					Irradiated				
		CA	WC	GTE	GSE	GSE+GTE	CA	WC	GTE	GSE	GSE+GTE
Pentanal	0	453.3^{aq}	402.9^{bcq}	424.0^{abq}	404.0^{bcq}	387.0^{cr}	452.0^{aq}	419.6^{abcr}	402.3^{bcq}	413.8^{bcq}	379.9^{bcr}
	6	579.2^{bp}	546.6^{bp}	481.7^{cp}	469.1^{cdp}	410.5^{dq}	771.2^{ap}	731.1^{aq}	482.0^{cp}	477.0^{cp}	432.5^{cdq}
	12	605.1^{bp}	566.4^{bcp}	496.9^{cdep}	480.3^{dep}	434.0^{ep}	801.3^{ap}	761.1^{ap}	516.1^{cdp}	498.1^{cdep}	469.4^{dep}
Hexanal	0	194.1^{ay}	1,189.3^{ay}	1,166.0^{az}	1,228.6^{az}	1,203.0^{az}	1,221.5^{ay}	1,142.1^{ay}	1,201.6^{az}	1,218.7^{ay}	1,199.6^{ay}
	6	2,767.9^{ax}	2,705.6^{ax}	1,743.8^{by}	1,689.0^{bcy}	1,380.5^{dy}	2,854.1^{ax}	2,758.6^{ax}	1,826.2^{by}	1,765.7^{bx}	1,450.6^{cdx}
	12	2,879.7^{ax}	2,778.8^{ax}	1,816.3^{bcx}	1,735.9^{bcdx}	1,461.9^{dx}	2,972.7^{ax}	2,882.1^{ax}	1,910.3^{bx}	1,858.0^{bx}	1,525.9^{cdx}

$^{a–e}$Values within a row with different letters are significantly different ($P < 0.05$).

$^{p–r}$Values within a column for pentanal with different letters are significantly different ($P < 0.05$).

$^{x–z}$Values within a column for hexanal with different letters are significantly different ($P < 0.05$).

[1]CA = noninfused control; WC = water control; GTE = green tea extract; GSE = grape seed extract.

Table 7. Volatile compound contents (ppb) of nonirradiated and irradiated cooked chicken breast meat infused with plant extracts and stored for 0 d at 5°C[1]

Volatile compound	Nonirradiated					Irradiated				
	CA	WC	GTE	GSE	GSE+GTE	CA	WC	GTE	GSE	GSE+GTE
Acetylaldehyde	532.7^{a}	553.9^{a}	442.2^{b}	569.4^{a}	525.3^{a}	380.5^{b}	414.3^{b}	416.4^{b}	407.6^{b}	376.6^{b}
Propanol	42.5^{abcd}	47.1^{a}	38.7^{d}	46.9^{a}	45.6^{ab}	40.7^{cd}	41.9^{cdef}	43.7^{abc}	43.1^{abcd}	44.4^{ab}
Propanal	306.4^{a}	270.5^{b}	231.6^{cd}	232.7^{cd}	219.9^{d}	249.9^{bc}	237.4^{cdef}	223.8^{d}	220.8^{d}	221.0^{d}
Butanal	228.1^{a}	228.8^{a}	176.3^{b}	229.1^{a}	153.2^{cd}	170.2^{bc}	165.3^{bcd}	139.1^{d}	162.4^{bcd}	137.4^{d}
Butanol	51.1^{a}	39.4^{bc}	34.7^{cd}	32.5^{d}	37.3^{bcd}	43.7^{b}	41.7^{b}	41.3^{b}	41.8^{b}	42.6^{b}
Pentanol	27.1^{a}	24.0^{a}	13.4^{c}	19.4^{b}	13.3^{c}	19.4^{b}	16.9^{b}	11.4^{c}	17.0^{b}	12.5^{c}
1-Octene	28.1^{ab}	29.0^{a}	19.6^{c}	21.2^{c}	21.2^{c}	23.3^{bc}	32.4^{a}	22.2^{c}	20.5^{c}	21.4^{c}
Heptanal	44.6^{bc}	43.3^{c}	44.4^{bc}	45.6^{bc}	41.3^{c}	43.8^{cd}	52.2^{a}	45.1^{bc}	46.1^{bc}	50.1^{ab}
1-Octen-3-ol	76.7^{a}	58.5^{bc}	51.1^{c}	60.3^{bc}	59.9^{bc}	63.0^{b}	66.0^{b}	64.9^{b}	64.1^{b}	60.5^{bc}
Nonanal	64.8^{a}	34.9^{b}	29.7^{b}	38.8^{b}	28.1^{b}	37.6^{b}	32.8^{b}	31.2^{b}	33.0^{b}	32.6^{b}

$^{a–f}$Values within a row with different letters are significantly different (P < 0.05).

[1]CA = noninfused control; WC = water control; GTE = green tea extract; GSE = grape seed extract.

Statistical Analysis

The results are presented as means of 3 determinations, and were analyzed for variance and multiple mean comparisons to compare treatments and storage times with the JMP 5 software package (SAS Institute, 2002). The significance of differences between means was determined by the Tukey HSD procedure at the 5% significance level.

RESULTS AND DISCUSSION

TBARS Analysis for Raw and Cooked Meat Samples

Tables 1 and 2 show the effects on TBARS values of irradiation of infused raw and cooked chicken breast meat and controls over 12 d of storage at 5°C. The TBARS values over 0 to 12 d of storage ranged from 15.5 to 71.4 and 17.3 to 80.1 mg of MDA/kg of chicken for nonirradiated and irradiated raw chicken, respectively. The TBARS values in cooked chicken ranged from 31.4 to 386.2 and 38.4 to 504.1 mg of MDA/kg of chicken for nonirradiated and irradiated chicken, respectively. There were significant differences ($P < 0.05$) for nonirradiated and irradiated chicken breast meat without infusion of plant extracts for raw and cooked chicken breast. Infusion with plant extracts had a similar effect in reducing TBARS values of the nonirradiated and irradiated raw and cooked chicken meat. Compared with controls, the TBARS values of nonirradiated, infused chicken breast meat were generally lower. The combination of grape seed and green tea extracts at 6,000 ppm was the most effective infusion treatment for decreasing lipid oxidation, followed by grape seed or green tea extracts at 3,000 ppm, respectively. Grape seed extract was slightly more effective in decreasing TBARS values of cooked and raw chicken during storage compared with green tea extract, possibly due to their different phenolic constituents. In a previous study, grape seed extract showed higher antioxidant activity than green tea extract (Rababah et al., 2004). Compared with controls, plant extract infusions minimized lipid oxidation in both nonirradiated and irradiated samples for 0 to 12 d. The results demonstrated that plant extracts were effective in preventing lipid oxidation in irradiated meat.

Although the underlying lipid oxidation mechanisms in irradiated meat are not fully understood, they may be similar to those in nonirradiated meat (Gray et al., 1996). Grape seed and green tea extracts, which contain a large amount of polyphenolic and phenolic compounds (Rababah et al., 2004), minimized lipid oxidation in both nonir-

Table 8. Volatile compound contents (ppb) of nonirradiated and irradiated cooked chicken breast meat infused with plant extracts and stored for 6 d at 5°C[1]

Volatile compound	Nonirradiated					Irradiated				
	CA	WC	GTE	GSE	GSE+GTE	CA	WC	GTE	GSE	GSE+GTE
Acetylaldehyde	680.7^{a}	671.5^{a}	558.1^{bc}	613.0^{ab}	565.1^{bc}	687.0^{a}	652.9^{a}	520.0^{c}	614.5^{ab}	567.6^{bc}
Propanol	46.1^{ab}	48.0^{a}	40.1^{bc}	45.0^{abc}	42.2^{abc}	45.0^{abc}	46.8^{a}	38.8^{c}	42.3^{abc}	41.9^{abc}
Propanal	291.5^{a}	290.7^{a}	270.4^{c}	237.1^{ef}	247.9^{d}	277.3^{b}	282.6^{b}	237.0^{ef}	239.1^{e}	232.6^{f}
Butanal	214.9^{a}	220.1^{a}	173.5^{c}	220.7^{a}	152.8^{c}	210.0^{ab}	211.0^{ab}	179.7^{bc}	215.3^{a}	150.0^{c}
Butanol	52.2^{a}	36.0^{bc}	39.3^{b}	29.8^{c}	37.7^{bc}	49.5^{a}	36.7^{bc}	35.0^{bc}	31.0^{bc}	36.3^{bc}
Pentanol	25.9^{a}	24.0^{b}	14.8^{e}	19.3^{d}	14.9^{e}	26.1^{a}	22.2^{bc}	13.7^{e}	20.7^{cd}	14.8^{e}
Heptanal	47.9^{bcd}	47.0^{d}	48.9^{abcd}	52.4^{abc}	52.1^{abcd}	52.9^{ab}	52.9^{ab}	47.0^{d}	53.8^{a}	47.4^{cd}
1-Octen-3-ol	80.6^{a}	53.7^{c}	61.3^{c}	62.8^{c}	65.1^{bc}	79.6^{ab}	57.9^{c}	54.7^{c}	66.8^{abc}	64.5^{bc}
Nonanal	51.4^{a}	33.3^{a}	31.8^{a}	35.7^{a}	31.5^{a}	41.5^{ab}	39.3^{ab}	30.5^{a}	34.5^{a}	31.0^{a}

$^{a–f}$Values within a row with different letters are significantly different (P < 0.05).

[1]CA = noninfused control; WC = water control; GTE = green tea extract; GSE = grape seed extract.

Table 9. Volatile compound contents (ppb) of nonirradiated and irradiated cooked chicken breast meat infused with plant extracts and stored for 12 d at 5°C[1]

Volatile compound	Nonirradiated					Irradiated				
	CA	WC	GTE	GSE	GSE+GTE	CA	WC	GTE	GSE	GSE+GTE
Acetylaldehyde	702.9^{a}	691.3^{abc}	573.9^{de}	632.8^{bcd}	581.7^{de}	701.1^{ab}	671.2^{abc}	548.2^{e}	632.1^{cd}	588.4^{de}
Propanol	46.9^{a}	45.6^{ab}	42.1^{ab}	46.1^{ab}	43.6^{ab}	45.6^{ab}	46.1^{ab}	39.5^{b}	41.6^{ab}	40.6^{ab}
Propanal	275.0^{abc}	284.2^{ab}	266.4^{bcde}	244.1^{f}	262.8^{cdef}	269.1^{bcd}	291.2^{a}	249.3^{ef}	253.8^{def}	245.6^{f}
Butanal	206.9^{ab}	221.7^{a}	159.5^{c}	210.0^{ab}	163.3^{c}	215.3^{a}	219.2^{a}	175.0^{bc}	207.9^{ab}	144.3^{c}
Butanol	53.1^{a}	34.0^{c}	42.0^{bc}	31.4^{c}	40.2^{c}	52.7^{ab}	33.4^{c}	34.2^{c}	31.7^{c}	34.0^{c}
Pentanol	26.6^{a}	23.4^{b}	14.7^{d}	18.6^{c}	14.3^{d}	26.8^{a}	20.5^{c}	14.7^{d}	19.8^{c}	15.4^{d}
Heptanal	49.3^{a}	51.5^{a}	46.5^{a}	50.5^{a}	50.3^{a}	52.1^{a}	49.6^{a}	52.4^{a}	48.8^{a}	49.6^{a}
1-Octen-3-ol	79.5^{ab}	51.7^{c}	60.0^{c}	64.1^{bc}	66.8^{abc}	80.7^{a}	59.2^{c}	57.3^{c}	64.4^{bc}	60.3^{c}
Nonanal	44.2^{a}	32.1^{b}	34.3^{ab}	37.8^{ab}	28.8^{b}	39.4^{ab}	36.9^{ab}	32.7^{b}	37.4^{ab}	29.4^{b}

$^{a–f}$Values within a row with different letters are significantly different ($P < 0.05$).

[1]CA = noninfused control; WC = water control; GTE = green tea extract; GSE = grape seed extract.

radiated and irradiated chicken breast samples separately or in combination. This could be because of inhibition of formation of free radicals during the initiation step or interruption of the propagation of the free radical chain reaction by acting as an electron donor (Ahmad, 1996; Nawar, 1998). In comparison, several studies have shown that electron beam irradiation increased TBARS values in meat due to lipid oxidation (Ahn et al., 1998; Nam et al., 2001).

Volatiles Determination

Tables 3 through 10 show the effects of irradiation and infusion of plant extracts on volatile compound contents in raw and cooked chicken breast meat and controls in storage at 5°C. At 0 d of storage (Tables 3 and 6), irradiation did not significantly ($P > 0.05$) affect the amounts of acetylaldehyde, propanol, propanal, butanal, butanol, pentanal, heptanal, 1-octene, 1-octen-3-ol, or nonanal in raw chicken meat or among treatments and controls despite significant differences in some values. Similar results were observed in cooked products (Tables 8 and 9) and at 6 and 12 d of storage. The substantial amounts of aldehyde compounds observed might be due to the secondary oxidation of the chicken samples during storage. This observation is similar to those of many studies (St. Angelo et al., 1987; Larick et al., 1992; Du et al., 2001). Cooking samples significantly ($P < 0.05$) increased the amount of all volatiles, especially hexanal and pentanal; this could be due to an enhanced level of oxidation due to processing compared with raw meat (Bagorogoza et al., 2001). Tables 6 and 10 also showed that hexanal had the highest intensity followed by pentanal and the other volatiles. St. Angelo et al. (1987) reported that out of all the volatile productions, hexanal reached the highest level.

In this study, hexanal and pentanal were selected to compare the effects of irradiation and infusion with plant extracts on volatile production in raw and cooked chicken stored at 5°C for up to 12 d. The results showed that irradiation increased the hexanal contents, which could be due to development of lipid oxidation. In the controls and infusion treatments, hexanal contents of samples after 6 d of storage were significantly ($P < 0.05$) higher compared with samples after 0 d; for the most part, no significant differences were observed between 6 and 12 d of storage. The combination of grape seed and green tea extracts (6,000 ppm) was the most effective infusion treatment in decreasing the amount of hexanal production, followed by green tea and grape seed extracts at 3,000 ppm. No significant differences ($P > 0.05$) were observed between grape seed and green tea extracts when used at the same level. In the cooked controls and infused samples, hexanal contents during storage and among treatments showed similar trends as for raw meat. Cooking

Table 10. Effect of storage time on pentanal and hexanal contents (ppb) of nonirradiated and irradiated cooked chicken breast meat infused with plant extracts and stored for up to 12 d at 5°C[1]

Volatile compound	Storage time (d)	Nonirradiated					Irradiated				
		CA	WC	GTE	GSE	GSE+GTE	CA	WC	GTE	GSE	GSE+GTE
Pentanal	0	1,579.9^{bq}	1,619.1^{abq}	1,650.1^{ar}	1,582.2^{bq}	1,615.7^{abq}	1,647.5^{aq}	1,659.9^{aq}	1,641.4^{aq}	1,658.6^{aq}	1,629.2^{abr}
	6	1,935.1^{abp}	1,883.5^{bp}	1,752.6^{cq}	1,695.5^{cp}	1,692.5^{cp}	2,035.4^{ap}	1,949.1^{abp}	1,723.5^{cp}	1,729.2^{cp}	1,666.2^{cq}
	12	1,965.0^{bp}	1,956.0^{bp}	1,790.0^{cp}	1,725.2^{cdp}	1,726.1^{cdp}	2,064.2^{ap}	1,999.2^{abp}	1,762.4^{cp}	1,745.5^{cdp}	1,689.1^{dp}
Hexanal	0	4,612.9^{aby}	4,595.6^{ay}	4,752.1^{ay}	4,636.5^{aby}	4,684.4^{az}	4,375.5^{by}	4,556.1^{aby}	4,615.6^{abz}	4,602.3^{aby}	4,570.8^{aby}
	6	5,705.0^{ax}	5,676.3^{ax}	5,036.5^{bx}	4,966.5^{bx}	4,818.1^{dy}	5,787.8^{ax}	5,729.3^{ax}	5,002.5^{by}	5,021.6^{bx}	4,845.1^{cx}
	12	5,782.7^{ax}	5,733.8^{ax}	5,097.5^{bx}	5,026.1^{bx}	4,865.0^{bx}	5,853.1^{ax}	5,799.1^{ax}	5,138.9^{bx}	5,103.0^{bx}	4,900.2^{bx}

$^{a–d}$Values within a row with different letters are significantly different ($P < 0.05$).

$^{p–r}$Values within a column for pentanal with different letters are significantly different ($P < 0.05$).

$^{x–z}$Values within a column for hexanal with different letters are significantly different ($P < 0.05$).

[1]CA = noninfused control; WC = water control; GTE = green tea extract; GSE = grape seed extract.

the samples significantly ($P < 0.05$) increased the amount of hexanal in both controls and infused samples, which could be due to increasing oxidation in cooked meat. Du et al. (2001) reported that hexanal is the main aldehyde produced during lipid oxidation and addition of antioxidants lowered the amount of hexanal production during storage.

In both controls and plant extract infusion treatments, pentanal contents significantly ($P < 0.05$) increased during storage, which could be because of lipid oxidation during storage. Larick et al. (1992) reported that pork meat during storage produced more aldehydes, especially pentanal and hexanal. In the controls and infusion treatments, pentanal contents significantly ($P < 0.05$) increased after 6 d of storage, whereas no significant differences were observed between 6 and 12 d of storage. The combination of grape seed and green tea extracts at 6,000 ppm was the most effective infusion treatment in decreasing the amount of pentanal, followed by green tea and grape seed extracts at 3,000 ppm. Cooking the samples after irradiation significantly ($P < 0.05$) increased the amount of pentanal in both controls and infusion treatments.

Irradiation of chicken breast meat can decrease the quality of the meat by generating lipid oxidation. However, this investigation showed that plant extracts infused into the meat could minimize lipid oxidation in both irradiated and nonirradiated chicken. The combination of grape seed and green tea extracts at 6,000 ppm was the most effective treatment in retarding lipid oxidation of chicken breast meat followed by grape seed or green tea extract at 3,000 ppm. Hexanal and pentanal were the main volatile compounds produced by oxidation of the chicken samples. These volatile compounds could be used to compare raw and cooked chicken meat samples. Although irradiation increases lipid oxidation, infusion of chicken meat with plant extracts could reduce lipid oxidation caused by irradiation. However, the impact of the plant extracts on the sensory quality of poultry breast meat needs to be studied.

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