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Far-Infrared Radiation Increases the Antioxidant Properties of Rice Hull Extract in Cooked Turkey Meat

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To determine the antioxidant effects of rice hull extract exposed to far-infrared radiation, the added extracts were compared with sesamol in cooked turkey breast. Rice hull extract showed antioxidant properties in cooked turkey breast by reducing lipid oxidation and volatile aldehydes. Far-infrared radiation increased significantly the antioxidant activities of rice hull extracts. Rice hull extract irradiated by far-infrared (FRH) had lower TBARS values and fewer volatile aldehydes (hexanal, pentanal, and propanal) than a non-irradiated extract (IRH) during the 3 days of aerobic storage. Addition of FRH at 0.2% (w/w) in turkey meat could reduce the amounts of volatile hexanal to 18−47% of the control during the storage. However, the antioxidant activities of rice hull extracts did not last as long as those of pure sesamol due to the relatively low concentration of phenolics, and the extracts had some peculiar odor. Addition of rice hull extracts also increased both *a* and *b* values of the samples due to its brown intensity.

KEYWORDS: Rice hull extract; far-infrared; turkey breast; antioxidant activity

INTRODUCTION

Antioxidant activities have been reported from various plant sources, such as grape seeds, pine bark, olive rape, rosemary, and cocoa byproduct (*1*−*3*). Some parts of plants may play an important role in chemical protection from oxidative damage because they possess endogenous antioxidant phenolic compounds, and the antioxidant activity of a certain fraction is higher than that of others (*4*, *5*).

Rice hulls also contain an antioxidant defense system to protect rice seed against oxidative stress (*6*). There have been a few reports on the antioxidant activities of rice hull extracts. Ramarathnam et al. (*7*) identified isovitexin as a natural component in white rice hull, which showed strong antioxidants inhibiting lipid peroxidation. Wu et al. (*8*) reported that wild rice kernels contained 2.1−2.4% phytic acid, a strong chelating agent showing antioxidant activity. Asamarai et al. (*9*) identified a few phenolic compounds, such as anisole, vanillin, and syringaldehyde, in wild rice hull extract. In our previous study (*10*), methanolic extracts of rice hull contained several phenolic compounds such as *o*-methoxycinnamic acid, 4,7-dihydroxybenzoic acid, and *p*-coumaric acid, which are known to have antioxidant effects. Thus, rice hull should receive greater attention as an economical natural antioxidant source.

Many natural antioxidant compounds, however, exist naturally bound to high molecular weight compounds or constitute part of the repeating subunits of high molecular weight polymers (*11*). Far-infrared (FIR) radiation was thought to liberate and activate low molecular weight natural antioxidant compounds, because it heats materials without degrading the constitutive molecules of the surface and contributes to an even transfer of heat to the center of the materials (*12*). We found antioxidant activities and phenolic contents increased after exposure of rice hulls to FIR radiation (*13*).

Precooked meats are easily susceptible to lipid oxidation and production of off-odor volatiles, and the use of antioxidants is commonly required to retard the oxidative quality deterioration during the meats' shelf life. The need for natural antioxidants is increasing in the food and meat industries to meet the requirements of consumers demanding safer and natural antioxidants. Although a few natural extracts with antioxidant activities are widely used as safe antioxidants, they are not as effective as the synthetic antioxidants and the manufacturing cost is high (*14*). Therefore, the antioxidant properties of rice hull extract treated by FIR can be evaluated in the poultry meat system, which is susceptible to lipid oxidation due to a relatively high proportion of polyunsaturated fatty acids.

The objectives of this study were to determine the effects of rice hull extract irradiated by FIR on lipid oxidation, production of volatile compounds, and color changes of cooked turkey breast during refrigerated storage.

MATERIALS AND METHODS

Preparation of Rice Hull Extracts. Rice hulls from a rice cultivar (*Oriza sativa* L. Japonica) were purchased from a local pounding plant (Kimcheon, South Korea). The rice hulls were ground in a mill to pass through a 48-mesh sieve. For FIR irradiation, rice hulls (5.0 g) in a

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wooden box (50 cm × 40 cm × 40 cm) were irradiated for 120 min with a FIR lamp (35 × 10 cm, 100 V, maximum 300 W, Hakko Electric Machine Works Co., Ltd., Nagano, Japan), generating heat in the wavelength range of 2−14 μm within the spectrum. The sample-holding tray in the middle of the treatment box faced the FIR heater in a parallel position, and the distance between the rice hull sample and the heater was 20 cm. Each 300 g portion of rice hulls irradiated by FIR or not was extracted with 1.5 L of methanol overnight at room temperature. The extract was filtered through a Whatman nylon membrane filter (0.2 μm), and then the filtrate was evaporated to dryness under reduced pressure on a rotary evaporator at 40 °C. The extract was stored at 4 °C with nitrogen filling and dissolved with ethanol before use. Consequently, two types of rice hull extracts were prepared, an intact rice hull extract not irradiated by FIR (IRH) and an irradiated rice hull extract (FRH).

Sampling of Turkey Breast Patties. Turkey breast muscles (Pectoralis major) from 16 different turkeys were divided into four groups and separately ground through a 3 mm plate. Six different turkey patty treatments were prepared using sesamol and rice hull extracts prepared as above: (1) control, no additive; (2) sesamol (3,4-methylenedioxyphenol; Sigma, St. Louis, MO), 0.01% added; (3) IRH, 0.1% added; (4) IRH, 0.2% added; (5) FRH, 0.1% added; and (6) FRH, 0.2% added. Each additive was added to the ground turkey breast and mixed for 3 min in a bowl mixer (model KSM 90; KitchenAid Inc., St. Joseph, MI). Rice hull extracts were dissolved in ethanol at the concentration of 200 mg/mL before addition, and the same amounts of ethanol were added to all treatments to minimize the effect of the solvent. The mixed meats were ground again through a 3 mm plate to ensure even distribution of the added additives. Turkey breast patties were prepared using ∼100 g of meat and were cooked in a convection oven to an internal temperature of 70 °C. After cooking, turkey patties were vacuum-packaged and chilled in running cold water for 10 min. Then the patties were individually transferred into oxygen-permeable bags (polyethylene, 4 × 6, 2 mil, Associated Bag Co., Milwaukee, WI). The aerobically packaged samples were stored at 4 °C, and lipid oxidation, color, and volatile compounds of the samples were determined at 0, 1, and 3 days.

2-Thiobarbituric Acid-Reactive Substances (TBARS) Values. Lipid oxidation was determined by measuring TBARS content (*15*). Minced sample (5 g) was placed in a 50 mL test tube and homogenized with 15 mL of deionized distilled water (DDW) using a Brinkman Polytron (type PT 10/35, Brinkman Instrument Inc., Westbury, NY) for 15 s at high speed. The meat homogenate (1 mL) was transferred to a disposable test tube (13 × 100 mm), and butylated hydroxytoluene (7.2%, 50 μL) and thiobarbituric acid/trichloroacetic acid [20 mM TBA and 15% (w/v) TCA] solution (2 mL) were added. The sample was mixed using a vortex and then incubated in a 90 °C water bath for 15 min to develop color. After cooling for 10 min in cold water, the samples were vortexed and centrifuged at 3000*g* for 15 min at 5 °C. The absorbance of the resulting upper layer was read at 531 nm against a blank prepared with 1 mL of DDW and 2 mL of TBA/TCA solution. The amounts of TBARS were expressed as milligrams of malonedialdehyde (MDA) per kilogram of meat.

Color Measurement. CIE color values were measured on the surface of samples using a LabScan colorimeter (Hunter Associated Laboratories, Inc., Reston, VA) that had been calibrated against black and white reference tiles covered with the same packaging materials as used for the samples. The CIE *L* (lightness), *a* (redness), and *b* (yellowness) values were obtained using an illuminant A (light source). Area view and port size were 0.25 and 0.40 in., respectively. The values from four random locations of upper and bottom surfaces were obtained, averaged, and used for statistical analysis.

Analysis of Volatile Compounds. A dynamic headspace analysis was performed using a Solatek 72 multimatrix vial autosampler and a purge and trap concentrator 3000 (Tekmar-Dohrmann, Cincinnati, OH) connected to a gas chromatograph−mass spectrometer (GC-MS, Hewlett-Packard Co., Wilmington, DE) according to the method of Ahn et al. (*16*). Minced sample (1 g) was placed in a 40 mL sample vial, and the vials were then flushed with helium gas (40 psi) for 3 s and capped airtight with a Teflon fluorocarbon resin/silicone septum (I-Chem Co., New Castle, DE). The maximum waiting time of a sample in a refrigerated (4 °C) loading tray was 2 h or less to minimize oxidative changes during the waiting period before the start of the analysis. The meat sample was purged with helium gas (40 mL/min) for 14 min at 40 °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 (−80° C), and then thermally desorbed into a column for 60 s at 225 °C.

Table 1. TBARS Values of Cooked Turkey Breast Meat with the Addition of Intact Rice Hull Extract (IRH) and Far-Infrared-Radiated Rice Hull Extract (FRH) during Refrigerated Storage[a]

storage time (days)	mg of MDA/kg of meat						
	control	sesamol	IRH		FRH		SEM
		0.01%	0.1%	0.2%	0.1%	0.2%	
0	1.35az	0.52dz	0.94bz	0.78cz	0.76cz	0.71cz	0.04
1	3.35ay	0.96ey	2.43by	1.86cy	1.92cy	1.38dy	0.07
3	6.56ax	2.21ex	6.01bx	4.50cx	4.16dx	2.04ex	0.10
SEM	0.07	0.05	0.02	0.10	0.10	0.07	

[a] Different letters (a–d) within a row are significantly different ($P < 0.05$), $n = 4$. Different letters within a column (x–z) with the same meat are significantly different ($P < 0.05$).

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; Hewlett-Packard Co., Wilmington, DE), and an HP-Wax column (7.5 m, 0.250 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 0 °C was held for 1.5 min. After that, the oven temperature was increased to 15 °C at 2.5 °C/min, increased to 45 °C at 5 °C/min, increased to 110 °C at 20 °C/min, and then increased to 170 °C at 10 °C/min and held for 2.25 min at that temperature. A constant column pressure at 20.5 psi was maintained. The ionization potential of the mass selective detector (model 5973; Hewlett-Packard Co.) was 70 eV, and the scan range was *m*/*z* 19.1−350. Identification of volatiles was achieved by comparing mass spectral data of samples with those of the Wiley library (Hewlett-Packard Co.). Standards, when available, were used to confirm the identification by the mass selective detector. The area of each peak was integrated using ChemStation software (Hewlett-Packard Co.), and the total peak area (total ion counts $\times 10^4$) was reported as an indicator of volatiles generated from the meat samples.

Statistical Analysis. The experimental design was to determine the effects of additives and storage time on lipid oxidation, volatile compounds, and color of the cooked samples using four replications. Analysis of variance was conducted according to the procedure of the General Linear Model using SAS software (*17*). Student−Newman−Keul's multiple-range tests were used to compare the significant differences of the mean values of treatments ($P < 0.05$). Mean values and standard error of the means (SEM) are reported.

RESULTS AND DISCUSSION

TBARS Values in Cooked Turkey Meat. Rice hull extracts showed significant antioxidant activity in precooked turkey breast (**Table 1**). At the beginning of storage, both IRH and FRH had antioxidant effects with lower TBARS values compared with the control, but their TBARS were higher than that of the sesamol despite the different concentrations. With lengthening storage, the overall lipid oxidation was drastically accelerated due to the denatured structure of the muscles by cooking and aerobic storage conditions.

The effects of FIR radiation and added concentration were more distinctive in stored samples. When IRH and FHE were added at the concentration of 0.2% in meat, the TBARS values decreased to 75 and 31% of the control, respectively, at 3 days. FIR radiation of rice hull extract elevated the antioxidant activity by >2 times in precooked turkey meat at 3 days. On the other

Table 2. Color Values of Cooked Turkey Breast Meat with the Addition of Intact Rice Hull Extract (IRH) and Far-Infrared-Radiated Rice Hull Extract (FRH) during Refrigerated Storage[a]

storage time (days)	control	sesamol	IRH		FRH		SEM
		0.01%	0.1%	0.2%	0.1%	0.2%	
			L Value				
0	81.65ax	82.04ax	81.95ax	80.67bx	81.86ax	79.95c	0.24
1	82.47ax	81.60bxy	80.71bcy	80.24bcx	80.65bcy	80.58c	0.24
3	80.77ay	80.22ay	80.52aby	79.28cy	79.80bcz	79.82bc	0.24
SEM	0.30	0.22	0.20	0.26	0.24	0.25	
			a Value				
0	6.65cx	6.97bcx	7.31bx	8.18ax	6.96bcx	8.04ax	0.15
1	5.36dy	6.83bx	6.31cy	7.16ay	6.80bx	6.92by	0.08
3	4.08fz	6.07by	4.95ez	5.41dz	5.79cy	6.50az	0.07
SEM	0.09	0.10	0.07	0.14	0.86	0.13	
			b Value				
0	16.91dy	17.58dx	19.32c	21.43ax	20.19bx	21.91ax	0.24
1	17.39dx	17.70dx	19.18c	20.47ay	19.95bx	20.83ay	0.17
3	17.84ex	16.89fy	19.07d	19.86by	19.41cy	20.55ay	0.11
SEM	0.17	0.14	0.16	0.29	0.11	0.19	

[a] Different letters (a–d) within a row are significantly different ($P < 0.05$), $n = 4$. Different letters (x–z) within a column with the same color value are significantly different ($P < 0.05$).

hand, the antioxidant effects of IRH did not last as FRH at 3 days and the TBARS of 0.1% IRH were almost the same as the control.

The TBARS value of FRH was very dependent on the level of added amounts, and 0.1% FRH was almost half of the 0.2% FRH for turkey meat stored for 3 days. The TBARS of 0.2% FRH treatment was the same as that of the 0.01% sesamol. Foti et al. (*18*) reported that the antioxidant activity of vegetable extracts is related to their polyphenol content and structure. In our previous study (*13*), FIR radiation for 120 min onto rice hull increased total phenolic contents from 0.12 to 0.18 mM, DPPH radical scavenging activity from 47.74 to 82.98%, and inhibition of lipid peroxidation from 41.07 to 48.44%, respectively. The GC-MS analysis results indicated that FIR radiation on rice hull increased many phenolic compounds and generated 3-vinyl-1-oxybenzene, *p*-hydroxybenzaldehyde, vanillin, *p*-hydroxybenzoic acid, 4,7-dihydroxyvanillic acid, and isoferulic acid. From this point, FIR radiation could increase antioxidant properties of rice hull extract; thus, FRH is better able to keep TBARS values in cooked meat lower than IRH.

Color Changes by Rice Hull Extracts. Due to the characteristic brown color of rice hull extracts, both *a* and *b* values drastically increased in cooked turkey breast and the *L* value had a tendency to decrease (**Table 2**). This should be a detrimental effect of added rice hull extracts in the aspect of color of turkey breast because consumers usually expect the color of cooked poultry breast meat to be white. To increase the availability of rice hull extracts as a food additive, a way to decrease the color intensity is needed by concentrating more antioxidant compounds and/or excluding the pigments portion.

At 3 days of refrigerated storage, the *a* and *b* values were higher in FRH-added samples than in IRH-added ones because the browning intensity of FRH rose during the irradiation by FIR. The sesamol-added treatment did not show any great color change at the beginning of storage, but the *a* values were maintained during the aerobic storage, whereas those of the control declined by pigment oxidation. This pigment-stabilizing

Table 3. Volatiles Profile of Cooked Turkey Breast Meat with the the Addition of Intact Rice Hull Extract (IRH) and Far-Infrared-Radiated Rice Hull Extract (FRH) at 0 Days[a]

compound	total ion counts × 10^4						SEM
	control	sesamol 0.01%	IRH 0.1%	IRH 0.2%	FRH 0.1%	FRH 0.2%	
hydrocarbons							
1,1′-oxybisethane	0	1798	497	1859	2508	964	566
1-heptene	460a	0b	236b	873ab	1178ab	2038a	340
2-octene	1254a	0d	449b	208cd	301bc	0d	65
nonane	306a	81ab	86ab	210ab	250a	0b	57
octane	4743a	1677b	3069b	3304b	2179b	1443b	458
pentane	42401a	3885d	22698b	11556c	13435c	7397cd	1962
toluene	428	447	398	257	285	629	89
alcohols							
2-butanol	428	613	338	180	211	682	188
2-propanol	807	920	721	654	2504	2473	567
carbonyls							
2-propanone	15592b	19825ab	15819b	17757b	23738ab	29896a	2855
3-methylbutanal	446d	187d	1142bc	1907a	954c	1364b	108
acetaldehyde	9205c	10345c	11196c	8888c	15703b	19466a	932
heptanal	1170a	337b	816ab	629b	724ab	666b	124
hexanal	88609a	7799c	39969b	14997c	25322c	16149c	4863
isobutyl aldehyde	168b	0b	1152a	641a	281b	1076a	229
pentanal	16890a	1872d	9994b	4188c	6640c	4465cd	1102
propanal	13470a	0d	7096b	2578cd	3878c	2578cd	870
acids							
ethyl acetate	1041	1983	2323	3728	3126	7589	1964
ethyl butyrate	284	148	99	127	384	275	81
ethyl propionate	0	0	0	0	206	432	114
methyl acetate	0c	0c	1167bc	1965bc	2975b	9868a	526
others							
dimethyl disulfide	1146a	324b	1017a	575ab	580ab	941a	144
formic acid ethyl ester	0b	0b	236b	873ab	1178ab	2038a	340
2-pentylfuran	332bc	0c	286bc	260bc	562ab	779a	113
total	199186a	52249d	120683b	78349cd	107934bc	111180bc	9423

[a] Different letters (a–d) within a row are significantly different ($P < 0.05$), $n = 4$.

Table 4. Volatiles Profile of Cooked Turkey Breast Meat with the Addition of Intact Rice Hull Extract (IRH) and Far-Infrared-Radiated Rice Hull Extract (FRH) at 1 Day[a]

	total ion counts × 10^4						
		sesamol	IRH		FRH		
compound	control	0.01%	0.1%	0.2%	0.1%	0.2%	SEM
hydrocarbons							
1,1′-oxybisethane	0	0	0	0	969	553	455
1-heptene	661a	0c	303b	132bc	48c	0c	65
2-octene	2462a	158cd	1656b	942c	240cd	0d	232
nonane	0	0	0	742	300	45	99
octane	6246a	1753c	4240b	3843b	1609c	1209c	427
pentane	55161a	8988c	26703b	22680b	14923bc	7617c	3418
toluene	303	0	0	137	289	183	110
alcohols							
2-butanol	0	0	0	166	155	102	101
2-propanol	1588	2272	2144	1567	952	1469	358
carbonyls							
2,3-pentanedione	373	0	329	66	0	0	104
2-propanone	26426ab	28991ab	25592ab	36519a	21734ab	17551b	4085
3-methylbutanal	305de	0e	2144b	3114a	619cd	866c	146
acetaldehyde	16753	18234	21723	21120	16469	16993	1931
heptanal	4067a	1293b	3015ab	2643ab	908b	395b	631
hexanal	226269a	43804cd	132153b	81432c	73389c	23761d	13541
isobutyl aldehyde	233c	569c	2391b	4140a	428c	312c	388
pentanal	37244a	6852d	27325b	17333c	11597cd	4375d	2518
propanal	36564a	6394c	19585b	11276bc	10933bc	4096c	2416
acids							
ethyl butyrate	685a	202b	566a	543a	127b	279b	70
ethyl propionate	0b	0b	0b	0b	362a	322a	74
ethyl acetate	0	0	0	1007	4587	6160	1507
methyl acetate	0d	0d	2484c	4143ab	3036bc	5174a	411
others							
dimethyl disulfide	1388a	444c	884bc	1101ab	495c	425tagnc	115
formic acid ethyl ester	1381	1629	2031	1726	1438	1935	270
2-pentyl furan	1906a	0b	1855a	1973a	272b	155b	269
total	420020a	121588d	277130b	218353bc	165886cd	93985d	23525

[a] Different letters (a–d) within a row are significantly different ($P < 0.05$), $n = 4$.

effect of antioxidants has been reported (*19*, *20*). Thus, the high *a* values in IRH- and FRH-added treatments can also be explained by their antioxidant effect as well as the original browning color of extracts.

Inhibition of Off-Odor Volatiles. The production of warmed-over flavor is the most critical problem, and the role of antioxidants is important in storing precooked meat. Rice hull extracts reduced effectively the off-odor volatiles in cooked turkey breast but produced newly a few volatiles that are supposed to be responsible for the characteristic rice hull odor (**Table 3**). Considerable amounts of total volatiles were reduced by the addition of rice hull extracts (both IRH and FRH), but they were higher than that of the sesamol treatment. When volatile compounds related with lipid oxidation were compared, volatile aldehydes (propanal, pentanal, hexanal, and heptanal) and hydrocarbons (pentane, octane, and nonane) were significantly decreased by the addition of rice hull extracts. Hexanal was the most predominant volatile compound in the control meat, taking up almost 50% of the total volatiles, and it was reduced to only 17−18% of the control by the addition of rice hull extracts at a 0.2% level. In general cases of cooked meat, the amount of hexanal was the most correlated with the TBARS value (*21*, *22*), and it can be a good indicator.

Although there was little difference of total volatiles between IRH and FRH treatments, the volatiles compositions were somewhat different. At the level of 0.1% addition, a lower level of volatile aldehydes was found in FRH-treated turkey meat, showing that the antioxidant activity of FRH was greater than that of IRH. However, FRH treatments had some peculiar volatiles, such as formic acid ethyl ester and methyl acetate, which might be responsible for the characteristic rice hull odor. This result showed that FIR radiation increased not only the antioxidant properties of rice hull extract but also the special rice hull odor. The effects of rice hull extracts on volatile compounds were concentration-dependent, and the effect of reducing aldehydes was much more distinct when both IRH and FRH were added at the level of 0.2% than when they were added at 0.1%. When the antioxidant effect of sesamol was compared in terms of hexanal content, only 9% of hexanal was present in sesamol-treated turkey breast compared with the control. Thus, the hexanal-inhibiting activity of pure sesamol at the level of 0.01% was ∼2 times higher than that of IRH and FRH at 0.1−0.2% at the beginning storage. This can be attributed to the difference of their antioxidant phenolic contents.

The antioxidant properties of FRH were more distinct after 1 day of aerobic storage of precooked turkey breast (**Table 4**). Despite the short period of storage (only 1 day), a considerable degree of lipid oxidation proceeded and large amounts of volatile aldehydes increased at all treatments. About 2.5 times higher amount of hexanal was found in the control meat compared with the beginning of storage. Sesamol at 0.01% showed still strong antioxidant effects, and an even more interesting finding was that 0.2% FRH treatment had antioxidant activities as strong as those of sesamol. The amounts of all volatile aldehydes in 0.2% FRH were statistically almost the same or less than the sesamol treatment. Therefore, the effects of FIR and added concentration of rice hull extracts were very clear after 1 day of aerobic storage. However, rice hull extract-treated samples

Table 5. Volatiles Profile of Cooked Turkey Breast Meat with the the Addition of Intact Rice Hull Extract (IRH) and Far-Infrared-Radiated Rice Hull Extract (FRH) at 3 Days[a]

	total ion counts × 10^4						
		sesamol	IRH		FRH		
compound	control	0.01%	0.1%	0.2%	0.1%	0.2%	SEM
hydrocarbons							
1,1′-oxybisethane	0	440	0	0	0	0	179
1-heptene	553a	53b	515a	681a	320ab	0b	103
2-octene	2906a	504d	2774a	1247bc	1587b	846cd	161
octane	7351a	1645d	7808a	5391c	4024b	2167c	535
pentane	47921a	7748c	48704a	38614a	28826b	11611c	3011
toluene	503ab	447ab	418b	512ab	510ab	678a	54
alcohols							
2-butanol	0b	236b	93b	123b	243b	609a	102
2-propanol	1921	2497	1664	920	647	1121	432
carbonyls							
2,3-pentanedione	543	58	575	687	427	332	144
2-propanone	15892	20698	14725	17561	16044	22651	2458
3-methylbutanal	293d	285d	1406b	2101a	945c	1169bc	109
acetaldehyde	15120b	23237a	27027a	27267a	25118a	27944a	1747
heptanal	3586	1668	3364	3450	3193	1885	469
hexanal	247075a	72834e	223960ab	200817b	159509c	114317d	11568
isobutyl aldehyde	191c	989b	1500ab	2050a	1471ab	1449ab	162
pentanal	41385a	11991c	42193a	40052a	26717b	15207c	2186
propanal	45531a	11432c	37261ab	28819b	26478b	14601c	3090
acids							
ethyl acetate	0b	397b	819b	2269ab	2500ab	6345a	1149
ethyl butyrate	214	90	0	0	176	107	91
ethyl propionate	0b	0b	0b	0b	0b	523a	22
methyl acetate	0d	0d	1113c	1401c	2151b	5026a	212
others							
dimethyl disulfide	805b	503b	1452a	1336a	852b	676b	126
formic acid ethyl ester	1115b	1083b	1452b	1712b	1599b	2982a	227
2-pentylfuran	235	140	668	1200	1144	646	296
total	433147a	158961d	419502a	313160b	304485b	232898c	18405

[a] Different letters (a–d) within a row are significantly different ($P < 0.05$), $n = 4$.

had still characteristic volatiles, and ethyl propionate was newly detected at the FRH treatments.

At 3 days, antioxidant effects were mainly found in the 0.01% sesamol and 0.2% FRH treatments (**Table 5**). In the case of the control meat, the amount of volatiles did not much increase between 1 and 3 days of storage. On the other hand, treatments with rice hull extracts had largely increased amounts of lipid oxidation product volatiles. The antioxidant properties of rice hull extracts did not last as long as those of sesamol did. This result can be attributed to the relatively low concentration of the phenolic compounds in rice hull extracts compared to the pure sesamol. Nevertheless, FRH treatments showed still more antioxidant activities than the IRH, and added concentration was a critical factor in inhibiting off-odor volatiles. Various volatiles responsible for the characteristic rice hull odor (formic acid ethyl ester, methyl acetate, ethyl acetate, and ethyl propionate) were mainly found at 0.2% FRH treatment at 3 days.

Conclusions. Reduced lipid oxidation products in cooked turkey breast verified the antioxidant properties of rice hull extracts, and FIR radiation could increase significantly the antioxidant activities. Turkey meat treated by rice hull extracts, however, had some problems in the increased brown color and the generation of characteristic rice hull odor. To increase the availability of rice hull extracts as a food additive, more efficient ways to increase the antioxidant activities are needed by concentrating more antioxidant components and/or excluding the unnecessary portions. This study showed a good method to increase the antioxidant activities of rice hull extract using FIR radiation. Consequently, rice hull extract will be an excellent natural and cheap antioxidant source.

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