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ORIGINAL ARTICLE

Changes in some physicochemical properties and fatty acid composition of irradiated meatballs during storage

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Abstract Meatball samples were irradiated using a ^{60}Co irradiation source (with the dose of 1, 3, 5 and 7 kGy) and stored (1, 2 and 3 weeks at 4°C) to appraise some physicochemical properties and the fatty acid composition. The physicochemical results showed no significant differences in moisture, protein, fat and ash content of meatballs because of irradiation. However, total acidity, peroxide and thiobarbituric acid (TBA) values increased significantly as a result of irradiation doses and storage period. The fatty acid profile in meatball samples changed with irradiation. While saturated fatty acids (C16:0, C17:0, C18:0, and C20:0) increased with irradiation, monounsaturated (C14:1, C15:1, C18:1, and C20:1) and polyunsaturated (C18:2, C18:3, and C22:2) fatty acids decreased with irradiation. *Trans* fatty acids (C16:1*trans*, C18:1*trans*, C18:2*trans*, C18:3*trans*) increased with increasing irradiation doses. Meatball samples irradiated at 7 kGy had the highest total *trans* fatty acid content. This research shows that some physicochemical properties and fatty acid composition of meatballs can be changed by gamma irradiation.

Keywords Fatty acid composition · Gamma-irradiation · Lipid oxidation · Storage period

Introduction

Food irradiation is a processing technology aimed at the improvement of food safety, which has gained the interest of researchers in the fields of food science and consumer research worldwide during the past decades (Behrens et al. 2009). It is a physical process involving the treatment of food with ionizing radiation (Sajilata and Singhal 2006). The forms of ionizing energy which may be used in food processing and are approved by the Food and Drug Administration (FDA) include gamma rays (from ^{60}Co or ^{137}Cs), electron beams, and X-rays (Kader 1986, Yilmaz and Gecgel 2007). Among these three irradiation applications, gamma irradiation has been preferred (Gecgel et al. 2011) in previous researches in preservation of animal foods such as meat, poultry and fish (Mahrour et al. 2003; Chouliara et al. 2005; Erkan and Özden 2007).

Several studies have reported that gamma irradiation in low doses under 10 kGy kill most organisms (at least 99.9% of *Salmonella* in meats and even higher percentage of *Escherichia Coli* 0157:H7) without deterioration of food quality (Thayer et al. 1995; Olson 1998; Gumus et al. 2008). On the other hand, international health and safety authorities have endorsed the safety of irradiation for all foods up to a dose 10 kGy, however, recent evaluation by an international expert study group appointed by Food and Agriculture Organization (FAO), International Atomic Energy Agency (IAEA) and World Health Organization (WHO) showed that food treated according to good manufacturing practices (GMPs) at any dose above 10 kGy is also safe for consumption (Maghraby 2007).

Lipid oxidation is the primary reason for quality deterioration of meat during storage. The susceptibility of irradiated meat to oxidative rancidity is connected with the nature, rate and degree of saturation of fatty acids and the composition of phospholipids in cell membranes (Ahn et al. 2000). Irradiation of lipid induces the production of free radicals, which react with oxygen, leading to the formation of carbonyls, responsible for alterations in food nutritional

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and sensorial characteristics (Chen et al. 2007). These changes (off-flavours due to radiolytic breakdown of proteins and lipids), is related to the irradiation dose (Merritt et al. 1975; Patterson and Stevenson 1995; Murano et al. 1998; Kim et al. 2002).

In this study it was aimed to determine the effects of irradiation followed by storage on some physicochemical properties and fatty acid composition in meatballs. For this purpose, meatballs were processed with ^{60}Co gamma irradiation and the effects were observed in the following 3 weeks of storage period.

Materials and methods

Preparation of meatball samples

Meatball samples were purchased locally in Tekirdag, Turkey. On the day of arrival, meatballs were randomly divided into 5 equal sections and then were packed in polyethylene film packs. Each meatball group was composed of equal sample weights of approximately 750±5 g. All samples were maintained at 4°C and were immediately transported for irradiation treatments.

Irradiation

The meatball samples were irradiated at the GAMMAPAK Company, Cerkezkoy, Tekirdag, Turkey. The irradiation process of the samples was carried out in a ^{60}Co gamma irradiator (MDS, Nordion, Canada). The applied dose levels were 1, 3, 5 and 7 kGy for exposure time of 52, 156, 260 and 364 min, respectively. According to Turkish Food Codex, all meat and meat products are allowed up to the 7 kGy irradiation dose. The absorbed dose was monitored by a Harwell Amber Perspex dosimeter. During the treatment, the sample temperature was maintained initially at 2–4°C while the temperature of the facility was maintained at 18–20°C. After irradiation, all meatball samples (control, 1, 3, 5, 7 kGy) were stored at 4°C for 3 weeks.

Chemical analysis

From each group, 100±5 g meatballs were mixed for 10 s in a laboratory grinder, and the mixture was used in all the chemical analyses. Each sample was homogenized and analyzed in triplicate to determine moisture, fat (Soxlet extraction method with petroleum ether) and protein (as Kjeldahl nitrogen) using standard methods (AOAC 1990), while the ash content was determined according to AOAC (1995) official methods.

Fat samples extracted from the meatballs were subjected to analyses of total acidity and peroxide value according to Egan et al. (1981) and AOAC (1990) respectively. TBA (Thiobarbituric acid) value of the meatball samples was analyzed by a spectrophotometer method described by Tarladgis et al. (1960).

Fatty acid analysis

Fatty acids, containing *trans* and total fatty acids were measured in homogenized meatball using a modification of AOAC official method (AOAC 1990). The modifications composed of GC column and operation of the GC with temperature programming that improved separation of *trans* and *cis* isomers. As stated before, total lipid was extracted according to AOAC (1990). Fatty acid methyl esters (FAME) were prepared after alkaline hydrolysis, followed by methylation in methanol plus BF_3 (14% boron trifluoride). The final concentration of the FAME was approximately 7 mg/ml in heptane (AOAC 1990).

Analyses of the FAME by capillary GLC were carried out on a Hewlett-Packard 6890 chromatograph, equipped with a flame ionization detector (FID) on a split injector (Chrompack, Middleburg, The Netherlands). A fused-silica capillary column was used, CP^{TM}-Sil 88, 50 m x 0.25 mm internal dia, 0.2 μm film thickness; Chrompack. The column was operated isothermally at 177°C and the injector and detector were kept at 250°C with gas flows of 40 mL/min for hydrogen and 450 mL/min for air. The carrier gas was helium at a flow rate of 1 ml/min; split ratio 1:100. A single injection of 1μL was made per sample duplicate. Oven temperature programming consisted of an initial temperature of 120°C held for 1 min, an increase in temperature of 3°C/min to 230°C and a hold time of 20 min at 230°C. The peaks were identified by comparing the retention times and area percentages with those of authentic standards of FAMEs obtained from Nu-Chek-Prep Inc. and on the basis of literature data (Pawlowicz and Drozdowski 1998).

Statistical analysis

The data obtained from three replications were analyzed by ANOVA using the SPSS statistical package program, and differences among the means were compared using the Duncan's multiple range test (Soysal 1992).

Results and discussion

Physicochemical properties of meatballs

The physicochemical characterization of the meatballs including moisture, protein, fat and ash are showed in Table 1.

Table 1 Effect of gamma irradiation on moisture, protein, fat and ash of meatball (%)

Treatment	Moisture	Protein	Fat	Ash
Control	58.31±2.57	19.65±2.09	18.24±0.79	2.71±0.96
1 kGy	58.99±2.74	19.82±1.57	18.57±1.72	2.64±0.86
3 kGy	58.13±1.96	18.77±2.07	18.32±1.17	2.82±1.32
5 kGy	59.39±1.75	19.16±1.91	18.27±0.52	2.77±0.27
7 kGy	58.15±1.90	19.29±2.14	18.02±1.57	2.85±0.20
Statistical significances	ns	ns	ns	ns

Each value is an average of three determinations

ns Not significant

The mean meatball characteristics were: moisture 58.31±2.57%, protein 19.65±2.09%, fat 18.24±0.79% and ash 2.71±0.96%. No significant ($P>0.05$) changes in the moisture, protein, fat and ash values of the meatballs were observed due to the irradiation process. Generally, the protein and lipid components are known to decline when exposed to higher irradiation doses. Reports in the published literature indicate that no significant differences in chemical compositions (for example; moisture content, crude protein, crude fat and ash) of various meat and meat products such as buffalo meat, lamb meat, camel meat, rabbit meat and raw meatballs were observed when processed with different doses of gamma irradiation (Mahmoud 1988; Badr 2004; Rady et al. 2005; Yildirim et al. 2005; Kanatt et al. 2006; Al-Bachir and Zeinou 2009). Therefore, the results in the current study are in agreement with the published literature.

Total acidity and oxidative stability of meatball

The total acidity, peroxide and TBA values of the meatballs are shown in Table 2.

According to these results, immediately after irradiation and after 1, 2 and 3 weeks of storage, all used radiation doses (control, 1, 3, 5 and 7 kGy) had statistically significant ($P<0.01$ and $P<0.05$) effects on the total acidity, peroxide and TBA values of the meatballs.

The total acidity contents of meatballs displayed a dose dependent increase upon irradiation. The total acidity was 0.34% before irradiation and increased to 0.56% after the 7 kGy irradiation. Similarly, during the storage period, total acidity values of control and irradiated meatball samples increased (0.60%) (Fig. 1).

A possible reason for the increase in acidity as a result of irradiation and storage might be related to the participation of free fatty acids in the process of lipid peroxidation. Previous studies have shown that significant differences in total acidity were observed as a result of both irradiation and storage (Sorman et al. 1987; Kanatt et al. 2006; Sweetie et al. 2006) However, Bakalivanova et al. (2009); Al-Bachir and Zeinou (2009) founds no significant change in acidity following both gamma irradiation and during storage in salami and camel meat respectively.

Irradiated meatballs showed significantly higher peroxide value (0.93 meqO_2/kg) than control sample (0.70 meqO_2/kg) and the amount of peroxide value was positively correlated with the applied dose and storage period (Fig. 2).

Table 2 Effect of gamma irradiation on some physicochemical properties of meatball during storage

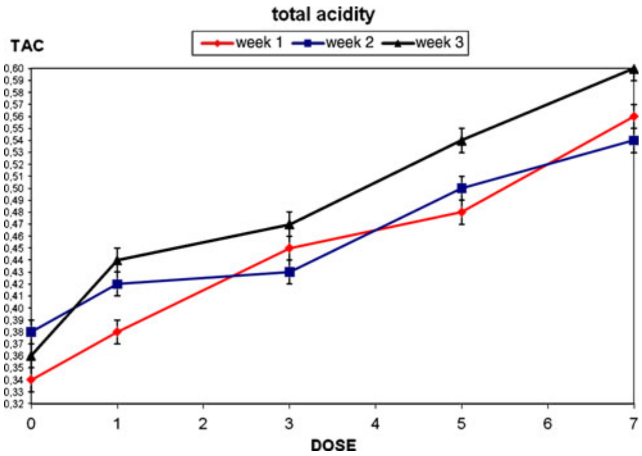
	Total acidity (% lactic acid)			Peroxide value (meqO_2/kg)			TBA (mg malonaldehyde/kg meatball)		
Treatment	1 week	2 week	3 week	1 week	2 week	3 week	1 week	2 week	3 week
Control	$0.34^{e,y}$	$0.38^{d,y}$	$0.36^{e,x}$	$0.70^{d,z}$	$1.08^{d,y}$	$1.20^{d,x}$	$0.45^{e,z}$	$0.98^{e,y}$	$1.45^{e,x}$
1 kGy	$0.38^{d,y}$	$0.42^{c,y}$	$0.44^{d,x}$	$0.72^{d,z}$	$1.08^{d,y}$	$1.18^{d,x}$	$0.47^{d,z}$	1.06^{dy}	$1.60^{d,x}$
3 kGy	$0.45^{c,y}$	$0.43^{c,y}$	$0.47^{c,x}$	$0.80^{c,z}$	$1.12^{c,y}$	$1.24^{c,x}$	$0.51^{c,z}$	$1{,}11^{c,y}$	$1.84^{c,x}$
5 kGy	$0.48^{b,y}$	$0.50^{b,y}$	$0.54^{b,x}$	$0.88^{b,z}$	$1.18^{b,y}$	$1.36^{b,x}$	$0.57^{b,z}$	$1.15^{b,y}$	$1.98^{b,x}$
7 kGy	$0.56^{a,y}$	$0.54^{a,y}$	$0.60^{a,x}$	$0.93^{a,z}$	$1.24^{a,y}$	$1.48^{a,x}$	$0.65^{a,z}$	$1.18^{a,y}$	$2.05^{a,x}$
I	**			**			**		
S	**			**			**		
IxS	*			*			*		

Each value is an average of three determinations

^{a,b,c,d,e} Irradiation dose (I)

^{x,y,z} Storage week (S)

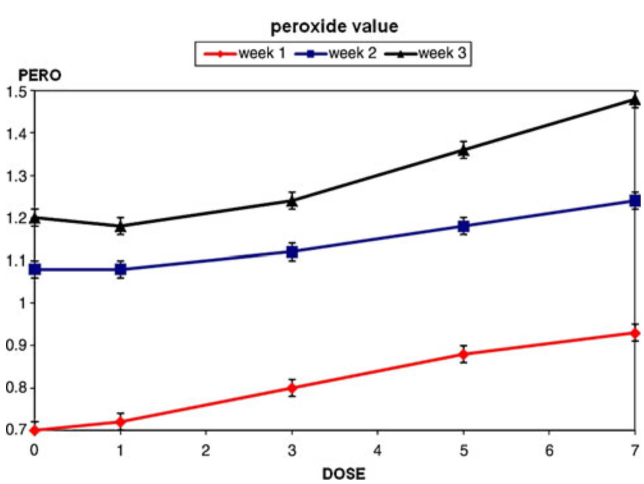
Any means in the same column followed by different letters (a, b, c, d, e) and (x, y, z) are significantly (*$P<0.05$ and **$P<0.01$) different by Duncan's multiple range test.



TAC: Total acidity (% lactic acid); DOSE: Irradiation dose (kGy)

Fig. 1 Effect of gamma irradiation on total acidity of meatball during storage (*n*=3)

Lipid oxidation is a complex autocatalytic procedure operating in two phases. Throughout the first phase, the initial products of oxidation are obtained such as peroxides and conjugated dienes. During the second phase, lipid oxidation is attributed to the combination of free radicals with O_2 to form hydroperoxides. Due to the high reactivity of hydroperoxides, they are changed into downstream products of oxidation, culminating in the formation of triens, aldehydes, ketones, volatile fatty-acids etc. (Javanmard et al. 2006; Bakalivanova et al. 2009). The results in this study are in agreement with the findings of other studies that have reported an increase in oxidation activity and lipid peroxidation as a result of both radiation treatment and storage time on meat and meat products (Luchsinger et al. 1996; Jo and Ahn 2000; Al-Bachir and Zeinou 2009; Bakalivanova et al. 2009). In addition, some researchers found that with increasing radiation doses, the peroxide numbers of lipids in beef increased (Sorman et al. 1987; Lambert et al. 1992; Lefebvre et al. 1994; Quattara et al. 2002). But, the data of Javanmard et al. (2006) reveal that immediately after irradiation there are no significant ($P>0.05$) differences in the peroxide value between irradiated and control chicken meat groups.



PERO: Peroxide value (meqO_2/kg); DOSE: Irradiation dose (kGy)

Fig. 2 Effect of gamma irradiation on peroxide value of meatball during storage (*n*=3)

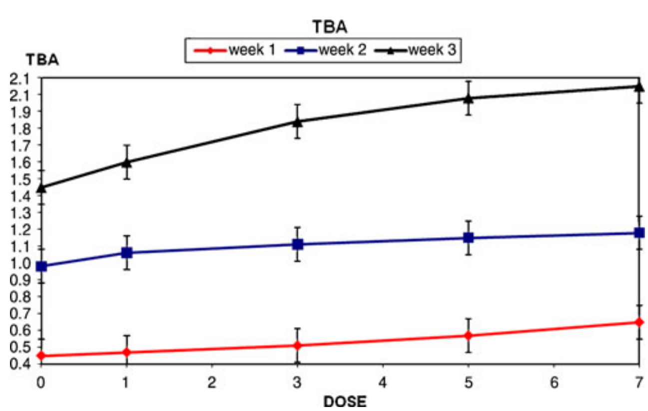
TBA values revealed that both irradiation and storage bring about an increase of lipid oxidation in meatball samples (Fig. 3).

An increasing TBA concentration was observed during the time course of the experiment with the highest values observed in the 3rd week, followed by the 2nd week and the 1st week. The TBA value of the irradiated meatballs after 3 weeks of storage were 1.45, 1.60, 1.84, 1.98, and 2.05 mg MDA/kg at Control, 1, 3, 5, and 7 kGy irradiation. Similarly, some researchers showed an increase in TBA values during both irradiation and storage in various meat and meat products (Luchsinger et al. 1996; Galvin et al. 1998; Formanek et al. 2003; Badr 2004; Kanatt et al. 2006; Chen et al. 2007). In contrast, Du et al. (2001) found low TBA values of chicken breast irradiated with gamma rays and no significant lipid oxidation occurring during the storage period. Similarly, Chun et al. (2010) reported no significant differences in TBARS values for both increasing irradiation doses and increasing storage period in chicken breasts.

Fatty acid composition of meatballs

The changes in fatty acid composition expressed as a percentage of the total lipid content of meatball samples as a function of storage period (1, 2, 3 weeks) and irradiation doses (Control, 1, 3, 5, 7 kGy) are shown in Tables 3 and 4.

Fatty acids vary from C8:0 to C24:0 in chain length. While C16:0 and C18:0 are the major saturated fatty acids, C18:1 and C18:2 are the major unsaturated fatty acids. Irradiation doses used in this study significantly ($P<0.01$ and $P<0.05$) affected the percentages of many fatty acids



TBA: Thiobarbituric acid (mg malonaldehyde/kg meatball); DOSE: Irradiation dose (kGy)

Fig. 3 Effect of gamma irradiation on TBA value of meatball during storage (*n*=3)

Table 3 Changes in saturated fatty acid composition of meatball with different irradiation dose and storage period

Fatty Acid (%)	1 week					2 week					3 week					Effect Significant		
	Control	1 kGy	3 kGy	5 kGy	7 kGy	Control	1 kGy	3 kGy	5 kGy	7 kGy	Control	1 kGy	3 kGy	5 kGy	7 kGy	I	S	I X S
C8:0	0.05^{c}	0.05^{bc}	0.05^{abc}	0.06^{ab}	0.06^{a}	0.05^{c}	0.05^{bc}	0.06^{abc}	0.07^{ab}	0.09^{a}	0.06^{c}	0.07^{bc}	0.07^{abc}	0.08^{ab}	0.08^{a}	*	ns	ns
C10:0	0.06^{b}	0.06^{b}	0.06^{ab}	0.06^{ab}	0.06^{a}	0.06^{b}	0.07^{b}	0.07^{ab}	0.06^{ab}	0.07^{a}	0.07^{b}	0.07^{b}	0.08^{ab}	0.08^{ab}	0.08^{a}	*	ns	ns
C12:0	0.08	0.08	0.08	0.09	0.09	0.08	0.08	0.09	0.09	0.09	0.08	0.09	0.08	0.09	0.09	ns	ns	ns
C14:0	2.23^{c}	2.25^{ab}	2.25^{bc}	2.27^{bc}	2.27^{a}	2.25^{c}	2.23^{ab}	2.25^{bc}	2.27^{bc}	2.27^{a}	2.23^{c}	2.25^{ab}	2.27^{bc}	2.27^{bc}	2.27^{a}	*	ns	**
C15:0	0.57	0.57	0.58	0.57	0.58	0.58	0.58	0.57	0.57	0.58	0.57	0.58	0.57	0.58	0.58	ns	ns	ns
C16:0	$26.47^{e,x}$	$26.20^{b,x}$	$26.65^{d,x}$	$27.73^{c,x}$	$28.20^{a,x}$	$26.37^{e,y}$	$26.58^{b,y}$	$27.02^{d,y}$	$27.80^{c,y}$	$28.45^{a,y}$	$26.35^{e,z}$	$26.70^{b,z}$	$27.27^{d,z}$	$27.92^{c,z}$	$28.05^{a,z}$	**	*	**
C17:0	1.45^{c}	1.46^{c}	1.45^{bc}	1.46^{b}	1.47^{a}	1.45^{c}	1.45^{c}	1.47^{bc}	1.49^{b}	1.51^{a}	1.47^{c}	1.47^{c}	1.49^{bc}	1.51^{b}	1.51^{a}	*	ns	*
C18:0	26.08^{d}	26.31^{b}	26.40^{c}	26.76^{c}	27.05^{a}	26.15^{d}	26.42^{b}	26.55^{c}	26.89^{c}	27.15^{a}	26.13^{d}	26.45^{b}	26.57^{c}	26.88^{c}	27.07^{a}	**	ns	**
C20:0	0.26^{b}	0.27^{ab}	0.26^{ab}	0.27^{a}	0.27^{a}	0.26^{b}	0.27^{ab}	0.27^{ab}	0.27^{a}	0.29^{a}	0.27^{b}	0.29^{ab}	0.29^{ab}	0.27^{a}	0.29^{a}	*	ns	ns
C22:0	0.11	0.12	0.11	0.12	0.13	0.12	0.12	0.13	0.13	0.13	0.12	0.12	0.13	0.13	0.13	ns	ns	ns
C24:0	0.05	0.07	0.05	0.07	0.07	0.06	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.07	0.07	ns	ns	ns
TSFA	$57.41^{e,x}$	$57.44^{b,x}$	$57.94^{d,x}$	$59.44^{c,x}$	$60.25^{a,x}$	$57.43^{e,y}$	$57.92^{b,y}$	$58.55^{d,y}$	$59.71^{c,y}$	$60.69^{a,y}$	$57.52^{e,z}$	$58.15^{b,z}$	$58.88^{d,z}$	$59.88^{c,z}$	$60.22^{a,z}$	**	**	**

Each value is an average of three determinations

^{a,b,c,d,e} Irradiation dose (I)

^{x,y,z} Storage week (S)

TSFA Total saturated fatty acids

ns Not significant

Any means in the same column followed by different letters (a, b, c, d, e) an (x, y, z) are significantly (*P<0.05 and **P<0.01) different by Duncan's multiple range test.

Table 4 Changes in *trans* and unsaturated fatty acid composition of meatball with different irradiation dose and storage period

Fatty Acid (%)	1 week					2 week					3 week					Effect Significant		
	Control	1 kGy	3 kGy	5 kGy	7 kGy	Control	1 kGy	3 kGy	5 kGy	7 kGy	Control	1 kGy	3 kGy	5 kGy	7 kGy	I	S	I X S
C14:1	1.09^{a}	1.09^{ab}	1.11^{ab}	1.09^{b}	1.07^{ab}	1.09^{a}	1.07^{ab}	1.09^{ab}	1.07^{b}	1.05^{ab}	1.09^{a}	1.07^{ab}	1.09^{ab}	1.07^{b}	1.05^{ab}	*	ns	*
C15:1	0.39	0.39	0.37	0.39	0.39	0.39	0.37	0.37	0.39	0.39	0.39	0.37	0.37	0.39	0.37	ns	ns	ns
C16:1	1.83	1.84	1.84	1.85	1.85	1.85	1.84	1.84	1.83	1.83	1.85	1.84	1.85	1.84	1.84	ns	ns	ns
C16:1 *trans*	0.05	0.06	0.06	0.06	0.07	0.06	0.06	0.07	0.07	0.07	0.06	0.07	0.07	0.07	0.07	ns	ns	ns
C17:1	0.48	0.48	0.47	0.47	0.47	0.48	0.48	0.47	0.47	0.47	0.48	0.47	0.48	0.47	0.47	ns	ns	ns
C18:1	33.19^{a,z}	33.18^{d,z}	32.90^{b,z}	31.93^{c,z}	31.26^{e,z}	33.17^{a,y}	32.83^{d,y}	32.45^{b,y}	31.87^{c,y}	31.07^{e,y}	33.10^{a,x}	32.75^{d,x}	32.13^{b,x}	31.70^{c,x}	31.58^{e,x}	**	**	**
C18:1 *trans*	0.08^{bc}	0.09^{bc}	0.10^{c}	0.11^{b}	0.11^{a}	0.08bc	0.08^{bc}	0.09^{c}	0.11^{b}	0.13^{a}	0.08^{bc}	0.11^{bc}	0.13^{c}	0.13^{b}	0.13^{a}	*	ns	*
C20:1	0.21^{a}	0.20^{ab}	0.19^{ab}	0.20^{ab}	0.17^{b}	0.20^{a}	0.20 ^{ab}	0.19 ^{ab}	0.17 ^{ab}	0.17^{b}	0.21^{a}	0.17 ^{ab}	0.19 ^{ab}	0.17 ^{ab}	0.17^{b}	*	ns	*
TMU	37.32^{a,z}	37.33^{d,z}	37.04^{b,z}	36.11^{c,z}	35.39^{e,z}	37.32^{a,y}	36.93^{d,y}	36.57^{b,y}	35.98^{c,y}	35.18^{e,y}	37.26^{a,x}	36.85^{d,x}	36.31^{b,x}	35.84^{c,x}	35.68^{e,x}	**	**	**
C18:2	4.21^{a,y}	4.18^{c,y}	3.97^{b,y}	3.43^{b,y}	3.33^{d,y}	4.20^{a,x}	4.07^{c,x}	3.85^{b,x}	3.28^{b,x}	3.10^{d,x}	4.15^{a,z}	3.95^{c,z}	3.80^{b,z}	3.27^{b,z}	3.10^{d,z}	**	**	**
C18:2 *trans*	0.15^{c}	0.16^{bc}	0.17^{ab}	0.17^{abc}	0.18^{a}	0.16^{c}	0.18^{bc}	0.18^{ab}	0.18^{abc}	0.19^{a}	0.16^{c}	0.18^{bc}	0.19^{ab}	0.19^{abc}	0.19^{a}	**	ns	ns
C18:3	0.60^{a}	0.59^{a}	0.59^{a}	0.58^{a}	0.56^{b}	0.59^{a}	0.59^{a}	0.58^{a}	0.56^{a}	0.56^{b}	0.59^{a}	0.58^{a}	0.56^{a}	0.54^{a}	0.54^{b}	**	ns	ns
C18:3 *trans*	0.14^{b}	0.14^{ab}	0.16^{ab}	0.16^{a}	0.18^{a}	0.14^{b}	0.16^{ab}	0.16^{ab}	0.18^{a}	0.18^{a}	0.16^{b}	0.18^{ab}	0.16^{ab}	0.18^{a}	0.18^{a}	*	ns	ns
C22:2	0.17^{a}	0.16^{b}	0.13^{b}	0.11^{b}	0.11^{c}	0.16^{a}	0.16^{b}	0.11^{b}	0.11^{b}	0.10^{c}	0.16^{a}	0.11^{b}	0.10^{b}	0.10^{b}	0.09^{c}	**	ns	**
TPU	5.27^{a,x}	5.23^{c,x}	5.02^{b,x}	4.45^{b,x}	4.36^{d,x}	5.25^{a,x}	5.15^{c,x}	4.88^{b,x}	4.31^{b,x}	4.13^{d,x}	5.22^{a,y}	5.00^{c,y}	4.81^{b,y}	4.28^{b,y}	4.10^{d,y}	**	*	**
TU	42.59^{a,z}	42.56^{d,z}	42.66^{b,z}	40.56^{c,z}	39.75^{e,z}	42.57^{a,y}	42.08^{d,y}	41.45^{b,y}	40.29^{c,y}	39.31^{e,y}	42.48^{a,x}	41.85^{d,x}	41.12^{b,x}	40.12^{c,x}	39.78^{e,x}	**	**	**
T*trans*	0.42^{d}	0.45^{c}	0.49^{bc}	0.50^{b}	0.54^{a}	0.44^{d}	0.48^{c}	0.50^{bc}	0.54^{b}	0.57^{a}	0.46^{d}	0.54^{c}	0.55^{bc}	0.57^{b}	0.57^{a}	**	ns	**

Each value is an average of three determinations

[a,b,c,d,e] Irradiation dose (I)

[x,y,z] Storage week (S)

TMU Total monounsaturated fatty acids

TPU Total polyunsaturated fatty acids; TU Total unsaturated fatty acids; T*trans* Total *trans* fatty acids; ns Not significant

Any means in the same column followed by different letters (a, b, c, d, e) an (x, y, z) are significantly (*$P<0.05$ and **$P<0.01$) different by Duncan's multiple range test.

such as C8:0, C10:0, C14:0, C16:0, C17:0, C18:0, C20:0, C14:1, C18:1, C18:1*trans*, C20:1, C18:2, C18:2*trans*, C18:3, C18:3*trans*, C22:2, total saturated fatty acids (TSFA), total monounsaturated fatty acids (TMU), total polyunsaturated fatty acids (TPU), total unsaturated fatty acids (TU), and total *trans* fatty acids (T*trans)*. However, the storage period significantly ($P<0.01$ and $P<0.05$) affected the percentages of only a few fatty acids such as C16:0, C18:1, C18:2, TS, TMU, TPU, and TU (Tables 3 and 4). In addition, the percentages of some of the fatty acids such as C14:0, C16:0, C17:0, C18:0, C14:1, C18:1, C18:1*trans*, C20:1, C18:2, C22:2, TS, TMU, TPU, TU, and T*trans* were affected significantly ($P<0.01$ and $P<0.05$) as a function of both irradiation dosage and storage time (Tables 3 and 4).

Of the major saturated fatty acids, the percentages of C16:0 and C18:0 increased ($P<0.01$) significantly with irradiation doses, however, it was only C16:0 that significantly ($P<0.05$) changed as a function of storage period. Generally, at the 1st, 2nd, and 3rd weeks after the irradiation of meatball samples, the proportion of TS increased ($P<0.01$). For example, at the 1st week, the percentage of TS for the control and 7 kGy dose samples was 57.41% and 60.25%, respectively. Similarly, Chen et al. (2007) showed that the percentage of C16:0 and total SFA increased ($P<0.05$) significantly after beef irradiation.

A comparison of the major unsaturated fatty acids as a function of both irradiation dosage and storage period showed that the C18:1 and C18:2 fatty acids decreased significantly upon radiation processing. The percentages of C18:1 and C18:2 in the total fat were higher in the control than the irradiated samples on the 1st, 2nd and 3rd weeks. Regarding the other minor unsaturated fatty acids, the percentages of C14:1, C20:1, C18:3 and C22:2 changed with irradiation doses ($P<0.01$and $P<0.05$), but did not change with storage period. The percentages of C15:1, C16:1 and C17:1 did not significantly ($P>0.05$) change with irradiation or storage period (Table 4). Percentages of TMU, TPU and TU significantly changed ($P<0.01$) with irradiation treatments and during the storage period. At the 1st, 2nd, and 3rd weeks after irradiation of the meatball samples, the proportions of TMU and TPU decreased ($P<0.01$). In the present study, the TU content of the 7 kGy irradiated meatball samples were lower than for control and all other irradiation doses on 1st, 2nd and 3rd weeks. The irradiation of food produces free radicals which, in turn, destroy antioxidants and may decrease the PUFA content of the food over time (Formanek et al. 2003). During the course of our experiments, all irradiated samples had significantly ($P<0.05$) less TPU in the 3rd week than in the 1st week. Similarly, Brito et al. (2002) reported that there was a decrease in C18:2 fatty acids due to the oxidation of lipids with different irradiation doses (4 and 8 kGy) in ground beef. Formanek et al. (2003) reported that irradiated minced beef samples had significantly less PUFA on day 8 than on day 0. Kanatt et al. (2006) reported that the contents of C18:1, C18:2, C20:4 unsaturated fatty acids and the ratio of PUFA/SFA decreased significantly with different irradiation treatments (Control, 2.5 and 5 kGy) in lamb meat. However, Al-Bachir and Zeinou (2009) reported that there were no significant differences of saturated (C14:0, C16:0, C17:0 and C18:0) and unsaturated (C18:1 and C18:2) fatty acids between lipids extracted from irradiated and non-irradiated camel meat.

The *trans* fatty acids (TFA) composition after different storage periods for each irradiation dose is shown in Table 4. The percentages of C18:1*trans*, C18:2*trans*, C18:3*trans* and T*trans* fatty acids increased only with irradiation doses ($P<0.01$ and $P<0.05$), however, the percentage of C16:1*trans* fatty acid did not change as a result of irradiation or storage period. During the storage period, no increase in the TFA values was observed ($P>0.05$). The T*trans* fatty acids were lower in the control (0.42%) and 1 kGy (0.45%) irradiated meatball samples than the other irradiated meatball samples, with the highest amount in the 7 kGy irradiated sample (0.57%). The present experimental results demonstrate that irradiation causes an increase in the TFA, which may be due to a change in the molecular structure of fatty acids, breaking down of double bonds, forming free radicals and TFA (Brito et al. 2002). Trindade et al. (2010) reported that temperature plays a significant role, since the irradiation of meat products under chilled conditions results in more efficient irradiation of water molecules, as well as the production of more free radicals. The mobility of the free radicals and the fatty acid chains supply desirable conditions for the formation of TFA. Brito et al. (2002) studied different doses of irradiation (from 0 to 8 kGy) and reported that storage time did not increase TFA values; however, a dose of 1 kGy of irradiation produced two times more TFA than the initial values. Yilmaz and Gecgel (2007) irradiated ground beef with 1, 3, 5 and 7 kGy and showed the increase in TFA values with the irradiation dose. The data presented in the current study are thus in agreement with the published data. On the other hand, other studies have indicated no major changes in TFA composition in various irradiated meat samples at doses up to 10 kGy (Chen et al. 2007). Considering that the World Health Organization recommends that diets should provide a very low intake of TFA, any process that increases TFA content in food must be avoided (Trindade et al. 2010).

Conclusions

The results obtained in this study suggest that the physico-chemical properties and fatty acid composition of meatball samples changed with irradiation dosage and storage time.

Oxidative rancidity, especially peroxide and TBA values increased as the irradiation dose and storage period increased. The percentages of TFA have showed an increase with irradiation dose from 1 to 7 kGy in the 3 weeks of storage.

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