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The effect of gamma irradiation and vacuum packaging upon selected quality traits of refrigerated ostrich meat. Part 2. Colour, texture and lipid oxidation properties

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Ostrich meat samples were irradiated with 0.0, 1.0 and 3.0 kGy of gamma rays, packaged under vacuum and held refrigerated for 21 days. Lipid oxidation, shear force, colour and sensory quality were determined on day 0, 7, 14 and 21. Irradiated meat showed higher values (P<0.05) for a* (redness) than the non-irradiated samples as from day 21 under refrigeration. Irradiation increased (P<0.05) the intensity of lipid oxidation, odour, loss of colour and sensory quality in aerobic packages, which was not significantly different in vacuum-packaged samples. Considering the sensory analyses, colour and TBA analyses as a whole, vacuum-packaged samples irradiated at 3.0 kGy were acceptable under refrigerated storage for 21 days, compared to 7 and 14 days for non-irradiated air-packaged, vacuum-packaged samples, respectively.

KEYWORDS: gamma irradiation / lipid oxidation / ostrich meat / refrigeration / vacuum packaging

Irradiation is an effective procedure to improve meat safety and extend its shelf-life [Dogbevi *et al*., 1999]. New trends in food irradiation technology exist to develop combined treatments in order to reduce the irradiation doses required to eliminate pathogenic bacteria and/or reduce overall microbial load [Lacroix and Ouattara 2000]. However, irradiation of meat accelerates lipid oxidation and produces off-odours under aerobic conditions. Food irradiation is generally defined as the process in which foods are exposed to certain forms of ionizing energy from radioactive sources, mainly gamma rays. Irradiation of food up to an overall dose of 10 kGy is

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accepted in several countries as commercial food processing [Lacroix and Quattara 2000]. In recent years, increasing attention has been paid to ostrich breeding worldwide on all continents [Cooper and Horbańczuk 2004]. The higher demand for ostrich meat is associated, among others, with growing interest for searching on the meat market alternative type of red meat from not traditional animal species after second outbreak of BSE in European cattle [Cooper *et al*. 2007, Horbanczuk *et al.* 2007, 2008, Poławska *et al*. 2013a]. Several studies have been published on physical properties, chemical composition, sensory properties and nutritive value of ostrich meat [Jouki 2012, Poławska *et al*. 2011, 2012, 2013b, Girolami *et al*. 2003, Paleari *et al*. 1998, Sales 1996, Sales and Hayes 1996, Sales and Horbanczuk 1998, Horbańczuk *et al*. 1998] whereas no data have been published on the preservation and extension of the shelf-life of fresh ostrich meat by gamma irradiation. Several reports claimed that gamma irradiation combined with frozen storage improves the fish [Jouki and Khazaei 2009] and turkey meat [Jouki 2013] shelf life. The objective of this study was to investigate the effects of gamma irradiation combined with vacuum packaging system on lipid oxidation, colour changes, and sensory qualities of ostrich meat during refrigerated storage.

Materials and methods

Sample preparation, packaging and irradiation

Sample preparation, packaging and irradiation were presented in Part 1 of this study.

Texture assessment

Tensile strength was calculated from the maximum load during a tension test carried to rupture the specimen [Honikel 1998] by using an Instron Model Testometric (M350-10CT, ROCHDALE, England). Muscles were cut perpendicular to the muscle fibre orientation to produce 2 cm thick slices. Slices were hooked to the testing machine and the resistance to tearing (tensile stress) was determined at tensile velocity of 60 mm/min.

Colour assessment

The colour of the raw muscle slices was recorded according to Honikel [1998] with the use of a Color-guide 45°/0° colorimeter (Cat no: 6805; BYK-Gardner, USA). Muscle slices (1.5-2.0 cm thick) were allowed to ‘‘bloom’’ for 30 min at room temperature (20°C) prior to colour measurements which were recorded in triplicate for each sample at randomly selected positions and expressed by the coordinates L*, a* and b* of the CIE Lab colorimetric space [MINOLTA 1998]. Total colour difference (ΔE) was calculated using the following equation:

$$\Delta E = \left[\left(\left[L^* - L^*_{day1} \right) \right]^2 \left(\left[a^* - a^*_{day1} \right) \right]^2 \left(b^* - b^*_{day1} \right)^2 \right]^{1/2}$$

where:

L* – lightness;

a* – redness;

b* – yellowness.

Five readings per package were recorded for a total of 10 readings per packaging treatment.

Lipid oxidation

Lipid oxidation was evaluated by the determination of thiobarbituric acid reactive substances (TBARS) using the extraction method described by Witte *et al.* [1970]. Twenty grams of the minced meat were blended with 50 ml of cold solution containing 20% trichloroacetic acid in 2 M phosphoric acid for 2 min. The resulting slurry was then transferred into a 100 ml volumetric flask and diluted to 100 ml with redistilled water, homogenized by shaking and filtered through Whatman no. 1 filter paper. Five ml of the filtrate was then pipetted into a test tube and 5 mL of fresh chilled 2-thiobarbituric acid (0.005 M in redistilled water) was added. The test tube was shaken well and placed in the dark at room temperature (25°C) for15 h to develop the colour reaction. The resulting colour was measured in a spectrophotometer at 530 nm to calculate the TBARS value. The results were expressed as mg malonaldehyde/ kg of meat (mg MDA/kg meat).

Sensory evaluation

In this study, a 5-member trained sensory attribute panel evaluated raw samples of ostrich meat. The panelists were staff members in the Department of Meat Science, University of Tehran. Panelists were given an orientation for 30 min about appearance (colour), odour, texture and overall quality of fresh ostrich meat. Samples were introduced to panelists in covered petri-dishes coded with 3-digit random numbers. Acceptability of raw meat was evaluated using a 9-point hedonic scale, where 9 – like extremely, 8 – like very much, 7 – like moderately, 6 – like slightly, 5 – neither like nor dislike, 4 – dislike slightly, 3 – dislike moderately, 2 – dislike very much, and 1 – dislike extremely [Peryam and Pilgrim 1957]. Scores from 6 to 9 were considered acceptable [Paul *et al*. 1990]. Evaluation was performed under cool white fluorescent light in the sensory laboratory. The same meat samples were evaluated over storage times. The shelf-life limit was defined as the point when 50% the panelists rejected the sample.

Statistical

Data from chemical and sensory analyses were subjected to an evaluation of simple and interaction effect of the irradiation doses (0, 1.0 and 3.0 kGy), and storage time (1, 7, 14, and 21 days) by simple and interaction effects using two-way ANOVA. Comparison of means was based on Tukey's Post Hoc multiple test. Data were analysed using the SAS [1988] statistical package.

Results and discussion

Textural analysis

Shear force (SF) values at different *post-mortem* times are presented in Figure 1. Analysis of variance showed that ageing of meat affected SF in all treatments, as has been found in other studies where *post-mortem* ageing increased meat tenderness [Pinkas *et al.* 1978, Jeremiah *et al.* 1997, Jouki and Khazaei 2011, Jouki *et al*. 2012]. Of the total reduction in shear force that occurred after 21 days of ageing 50% occurred during the first 7 days of ageing. Other authors also reported that the greatest improvement in shear force occurred during the 1st week [Campo *et al*. 2000, Monson et al. 2005. Jouki and Khazaei 2012a]. Significant differences occured among the different package systems in the shear force values of meat. Warner-Bratzler tests suggest air-packaged samples stored at 4°C tend to have lower shear forces than those stored under vacuum (Fig. 1). Air packaging for ostrich meat were found to negatively influence shear force values as well as the sensory attributes (tenderness and meat aroma), compared to meat samples packaged in vacuum. Shear force values of irradiated ostrich meat were significantly ($P<0.01$) higher than non irradiated. Mean value of shear force of irradiated ostrich muscle during 21 days refrigerated storage was significantly ($P<0.01$) higher than those of the non irradiated samples. The results of this study clearly indicate that irradiation affects the texture quality of ostrich meat. These findings are directly contradictory to those reported by Abu-Tarboush *et al*. [1997], Hashim *et al*. [1995] and Heath *et al*. [1990], who found no significant change in the sensory characteristics of chicken meat after irradiation. However, these contradictory findings may reveal the complexity in understanding of texture characteristics of irradiated poultry meat.

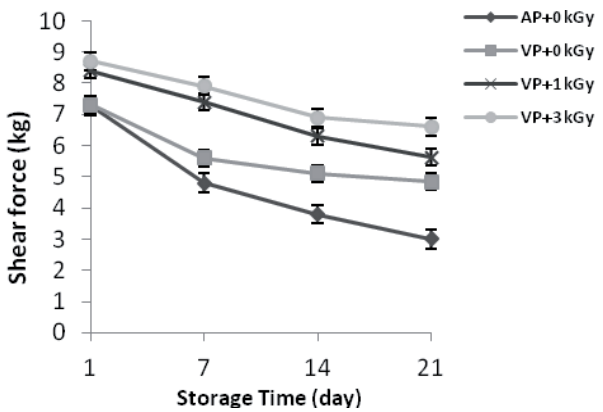

Fig. 1. Shear force changes of packaged ostrich meat affected by irradiation dose and different atmosphere during the storage time at 4°C. AP – air-packaged; VP – Vacuum-packaged; 0 kGy – non irradiated (control); 1 kGy – irradiated by dose 1 kGy; 3 kGy – irradiated by dose 3 kGy.

Lipid oxidation

Effects of ostrich meat packaging conditions and irradiation doses on lipid oxidation of ostrich meat during storage are compared on Figure 2. Analysis of variance showed that ageing of meat affected the lipid oxidation in all treatments, as has been found in another study where *post-mortem* ageing increased meat TBARS [Jouki and Khazaei 2012b]. The TBARS values of aerobically packaged meat increased with storage time. Irradiation and storage time did not significantly affect the lipid oxidation in vacuum-packaged meat. After 7 days storage, TBARS of ostrich meat with vacuum packaging (VP) remained unchanged or increased slightly. Although lipid oxidation was not directly related to the pink colour of irradiated ostrich meat, the high TBARS values in aerobically packaged meat partially explained the low air-packed values compared to the vacuum-packaged meat. Lipid oxidation proceeded along with pigment oxidation during aerobically packaged storage. When vacuum-packaged, TBARS values of meat increased very slowly during the three-week storage regardless of irradiation conditions and the increases were very small. Under air packaging conditions, the TBARS values of meat increased by approximately 5-fold from day 1 to day 21 of storage. After 7 days of storage were the lowest in vacuum-packaged meat samples. Figure 2 illustrates that preceding irradiation causes accelerated lipid oxidation in ostrich meat during storage. TBA values for air-packaged samples on day 7 of display exceeded 3 mg MDA/kg meat, respectively. In vacuum-packaged meat, the amount of TBARS formed in the course of storage was far below the critical value of 3 mg/kg at which rancidity is detected [Wong *et al.* 1995]. The TBA values have commonly been considered as an index of lipid rancidity. Subsequent decomposition of the unstable lipid oxides produces malonaldehyde. Increase in the TBA values during storage is due to the decomposition of the oxidized lipids [Alam *et al*. 2005]. Spainer [1992] stated that the amount of heme catalyst (from hemoglobin, myoglobin and

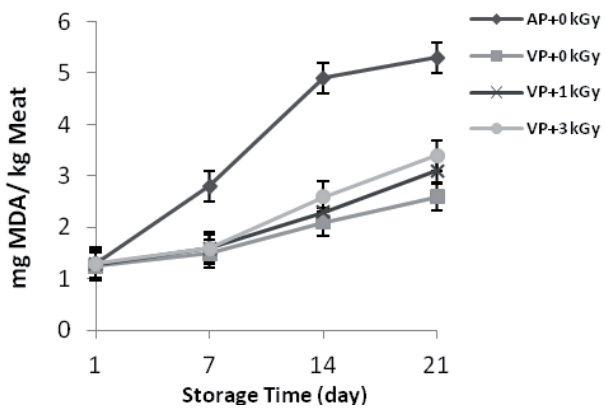

Fig. 2. Changes in Thiobarbituric acid (TBA) value of irradiated and non irradiated ostrich meat under different atmospheres packaging during refrigerated storage. AP – air-packaged; VP – Vacuum-packaged; 0 kGy – non irradiated (control); 1 kGy – irradiated by dose 1 kGy; 3 kGy – irradiated by dose 3 kGy.

cytochrome) and the amount of heme and non-heme iron present in meat tissue was related to lipid oxidation rate. Ostrich meat is rich in heme iron [Sales and Hayes 1996], and polyunsaturated fatty acids [Sales *et al*. 1996] contents makes it susceptible to oxidation. There are many factors such as fat content, pro-oxidant concentrations (e.g. iron), antioxidant types and concentrations (e.g. tocopherol and antioxidant enzymes), and lipid membrane concentrations (e.g. amount of mitochondria) that could be responsible for some of the differences in oxidation rate of different muscles. However, fat content in meat might have played an important role in lipid oxidation of raw meat [Ahn *et al*. 1998].

Colour values

Table 1 presents the influence of vacuum packaging and gamma irradiation conditions on colour L-values of ostrich meat during storage. It includes the three primary (L*, a* and b*) colour co-ordinates used in the Hunter system to determine colour. Chemical changes in raw meat such as protein denaturation, oxidation, hydrolysis, changes in pH, and enzyme action are also significant factors affecting the colour of raw meat [Reid 1999]. Initial mean surface L* value of 39.5 was similar to that reported by other authors [Navarro *et al*. 2000] and it decreased during storage in all cases. We also observed that L* value differed between packaged-meat samples under vacuum and air packaging. The lowest L* values after 21 days corresponded to

Table 1. Changes of colour (L*, a*and b*) of irradiated and non-irradiated ostrich meat packaged under different atmospheres during storage at 4°C

Colour attributes	Time	AP + 0 kGy	VP + 0 kGy	VP + 1 kGy	VP + 3 kGy
Lightness (L)	day 1	$39.92^{a}\pm0.58$	$38.98^{a}\pm0.46$	$39.31^{a}\pm0.40$	$39.59^{a}\pm0.45$
	day 7	$38.17^{b}\pm0.51$	$37.16^{ab}\pm0.47$	$37.20^{b}\pm0.32$	$37.90^{b}\pm0.72$
	day 14	$38.11^{bw}\pm 0.33$	$36.33^{bx}\pm0.22$	$36.52^{bcx}\pm0.82$	$36.45^{bcx}\pm0.90$
	day 21	$35.97^{cw}\pm0.35$	$33.58^{cy}\pm0.67$	$34.95^{cx}\pm0.70$	$35.12^{c,wx}\pm0.39$
Redness (a*)	day 1	$16.22^{a}\pm0.55$	$15.51^{a}\pm0.35$	$15.71^{a}\pm0.40$	$15.40^{a}\pm0.58$
	day 7	$15.31^{b,wx}\pm0.19$	$15.59^{awx}\pm0.41$	$15.84^{awx}\pm0.65$	$16.13^{aw}\pm0.43$
	day 14	$14.67^{cy}\pm0.31$	$16.10^{ax}\pm0.39$	$16.45^{awx}\pm0.39$	$17.04^{aw}\pm0.30$
	day 21	$11.80^{dy}\pm0.79$	$15.39^{ax}\pm0.28$	$16.10^{awx}\pm0.40$	$16.90^{aw}\pm0.37$
Yellowness (b*)	day 1	$10.95^{a}\pm0.22$	$10.73^{a}\pm0.35$	$10.90^{a}\pm0.47$	$10.59^{a}\pm0.33$
	day 7	$8.10^{abwx}\pm0.36$	$7.96^{bwx}\pm0.33$	$8.67^{bw}\pm0.24$	$8.22^{bwx}\pm0.29$
	day 14	$7.27^{bw}\pm0.14$	$6.56^{cx}\pm0.22$	$7.38^{cw}\pm0.21$	$7.30^{cw}\pm0.38$
	day 21	$5.91^{cwx}\pm0.44$	$3.22^{dx}\pm0.66$	$5.54^{dwx}\pm0.48$	$6.18^{dw}\pm0.20$
ΔE	day 1	0	0	0	0
	day 7	3.17^{c}	2.23^{c}	3.00^{b}	3.13^{c}
	day 14	4.55^{b}	4.51^{b}	4.66^{ab}	4.83^{b}
	day 21	8.01^{ax}	9.16^{aw}	5.77^{ay}	6.45^{axy}

$^{a-d}$ values in the same column with different superscripts are significantly different ($P<0.05$).
$^{w-z}$ values in the same raw with different superscripts are significantly different ($P<0.05$).
AP – air-packaged; VP – Vacuum-packaged; 0 kGy – non irradiated (control); 1 kGy – irradiated by dose 1 kGy; 3 kGy – irradiated by dose 3 kGy.

samples under vacuum which showed significant differences with samples under air. Although the samples were irradiated the values were reduced in all cases (*i.e*. meat darkening) and the differences were not significant. Results for colour determination show that irradiation doses of 1.0 and 3 kGy had no effect on the L* values when compared to the non-irradiated controls (Tab. 1). High L* values indicate samples light (white) in colour, whereas low L* values indicate dark samples. Although no differences in L* values were found among the treatment groups and controls, differences in a* and b* values were detected. Specifically, a* values were higher in irradiated vacuum-packaged samples, indicating they were pinker in colour. Colour a-values of meat during storage were influenced ($P<0.05$) by the vacuum-packaging irradiation treatments. The colour a-values (redness) of the ostrich meat stored by vacuum-packaging were higher than those in aerobic packaging. The surface colour was grayish brown regardless of irradiation, and the a-values decreased due to colour oxidation during storage. The a* values decreased ($P<0.05$) for meat in air-packages in the first 7 days of display whereas during 14 days VP meat did not change ($P>0.05$). The pink colour intensity inside the ostrich meat was stronger in irradiated than in non-irradiated samples, and the a-value was dependent on irradiation dose. The pink colour inside of aerobically packaged meat, however, mostly discoloured to brown or yellow regardless of irradiation at 3 weeks because of pigment oxidation. Under vacuum packaging, the increased redness was irradiation dose-dependent, and it was stable during the storage. Results similar to these found in the present study have also been observed in other studies. A study by Byun *et al*. [1999] indicated that irradiation with 3 and 5 kGy caused significant increase in a* values in raw and cooked pork loins. Colour b-values of ostrich meat during storage were also influenced ($P <0.05$) by the irradiation treatment. Air-packaged samples had higher b^*-values than vacuum-packaged meat. The colour data of ostrich meat with different packaging-irradiation indicated that irradiation had a significant ($P<0.05$) effect on color components (L*, a*, b* values). Irradiation would not have adverse effect on the acceptability of ostrich meat during storage when vacuum packaged. Colour changes of ostrich meat were not directly related to lipid oxidation and the generation of off-flavour in irradiated ostrich meat. Total colour difference (ΔE) indicates the magnitude of difference between locations in the CIE L* a* b* colour system (Tab. 1). Higher ΔE results indicate a greater relative change in colour compared to the meat's original colour. The ΔE results for all samples showed significant differences over time. ΔE value was highest for packaged-meat samples under vacuum and air packaging. According to the present results, samples of not irradiated ostrich meat were considered less acceptable than those irradiated. Additionally, red colour is best kept in vacuum-packaged meat for 21 days, while the same score for red colour remains in air-packaged samples only for 14 days.

Sensory quality

The ostrich meat was also evaluated for changes in surface colour, texture, and odour by semi-trained panelists. The sensory attributes of irradiated ostrich meat

during storage at 4˚C are shown in Figure 3. By the 21 days of the storage time, irradiated vacuum-packaged samples were acceptable (scores >6). The surface of the samples, especially those irradiated vacuum-packaged, was not severely discoloured and remained acceptable even after 21 days storage. Storage time effect within treatment indicated that surface discoloration increased ($P<0.05$) especially at day 21 in not irradiated vacuum-packaged samples. The data suggest that gamma irradiation of vacuum-packaged meat samples protected the surface colour. The colour and odour changes in meats are highly dependent upon packaging condition [Layrisse and Matches 1984]. At day 14, air-packaged ostrich meat samples received lower scores than other samples (about colour and texture), significant differences ($P <0.05$) were identified between them at day 14 and during storage time. By the end of the storage time irradiated vacuum-packaged samples had acceptable texture. The acceptable samples were described as having good appearance or natural odour without any sign of rancidity. The ostrich meat packaged in air quickly lost its qualities (especially odor and texture) during 7 days of storage period. In our present study, irradiation at dose 3 kGy extended the shelf life of vacuum-packaged ostrich meat about 21 days as compared to the air-packaged samples (7 days) stored at refrigeration temperature. Miyauchi *et al*. [1964] stated that the average sensory score of 6 might be acceptable. On the basis of organoleptic evaluation, it was concluded that the combined use of vacuum packaging and irradiation dose of 1 kGy and 3 kGy could extend the shelf life of ostrich meat for 14 and 21 days respectively. In our earlier study, irradiation at dose 3 kGy decreased the shelf life of air-packaged ostrich meat by about 5 days as compared to the unirradiated samples (7 days) stored at refrigeration temperature [Jouki 2012].

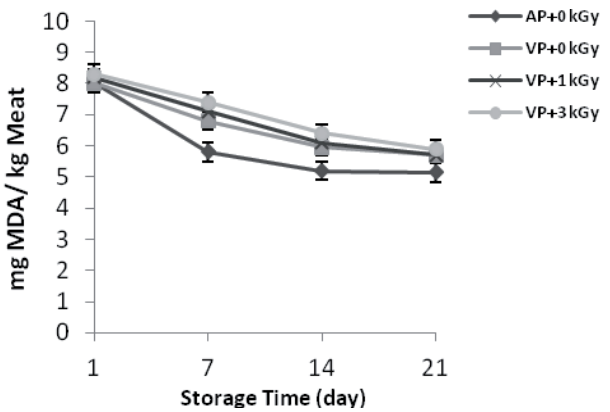

Fig. 3. Organoleptic scores of irradiated and vacuum packaged ostrich meat during refrigerated storage. AP – air-packaged; VP – Vacuum-packaged; 0 kGy – non irradiated (control); 1 kGy – irradiated by dose 1 kGy; 3 kGy – irradiated by dose 3 kGy.

Irradiation increased TBARS and off-odour in aerobically packaged ostrich meat. But vacuum-packaged meat was more stable and resistant to lipid oxidation and off-odour production by irradiation. Irradiation improved the colour of meat. The reduction of the L* parameter for all exposed samples, was not significant (P = 0.05). A significant reduction in the a* parameter was observed in meat for a dose of 3 kGy. Packaging and storage condition of raw meat after irradiation were both important factors with lipid oxidation of meat. Also, oxygen exclusion from the meat was very important in preventing lipid oxidation of ostrich meat. If ostrich meat samples are vacuum-packaged before irradiation, meat samples can be stored for about 3 weeks without problems in lipid oxidation. This indicates that lipid oxidation is not a major problem in irradiated (1 and 3.0 kGy) vacuum-packaged ostrich meat stored at 4°C up to 21 days, but it is the most important problem in all air-packaged samples. Irradiation also caused significant loss of colour and sensory quality in aerobic packages. Considering the sensory analyses, colour and TBA analyses as a whole, vacuum-packed samples irradiated at 3.0 kGy were acceptable for 21 days under refrigerated storage.

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