Effect of the Gamma Radiation Dose Rate on Psychrotrophic Bacteria, Thiobarbituric Acid Reactive Substances, and Sensory Characteristics of Mechanically Deboned Chicken Meat

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Abstract: Frozen samples of mechanically deboned chicken meat (MDCM) with skin were irradiated with gamma radiation doses of 0.0 kGy (control) and 3 kGy at 2 different radiation dose rates: 0.32 kGy/h (3 kGy) and 4.04 kGy/h (3 kGy). Batches of irradiated and control samples were evaluated during 11 d of refrigerated (2 ± 1 °C) storage for the following parameters: total psychrotrophic bacteria count, thiobarbituric acid reactive substances (TBARS), evaluation of objective color (L^*, a^*, and b^*) and a sensory evaluation (irradiated odor, oxidized odor, pink and brown colors). No statistical difference ($P > 0.05$) was found amongst the TBARS values obtained for the MDCM samples irradiated with dose rates of 0.32 and 4.04 kGy/h. There was a significant increase ($P < 0.05$) in the psychrotrophic bacterial count as from the 7th day of refrigerated storage, for the MDCM samples irradiated at the dose rate of 4.04 kGy/h. With respect to the attribute of oxidized odor, the samples irradiated with a dose rate of 0.32 kGy/h showed a stronger intensity and were significantly different ($P < 0.05$) from the sample irradiated with a dose rate of 4.04 kGy/h on days 0 and 2 of refrigerated storage. Irradiation with a dose rate of 4.04 kGy/h (3 kGy) was shown to be the best condition for the processing of MDCM according to the evaluation of all the variables, under the conditions of this study.

Keywords: food irradiation, food quality, food technology, lipid oxidation, sensory analysis

Practical Application: The results obtained for the application of different dose rates of ionizing radiation to mechanically deboned chicken meat will provide the food industry with information concerning the definition of the best processing conditions to maximize the sensory and food quality.

Introduction

Many researchers have verified the fact that a gamma radiation dose below 10 kGy is sufficient to eliminate the majority of harmful microorganisms found in chicken meat (Thayer and others 1995; Miyagusku and others 2003; Gomes and Silva, 2006; Javamard and others 2006). Gomes and others (2006) concluded that a dose of 3 kGy was the best for the irradiation of mechanically deboned chicken meat (MDCM), since this dose caused a reduction in the microorganisms, but showed a less negative effect on sensorial attributes such as odor in comparison with a dose of 4 kGy. According to Adu-Gyamfi and others (2008), 3 kGy is effective in eliminating *E. coli* and Staphylococcus *aureus* on chicken meal and minced chicken substrate. The gamma irradiation process can be applied to raw products based on its high level of success in decreasing the number of microorganisms, and its ability to cause minimal alterations in the natural characteristics of the product (Yildirm and others 2005; Blanch and others 2009). Shahidi and others 1991 reported that irradiation had no detrimental effect on the color or oxidative stability of nitrite-cured or cooked cured-meat pigments.

Similar to the reactions caused by other types of processes, irradiation also promotes chemical alterations in food, including the production of volatile compounds and reactive oxygen species (ROS). The irradiation of frozen chicken could reduce or eliminate the negative effects of this process, mainly those associated with the generation of off-flavors, irradiated odor, and the formation of ROS. The ROS also catalyze lipid auto-oxidation (Shahidi 1998), which is one of the main causes of deterioration in the quality of raw or cooked meat products during refrigerated or frozen storage (Gomes and others 2003). In addition, the color change that occurs in the fresh meat because of the irradiation process makes the myoglobin molecule, especially the iron content, susceptible to alterations in the chemical environment and to the energy input (Brewer 2004).

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Several studies have attempted to establish the best dose of radiation to decrease the microbial load of a foodstuff, without significantly altering its sensory characteristics. However, there is little information available regarding the use and effects of different radiation dose rates (the radiation dose absorbed per unit time) of gamma radiation in industrial food processing (Diehl 1995). Lacroix and others (2000) used 2 different dose rates (2 and 20 kGy/h) to evaluate the microbiological and quality characteristics of pork loin protein, and found significant differences between the dose rates tested. Beaulieu and others (2002) evaluated the effect of the dose rate (4.5 and 32 kGy/h) of gamma radiation on the biochemical quality and browning of mushrooms *Agaricus bisporus*, and found significant differences between the dose rates tested.

According to the Codex General Standard for Irradiated Foods of the Codex Alimentarius Commission, 3 types of radiation source are currently permitted for the irradiation of food: (1) the radionuclide Cobalt-60 or Cesium-137; (2) electrons generated by a machine at a maximum energy of 10 million electron volts (MeV); and (3) X-rays generated by a machine at a maximum energy of 5 MeV (ICGFI 1995). According to the configuration of the radiation source, the radiation dose rates can change from kilograys per hour to kilograys per second. In this context, studies that determine the effects of different irradiation dose rates on the sensory and quality characteristics of MDCM could provide the food industry with different options of irradiation processing.

The present study aimed to verify the effects of different gamma radiation doses rates on the sensory characteristics, psychrotrophic bacteria, and thiobarbituric acid reactive substances (TBARS) of MDCM during refrigerated storage.

Material and Methods

Experimental design

Samples of chicken backs with the skin were taken for analysis during 3 visits to the same slaughterhouse. Each 100 g sample was conditioned in a transparent, low-density polyethylene oxygen permeable bag, frozen overnight at a temperature of −18 ± 1 °C in a chamber, and irradiated in this state, maintaining the temperature low with dry ice. Individual batches were irradiated with doses of 0 kGy (control) and with 3 kGy at 2 different radiation dose rates: 0.32 kGy/h (3 kGy) and 4.04 kGy/h (3 kGy). After this process, the samples were stored under refrigeration (2 ± 1 °C) and evaluated for the following parameters: total psychrotrophic bacteria count, TBARS, and a sensory evaluation (irradiated odor, oxidized odor, pink and brown colors), carried out after 0, 2, 4, 7, 9, and 11 d of refrigerated storage. An objective color analysis (L^*, a^*, and b^*) was also performed after 0, 4, 7, and 11 d of refrigerated storage (2 ± 1 °C). The analytical procedures described above were performed on samples taken from each of the 3 collections.

Irradiation

To obtain different radiation dose rates, 2 different sources of gamma ionizing radiation were used to irradiate the MDCM samples with the 3 kGy dose: a Co^{60} source (obtained from the Brazilian Sterilization Company in São Paulo), producing a dose rate of 0.32 kGy/h, and a Co^{60} "gammacell" type radiation source (obtained from the Inst. of Nuclear and Energetic Research in São Paulo), producing a dose rate of 4.04 kGy/h. A Harwell Perspex (polymethylmetacrilate) dosimeter was used to perform the dosimetry routine for the samples that were submitted to the 0.32 kGy/h dose rate, and the average standard deviation for the 3 kGy dose was recorded as 0.25. The Gammachrome YR Batch 63 dosimeter was used to perform the dosimetry routine on the samples submitted to the 4.04 kGy/h dose rate, and a value of 0.37 was recorded as the average standard deviation for the 3 kGy dose.

Chemical analysis

The characteristics of lipid oxidation were measured from the TBARS values, using a modified version of the method developed by Tarladgis and others (1960). However, based on the recommendation of Pikul and others (1983), this method was modified by adding hydroxytoluene butylate to the MDCM sample before the homogenization step to prevent self-oxidation. The results were expressed as milligram of Malonaldehyde per kilogram MDCM. The average values for the percent recovery of 1,1,3,3 - Tetraethoxypropane (TEP) were found to be 80.66%, 72.86%, and 74.3%, and the average values for the conversion factor of the control samples and the irradiated samples at the dose rates of 0.32 and 4.04 kGy/h were computed as 8.76, 9.17, and 10.08, respectively. The average results for the proximate analysis of the meat were 64.2% ± 0.35% moisture, 13.2% ± 0.29% protein, 22.9% ± 0.38% fat, and 0.99% ± 0.08% ash (Horwitz 2000). The proximate analysis was carried out in triplicate.

Microbiological analyses

The total psychrotrophic bacterial count was obtained using 25 g of each MDCM sample and blending in 225 mL peptone water. Additional decimal dilutions were prepared for plating in Plate Count agar and the plates incubated at 7 ± 1 °C for 10 d before counting the colony forming units (Vanderzant and Splittstoesser 1992). The results were expressed as the logarithm of the colony forming units per gram.

Sensory analysis

Total of 15 assessors were recruited from a list of trained panelists who had participated previously in descriptive analysis tests in the sensory laboratory for meat products for more than 20 h of evaluation, and of these, 9 were selected. The criteria for recruitment were: age between 18 and 43, normal or superior visual acuity, which was checked using the Farnsworth Munsell 100 Hue Test, chicken consumers and available and willing to evaluate the appearance and color of irradiated MDCM. The assessors carried out 6 training sessions (45 min) with nonirradiated samples, samples irradiated with 3 kGy doses and the reference samples (those of fresh MDCM and also those refrigerated at +2 °C for 3 d) for the development of a sensory memory with respect to each descriptive term throughout refrigerated storage. The Grid method was used to prepare the list of descriptive terms, the MDCM samples being presented in pairs for the assessors to list the differences and similarities (Moskowitz 1983). By consensus amongst the panel, of the 10 sensory attributes initially suggested (brown color, pink color of the mass, proportions of brown and pink colors in the mass, cream color of the fat, shine, homogeneity of the mass, amount of exudate, irradiation odor, oxidation odor, deterioration odor), 4 were chosen as best discriminating the samples (Table 1). The scorecard was prepared by the taste panel using a 10 cm non-structured scale ranging from 0 to 10, anchored at the ends in terms of intensity: 1 = slight, 9 = strong. The MDCM samples were maintained under refrigeration (5 to 7 °C) until the moment of evaluation and presented raw to the assessors. A trained team comprising 9 people carried out a quantitative sensory descriptive evaluation. The testing procedure was carried out in the Sensory

Lab. of the Meat Technology Center of the Campinas Food Technology Inst. The sensory evaluation of the sample appearance was carried out in a Macbeth color cabin with standard D65 fluorescent lighting that simulated daylight. The sensory evaluation of the odors was carried out in computerized (Compusense Five, version 4.2) individual test cabins at room temperature, as well as under other conditions as mentioned by Meillgaard and others (1999). The MDCM samples were submitted to the sensory analysis packaged in transparent, low-density polyethylene oxygen permeable bags, to evaluate their appearance: the presence of the brown and pink colors. The packaged samples were then opened to evaluate their odor: irradiated odor and oxidation odor (Table 1). The assessors received the samples monadically in a balanced order of presentation, labeled with 3 randomized digits.

Color analysis

A MINOLTA model CM-508d Spectrophotometer (Japan) was used to measure the parameters $L*$ (luminosity), a^* (intensity of red/green), and b^* (intensity of yellow/blue) of the samples under the following conditions: D65 illuminant, angle of vision: 8 degrees, standard observer angle: 10 degrees, including the mirror component, according to the specifications of CIE 1986 (Commission Internacional d'le Ecleraige [CIE Central Bureau, Vienna, Austria]). The equipment was calibrated with specular reflectance with white standard calibration (Japan 12771056; 400 nm: 99.01 and 700 nm: 96.53). The calibration was carried out using a white plate covered with the same polyethylene film used for the MDCM samples. The color of the MDCM samples was evaluated from the surface of the packaged sample placed on a white surface. Total of 3 readings were taken for each package and 3 packages were evaluated, giving a total of 9 readings for each treatment.

Statistical analysis

The results for TBARS were analyzed statistically considering a first-order self-regressive covariance structure, using the MIXED procedure of the SAS 9.1 statistics program of the SAS Inst., Cary, N.C., U.S.A. Such a covariance structure was used due to the presence of repetitive measurements. This structure permits the evaluation of homogeneity of the variances and an adjustment for the covariance of the samples. The mathematical model included the effects of the treatment, the effects of processing, the interaction between the treatment and the days of storage and the experimental error. The results were presented as the average parameters, fitted according to the minimal square method. The results of the samples were expressed in the standard error values.

For the analysis of the variable of psychrotrophic bacteria, the minimal square method was used with a factorial design. In this case, the mathematical model included the effects of the treatment, the effects of processing, the interaction between the treatment and the days of storage, and the experimental error. In addition, when the variable was significant ($P < 0.05$), a regression analysis was carried out as a function of the days of storage. The results of the samples were expressed in the standard error values.

The statistical design used for the sensory analyses consisted of complete balanced blocks for each assessor. An analysis of variance (ANOVA) was constructed with the variation sources of treatment, processing, and their interactions, for each day of evaluation. An ANOVA was also constructed for the instrumental color analysis of the samples, with the following sources of variation: processing, treatment, and their interaction. The Tukey Test ($P < 0.05$) for the paired comparison analysis was carried out on the treatment averages. The results of the samples were expressed in the deviation standard error values.

Results and Discussion

Chemical analysis

The average initial values (D0) for the TBARS of the MDCM control sample, the samples irradiated with a dose rate of 0.32 kGy/h and the samples irradiated with a dose rate of 4.04 kGy/h were, 0.25 ± 0.85, 0.52 ± 0.85, and 0.62 ± 0.85 mg Mal/kg MDCM, respectively. Gomes and others (2003, 2006) reported a lower D0 for the TBARS value (an average value of 0.39 mg Mal/kg MDCM) for the MDCM sample irradiated with a dose of 3 kGy. For these studies, the MDCM sample used was obtained from skinless chicken backs that contained a lower percentage of fat (19.1%) in comparison with the MDCM samples used in the present study (22.9%).

According to Figure 1, it can be seen there was no difference in the TBARS values ($P > 0.05$) of the irradiated and control samples up to the 4th day of refrigerated storage. On the other hand, Gomes and others (2003) noted a significant difference ($P < 0.05$) between the nonirradiated samples of MDCM and those irradiated with a dose of 3 kGy even on the 4th day of refrigerated storage. The difference in the production process, including avian lineage, feeding, and the production of MDCM, could affect the results obtained. After the 7th day of refrigerated storage, the TBARS values for the irradiated samples increased significantly ($P < 0.05$) in comparison with the control samples. The average TBARS levels observed on the 7th day of refrigerated storage for the control samples and for the samples irradiated with dose rates of 0.32 and 4.04 kGy/h were recorded and found to be: 0.31± 0.85, 5.42 ± 0.85, and 4.48 ± 0.85 mg Mal/kg MDCM, respectively. These results showed the effect of the ionizing radiation dose ($P < 0.05$) on the lipid oxidation of MDCM beginning

Table 1–Definitions and references used to evaluate the sensorial attributes in MDCM.

Attribute	Definition	Reference: consensus value on 0-10 scale	
		Value 1 (slight)	Value 9 (strong)
Odor of oxidation	Odor of fat of oxidized chicken	Odor of fresh MDCM	Odor of chicken fat aged by freezing
Odor of irradiation	Odor of burnt chicken skin—after manual feather plucking the feathers are scorched over flame to facilitate the manual removal of feathers	Odor of fresh MDCM	Odor described in the definition
Pink color	Intensity of color of MDCM oxygenated by 5 min	Color of fresh MDCM wrapped in polyethylene film and refrigerated for 3 d	Color of MDCM described in the definition
Brown color	Intensity of color of MDCM oxidized, when wrapped in polyethylene film and refrigerated for 3 d	Color of fresh MDCM wrapped in polyethylene film and refrigerated for 3 h	Color of MDCM described in the definition

on the 7th day (D7). However, there was no statistical difference ($P > 0.05$) between the TBARS values obtained for the MDCM samples irradiated with dose rates of 0.32 kGy/h and those for the samples irradiated with 4.04 kGy/h. Several researchers have reported success in using a combination of different types of antioxidant to prevent lipid oxidation in irradiated meat (Nam and others 2007; Ismail and others 2008, 2009a, 2009b; Trindade and others 2009). More studies are required to determine whether the lipid oxidation generated during the irradiation of mechanically deboned chicken meat can be reduced or eliminated by the use of antioxidants.

Microbiological analysis

The average values for the psychrotrophic bacteria counts obtained for the control and the samples irradiated at dose rates of 0.32 and 4.04 kGy/h, between the 2nd and 11th days of refrigerated storage were, 8.17 ± 0.56, 3.94 ± 0.56, and 3.61 ± 0.56 log CFU/g, respectively. These results showed a significant effect ($P < 0.05$) of the ionizing radiation dose on the reduction in the microbial count. Similar results were also noted in other studies (Gomes and others 2003, 2006; Yildirim and others 2005; Javanmard and others 2006). No statistical difference ($P > 0.05$) was found amongst the values for the psychrotrophic bacteria counts obtained for the MDCM samples irradiated at dose rates of 0.32 and 4.04 kGy/h.

Table 2 shows that the only day for which no significant reduction ($P > 0.05$) was recorded in the values for the psychrotrophic bacteria count was 0 d of storage for the MDCM sample irradiated with dose rates of 0.32 and 4.04 kGy/h, as compared with the values found for the control sample.

There was an increase ($P < 0.05$) in the psychrotrophic bacteria count of the control samples as from the 2nd day of refrigerated storage, which intensified ($P < 0.05$) on the 7th and 9th days, thus showing that the product deteriorated quickly in the absence of treatment.

On the other hand, for the samples irradiated at a dose rate of 0.32 kGy/h, no significant increase was noted ($P > 0.05$) during the period of refrigerated storage. However, for the MDCM samples irradiated at a dose rate of 4.04 kGy/h, a significant increase ($P < 0.05$) was noted as from the 7th day of refrigerated storage.

Sensory analysis

In the sensory analysis of the samples submitted to the various refrigerated storage periods, the control samples showed the lowest levels of odor as compared to the samples irradiated at dose rates of 0.32 and 4.04 kGy/h for: irradiated odor (the odor of burnt feathers or burnt skin) (0.2 to 2; 4.4 to 7; 2.9 to 7.1, respectively), oxidized odor (a rancid odor) (0.6 to 4.4; 4.3 to 6.7; 1.6 to 6.9), and the brown color (1.2 to 7.5; 1.6 to 8.3; 2.9 to 7.1). The intensity of the pink color was found to be higher in the control sample than in the irradiated samples (1 to 6.9; 1.5 to 4.2; 1.3 to 5.3, respectively) throughout most of the refrigerated storage period (Figure 2 and 3). Similar results were also obtained in other studies (Miyagusku and others 2003; Lee and Ahn 2005).

For the perception of irradiated odor, the only significant effect ($P < 0.05$) was noted between the irradiated samples on day 0 of refrigerated storage. A statistical difference ($P < 0.05$) was found amongst the perception of irradiated odor obtained for the MDCM samples irradiated with 0.32 kGy/h and the control samples, on the 2nd day of refrigerated storage (Figure 2).

For the attribute of oxidized odor, the samples irradiated with a dose rate of 0.32 kGy/h showed a greater intensity and were significantly different ($P < 0.05$) from the sample irradiated with a dose rate 4.04 kGy/h on day 0 and 2 of refrigerated storage (Figure 2). The complex oxidation process of the lipids in the

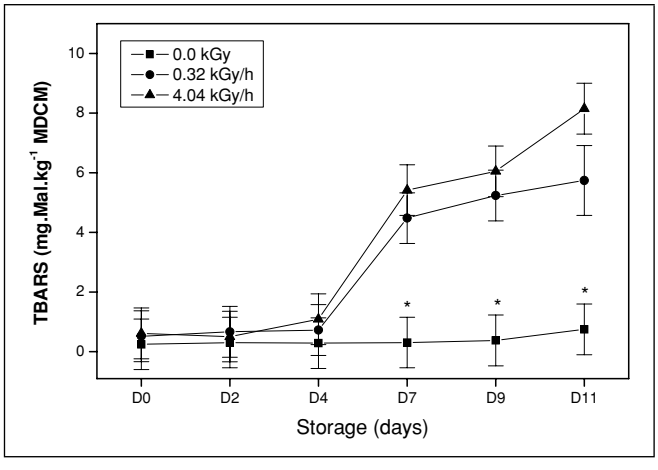

Figure 1–Average TBARS values for the MDCM samples, irradiated and nonirradiated, throughout the refrigeration storage period (2 ± 1 °C). The experiments were carried out in triplicate. The vertical bars represent the standard error values. *$P < 0.05$.

Table 2–Average psychrotrophic bacteria values in irradiated at dose rates of 0.32 kGy/h, 4.04 kGy/h, and nonirradiated MDCM samples (control) over the refrigerated storage period (2 ± 1 °C).

	log (CFU)/g ± SE		
Storage (d)	Control	0.32 kGy/h	4.04 kGy/h
0	2.87 ± 0.56^{Aa}	2.98 ± 0.56^{Aa}	2.10 ± 0.56^{Aa}
2	4.59 ± 0.56^{Ba}	2.80 ± 0.56^{Ab}	2.39 ± 0.56^{Ab}
4	4.90 ± 0.56^{Ba}	3.27 ± 0.56^{Ab}	2.10 ± 0.56^{Ab}
7	8.74 ± 0.56^{Ca}	4.22 ± 0.56^{Ab}	4.11± 0.56^{Bb}
9	11.02 ± 0.56^{Da}	4.33 ± 0.56^{Ab}	4.80 ± 0.56^{Bb}
11	11.61 ± 0.56^{Da}	5.10 ± 0.56^{Ab}	4.64 ± 0,56^{Bb}

Different capital letters in the same column or a different lower case letter in the same line represent significant differences ($P < 0.05$).
SE = standard error.

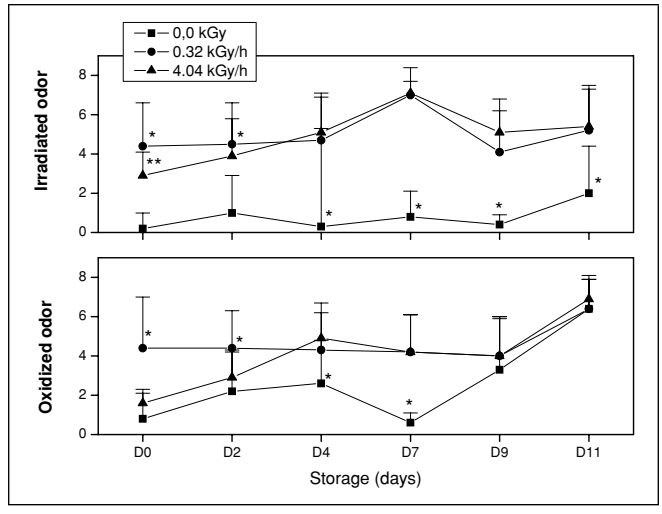

Figure 2–Average values for the sensorial attributes of the irradiated (a) and oxidized (b) odor in the MDCM samples, irradiated and nonirradiated, throughout the refrigerated storage period (2 ± 1 °C). The vertical lines represent the standard deviation. *$P < 0.05$. **Average value significantly different from those noted for 0.0 and 0.32 kGy ($P < 0.05$).

stored samples as well as the slow radiation process might have contributed to this perception. The volatile substances, which contain sulfur compounds such as, dimethyl disulfite, amongst others, are responsible for generating residual odors in irradiated meat by the radiolytic degradation of the sulfur-bearing amino acids. These subsequently become volatile under aerobic conditions, and eventually the oxidation process begins via self-oxidation reactions and the formation of ROS (Shahidi 1998; Ahn 2003).

With respect to the color parameters evaluated, significant differences ($P < 0.05$) were perceived amongst the samples irradiated with different doses and dose rates, throughout the period of refrigerated storage studied. As far as the evaluation of the colors pink and brown were concerned, significant differences ($P < 0.05$) were noted between the irradiated samples on day 0 of refrigerated storage (Figure 3).

The low intensity ($P < 0.05$) of the pink color noticed during the first couple of days of storage for the samples irradiated with a dose rate of 0.32 kGy/h, was an indication of the effect of the slow irradiation process, as in the perception of odor (Figure 3).

Variations in the color of the fat occurred as a result of the oxidation of beta carotene present in meat fat and susceptible to radiolytic attack. In the presence of oxygen, the effects of the irradiation process can be accelerated by one or more of the following reactions: the formation of free radicals, which can combine with oxygen to form hydroperoxides; the breakdown of hydroperoxides, giving rise to several decomposition products, particularly carbonylic compounds; and the destruction of antioxidants (Fennema 1996). At the end of the storage period, the free fatty acids produced by microbial action can also contribute to the oxidation odor (Lawrie 1998) perceived in the samples, especially in the control sample.

Color analysis

Regarding the color parameters evaluated (L^*, a^*, and b^*), a significant difference ($P < 0.05$) was only noted between the irradiated samples and the control samples with different dose rates of ionizing radiation on some days of refrigerated storage.

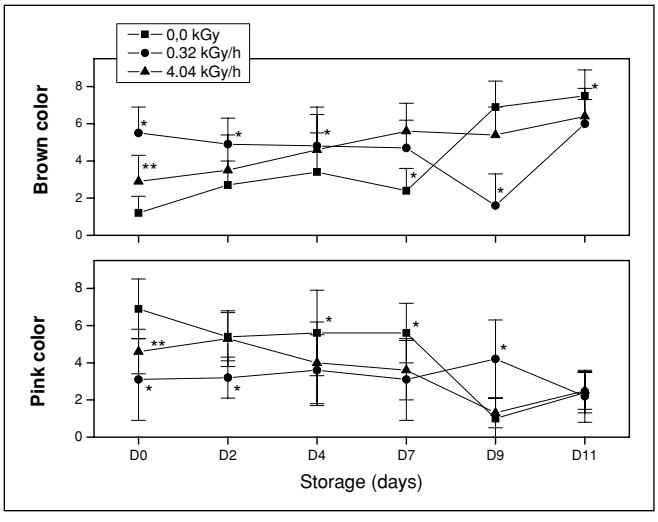

Figure 3–Average values for the attributes of the brown (a) and pink (b) color in the MDCM samples, irradiated and nonirradiated, throughout the refrigerated storage period (2 ± 1 °C). The vertical lines represent the standard deviation. *$P < 0.05$. ** Average value significantly different from those noted for 0.0 and 0.32 kGy ($P < 0.05$).

Table 3 shows the values that highlight the color analysis for L^*, a^*, and b^*.

The samples irradiated with a dose rate of 0.32 kGy/h presented small values ($P < 0.05$) for the parameter of L^*, on the 7th day of refrigerated storage, in comparison with the samples irradiated with a dose rate of 4.04 kGy/h and the control samples. No statistical difference ($P > 0.05$) was noted for the parameter L^* between the samples that received irradiation at a dose rate of 4.04 kGy/h and the control samples, during the refrigerated storage period.

The irradiated samples only showed lower values than the control samples for the parameter of a^*, ($P < 0.05$), during the initial period of refrigerated storage (OD). On the 4th day, a more intense red color (a^*) was observed in samples treated at 4.04 kGy/h as compared to the sample treated at 0.32 kGy/h. The results are according to Lacroix and others 2000, who found a more intense red color (a^*) in pork loin samples treated with 20 kGy/h, as compared to samples treated with 2 kGy/h.

A statistical difference was only noted for the parameter b^* ($P > 0.05$) between the irradiated samples and the control samples on the first day of refrigerated storage (OD). The judges noticed more alterations in the color than those registered in the objective analysis, because a non-uniform product such as MDCM was under evaluation.

The change in color of the irradiated foodstuff under refrigerated storage occurred due to the susceptibility of the myoglobin molecule, especially iron, to chemical alterations and changes in the energy input that eventually changed its state. The generation of red or brown pigments that cause the final color of the process, can be explained by the formation of ROS, generated through irradiation, which form ferrilmyoglobin and gases, such as carbon monoxide (Brewer 2004).

Gomes and others 2003, found no significant differences ($P > 0.05$) between the MDCM samples, which were not irradiated, and those which received irradiation doses of 3 and 4 kGy for the attributes of L^* and b^* in color analysis. As far as the attribute of a^* is concerned, the authors of this study previously found a significant difference ($P < 0.05$) between the control and the irradiated samples, as from the 4th day of refrigerated storage, the control samples showing lower values than the irradiated samples.

Lee and Ahn (2005) performed studies with irradiated turkey breast and found no significant difference in the attributes of L^*,

Table 3–Average values of luminosity (L^*), intensity of red (a^*), and intensity of yellow (b^*), obtained in nonirradiated MDCM samples and those irradiated at dose rates of 4.04 and 0.32 kGy/h over the refrigerated storage period (2 ± 1 °C).

Storage (d)	Dose rate (kGy/h)	L^* ± SD	a^* ± SD	b^* ± SD
0	0.0	50.20 ± 2.77	13.31 ± 1.83^a	13.77 ± 1.96^a
	0.32	49.45 ± 3.13	11.53 ± 1.72^b	11.85 ± 1.81^b
	4.04	50.94 ± 2.53	11.40 ± 1.65^b	12.29 ± 2.30^b
4	0.0	51,33 ± 2.51	11.48 ± 2.31^a	10.93 ± 1.43^a
	0.32	51.11 ± 2.34	9.26 ± 1.07^b	9.55 ± 1.52^b
	4.04	52.13 ± 2.60	10.95 ± 1.38^a	10.49 ± 2.45$^{a\,b}$
7	0.0	50.43 ± 2.29^a	10.31 ± 1.75	9.75 ± 2.05
	0.32	48.77 ± 2.07^b	10.28 ± 1.44	10.45 ± 1.33
	4.04	50.98 ± 2.62^a	9.75 ± 1.69	9.99 ± 2.14
11	0.0	49.89 ± 3.22	9.92 ± 2.46	10.75 ± 2.69
	0.32	50.94 ± 2.00	9.02 ± 1.27	11.39 ± 1.67
	4.04	50.13 ± 3.31	9.86 ± 1.65	11.28 ± 1.77

Different letters in the same column and on the same day represent significant differences between the treatments ($P < 0.05$).
SD = standard deviation.

a^*, and b^* between the samples irradiated with a dose of 3 kGy and the nonirradiated sample during refrigerated storage.

The contradictions that exist between the results generated by the present study and the research carried out in the past by other researchers can be explained by the differences in the samples evaluated in the 2 studies. The present study used a MDCM sample with the skin, which is a raw material with a high concentration of fat and hence more prone to the oxidation process and thus to color alterations.

Conclusions

Taking all the results of the variables analyzed in the present study into consideration, that is, the psychrotrophic bacterial count, the characteristics of lipid oxidation, and the color and sensory analyses, it was found that of the dose rates studied, that of 4.04 kGy/h was considered the best for the processing of the MDCM sample. Both the irradiated samples had a shelf life of 4 to 7 d, quite superior to the control sample, which had a shelf life of 0 to 2 d under the conditions of the present study. However, comprehensive studies involving larger samples, such as those used in the processing industry, are necessary to provide additional knowledge on this subject.

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