Effect of high-dose irradiation on quality characteristics of ready-to-eat broiler breast fillets stored at room temperature


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ABSTRACT The effect of high-dose irradiation on the physical, chemical, and bacteriological parameters of ready-to-eat vacuum-packed broiler breast meat after 430 d of storage at room temperature was investigated. Ready-to-eat broiler breast fillets were immersed in brine with garlic powder and then drained, grilled, and vacuum-packed (primary packaging). The high-dose irradiation used was approximately 48 kGy. The treatments were designated as A (irradiated samples stored at room temperature), B (irradiated samples stored at −25°C), and C (nonirradiated samples stored at −25°C). All samples were packaged in polyethylene bags containing aluminum to exclude light (secondary packaging). Proximate composition, pH, 2-thiobarbituric acid reactive substance (TBARS), and heterotrophic aerobic mesophilic bacteria were analyzed during 430 d of storage. Results were analyzed using 1-way ANOVA and the Tukey test. Linear regression was used to analyze the correlation between the results for each parameter and storage time of the different treatments. The gamma radiation caused slight changes \( (P < 0.05) \) in the moisture and fat content, regardless of storage temperature. After storage d 110, TBARS values remained stable \( (P > 0.05) \) in all the treatments. The preservation methods used were effective in maintaining the mesophilic counts below the detection level during the entire storage period. We concluded that, among the treatments studied, high-dose irradiation with storage at room temperature showed potential for the preservation of ready-to-eat products made from poultry meat, to provide foods safe for consumption.

Key words: chicken meat, gamma radiation, vacuum packaging, storage

INTRODUCTION

Over the last decade, the poultry industry was the largest growing business among all meat industries (FAO, 2010). In Brazil, the poultry industry has undergone profound changes related to the organizational structure and encompassing much of the production process, administrative, and work organization (Buzanello and Moro, 2012). Since 2004, Brazil has become the world’s largest exporter and third largest producer, just after the United States and China. In 2012, Brazilian chicken meat production reached 12.645 million metric tonnes. Of the total national production of chicken, 69% was intended for domestic consumption and 31% for export. Therefore, the per capita consumption of chicken was 45 kg last year; whereas in 2000 the per capita consumption of chicken was 29.91 kg (Brazil, 2013).

Potential contamination with spoilage or pathogenic bacteria due to failures in the manufacturing process represents a problematic to poultry production chain (Barker et al., 2004; Yun et al., 2012), including the ready-to-eat chicken breast products which are popular foods worldwide (Rodríguez et al., 2014). Therefore, the adoption of good manufacturing practices is necessary to ensure the physical, chemical, bacteriological, and sensorial quality in these products (Barker et al., 2004; Yun et al., 2012).

Moreover, preservation methods have been applied to foods to increase shelf life, prevent losses, reduce the use of artificial preservatives, allow distribution over long distances, and provide food that is safe for consumption (Koutsoumanis et al., 2008; Monteiro et al., 2013). Gamma radiation is the most effective method for sterilization of food products. Recently, research studies are focused on using this technology for the development of foods with specific purposes including the space program, military activity, and geriatric and immunocompromised patients. Brazilian legislation of food irradiation promulgated in 2001 “does not estab-
lish quantitative limits of doses for the treatment of food. Instead, it determines that the minimum absorbed dose should be sufficient to achieve the intended purpose and the maximum absorbed dose should be lower than that which would compromise the functional properties or sensory attributes of the food products (Brazil, 2001).

Food products in this category must be safe to consume even after a long storage period. Commonly, 40 to 50 kGy of high-dose irradiation is applied to ensure sterilization of radiation-resistant fungi and bacteria (Bourland, 2008), mainly to guarantee the inactivation of spores of Clostridium botulinum, which represent a worry in poultry meat consumption (Cereser et al., 2008; Vital and Freire, 2008). Due to the highly resistance of these pathogenic spores, the recommended minimum dose for the sterilization of vacuum-packed meat, poultry, and fish products is 45 kGy (IAEA, 1995). Although this is considered high, the dose of 48 kGy was chosen in our study because it is able to inactivate spores of Clostridium botulinum, while keeping unchanged the physical, chemical, and sensory properties of meat products, especially when technological alternatives such as vacuum packaging are used to minimize chemical changes from gamma irradiation (Chouliaira et al., 2008; Damodaran et al., 2010; Vital and Freire, 2008; Yun et al., 2012).

Despite gamma irradiation and vacuum packaging have proven effective, the effects of these preservation methods on the quality of ready-to-eat broiler breast fillets during a long storage period at room temperature are not well known to consumers. The objective of this study was to evaluate the effect of high-dose irradiation on the quality of ready-to-eat broiler breast during 430 storage days at room temperature (25 ± 5°C).

MATERIALS AND METHODS

Experimental Design

Refrigerated broiler breast fillets (n = 80) and other ingredients were purchased from a retail market (Rio de Janeiro, Brazil). All fillets were obtained from the same lot. The samples were placed on ice and transported to the laboratory. The period from purchase to arrival at the laboratory did not exceed 2 h. Broiler breast fillets were prepared as described below and were wrapped in individual multilayered structures of polyethylene with low permeability to gases (primary packaging) and vacuum sealed. A TEC MAQ brand, model AP450 (BossVacuum, Bad Homburg vor der Höhe, Germany) sealer was used for vacuum packaging all the samples, which were placed in an ultrafreezer at −75°C. Nonirradiated samples were packaged in aluminized polyethylene film for protection against light (secondary packaging) and stored at −25°C (treatment C).

Gamma Irradiation

The samples corresponding to groups A and B were irradiated in the gamma irradiator (Army Technology Center, Rio de Janeiro, Brazil), using dry ice (−78°C/48 h) to prevent any excessive temperature during the irradiation process. Exposure to gamma radiation at a dose of 48 kGy was performed in a cavity-type 42 kCi cesium-137 source-driven research irradiator of accurately known dosimetry. The average dose rate was 16.8 Gy/min. After the irradiation process, the samples were packaged in a secondary packaging as described for the nonirradiated samples.

Bacteriological, Physical, and Chemical Analyses

Plate count agar medium was used for the count of heterotrophic aerobic mesophilic bacteria, and the plates were inverted for incubation at 35 ± 1°C for 48 h.
and different ingredients and manufacturing processes can influence physical and chemical parameters such as texture, pH, cooking yield, and moisture content, which are directly related to microbial growth and changes during storage. Freezing increases the shelf life of meat products by injuring bacterial cells, which are unable to survive or grow under stress conditions (Black et al., 2010). Therefore, studies focused on specific-purposed foods are necessary.

Yun et al. (2012) observed that cooked samples, both nonirradiated and irradiated at 5 kGy, showed increases in the number of microorganisms over a 10-d storage period. Our results indicate that the cooking process used in combination with high-dose irradiation (48 kGy) was enough to inhibit bacterial growth in broiler breast fillets during 430 storage days allowing foods storage at room temperature.

Some variations were observed in the proximate composition between the treatments during the storage. The moisture and fat contents differed significantly ($P < 0.05$) between irradiated and nonirradiated samples, whereas no significant difference ($P > 0.05$) was observed in protein and ash among all treatments. The moisture values (Table 1; Figure 1a) of irradiated samples were lower ($P < 0.05$) than in nonirradiated samples, and showed a range of 1.3 and 1.9%, respectively, during storage, regardless of the storage temperature. This difference might be related to deterioration in the hydration capacity of the meat-protein fractions induced by gamma rays. In general, the water content is expelled as drip and remains on the surface of foods, decreasing the moisture at higher irradiation doses (Wang et al., 2010). According to Wang and Chao (2002), damage and changes in the structure of foods caused by irradiation are the main reasons for the higher dehydration rate.

In accordance with our findings, Leo and Fidel (2006) reported that the mechanism for irradiation-induced water loss could involve damage to the integrity of the membrane structure of muscle fibers and denaturation of muscle proteins. Riebroy et al. (2007) argued that irradiation promotes protein denaturation resulting in an increase of exudates of Som-fug (a fermented Thai fish mince), especially after irradiation at high doses.

The fat levels (Table 1; Figure 1b) of irradiated samples were higher ($P < 0.05$) than nonirradiated samples, independently of storage temperature. This parameter showed a range of 0.11, 0.10, and 0.12% for treatments A, B, and C, respectively, during the entire storage period. This result may be explained by the inverse relationship between fat and moisture contents (Fernández-López et al., 2003) or a dose-dependent effect of irradiation on the fatty acid profile (Stefanova et al., 2011). These authors observed a trend toward an increase in the amount of saturated fatty acids and a decrease in the amount of polyunsaturated fatty acids in the triacylglycerol composition of irradiated beef samples compared with nonirradiated samples. The effect of the gamma radiation on the fatty acid composition can be attributed to the production of free radicals...
during the irradiation process. The electron-deficient carbon-carbon double bonds of unsaturated fatty acids and carbonyl groups are particularly susceptible to free radical attack (Brewer, 2009). However, the degree of change in the lipid fraction induced by gamma radiation depends on several factors such as the irradiation dose (Stefanova et al., 2011) and the proportion of saturated and unsaturated fatty acids in the food, which is directly dependent on age (Badr, 2005) and feed provided to the animal (Morales-Barrera et al., 2013). High radiation doses cause more changes in lipids (Stefanova et al., 2011), mainly in the matrix with unsaturated fatty acids, which are more susceptible to oxidation (Ladeira et al., 2014).

Nevertheless, similar to this study, Özden and Erkan (2010) observed that irradiation (2.5 and 5.0 kGy) increased the total fat content of cultured sea bass, probably due to the high levels of saturated and unsaturated fatty acids induced by gamma radiation. On the other hand, Badr (2005) found no significant difference in total fat content between irradiated (1.5 and 3.0 kGy) and nonirradiated chicken breast.

No significant difference ($P > 0.05$) was observed in the levels of protein (Table 1; Figure 1c) and ash (Table 1; Figure 1d) among all treatments, indicating that high-dose irradiation and frozen storage ($-25^\circ$C) did not affect these parameters during 430 storage days. This might be attributed to the gamma radiation process affecting mainly the water and fat molecules. Ionizing radiation initially causes the radiolysis of water, which makes up a high proportion of animal tissue, generating free radicals that lead to chemical reactions in the food constituents. The most susceptible site for free radical attack is the double bond of lipid molecules (Giroux and Lacroix, 1998). In accordance with our results, Badr (2005) observed no significant differences in ash and protein contents between irradiated (1.5 and 3.0 kGy) and nonirradiated chicken breast. Gecgel

Table 1. Physical and chemical parameters of ready-to-eat broiler breast fillets

| Treatment | Moisture (%) | Fat (%) | Protein (%) | Ash (%) | pH | TBARS$^3$
|-----------|-------------|---------|-------------|--------|----|----------
| A         | 64.92$^{a}$ ± 1.3 | 1.52$^{a}$ ± 0.11 | 30.04 ± 1.82 | 1.81 ± 0.14 | 6.03 ± 0.20 | 0.71 ± 0.31 |
| B         | 64.62$^{a}$ ± 1.3 | 1.46$^{a}$ ± 0.10 | 30.70 ± 1.13 | 1.73 ± 0.15 | 6.06 ± 0.20 | 0.54 ± 0.21 |
| C         | 66.98$^{b}$ ± 1.9 | 1.17$^{b}$ ± 0.12 | 28.75 ± 2.22 | 1.71 ± 0.16 | 6.06 ± 0.23 | 0.63 ± 0.27 |

$^{a,b}$Different superscripts in the same column indicate significant differences ($P < 0.05$), whereas numbers without superscripts in the same column indicate no significant differences ($P > 0.05$).

$^1$Values are means ± SD.

$^2$Treatments: A, irradiated samples and at room temperature ($25 ± 5^\circ$C); B, irradiated samples and frozen storage ($-25^\circ$C); C, nonirradiated samples and frozen storage ($-25^\circ$C).

$^3$TBA reactive substances (TBARS); results expressed in mg of malonaldehyde/kg of sample.

![Figure 1](https://academic.oup.com/ps/article-abstract/93/10/2651/2730496)
breast fillets were irradiated at 48 kGy and the TBARS of meat irradiated at 4.0 kGy. In our study, the broiler of malonaldehyde/kg for mechanically deboned chicken age.

values cannot be predicted up to the end of frozen stor-
due to their chemical instability, and therefore, TBARS of the products of lipid oxidation to rapidly recombine. These authors attributed this result to the tendency > 0.05) levels of TBARS. However, at 90 d, both the irradiated and nonirradiated chicken meat in the first days of frozen storage (−18°C).

increased the TBARS values of mechanically deboned chicken with other compounds such as free amines from proteins, which leads to wide ranges of this parameter during storage (Al-Kahtani et al., 1996; Monteiro et al., 2012).

In general, the TBARS (Table 1; Figure 1f) showed no significant difference (P > 0.05) among treatments. The TBARS values exhibited an irregular trend (increase or decrease) during storage, probably because malonaldehyde has the ability to form covalent bonds with other compounds such as free amines from proteins, which leads to wide ranges of this parameter during storage (Al-Kahtani et al., 1996; Monteiro et al., 2012).

In the present study, the irradiated samples held at room temperature (treatment A) showed higher TBARS levels (P < 0.05) than in the other samples (treatments B and C) during the first 110 storage days. These results suggest that gamma rays could split water molecules into free radicals and ions, which induces oxidative rancidity (Brewer, 2009). However, undesirable changes from gamma radiation can be reduced by storage at low temperatures (Vital and Freire, 2008), which explains the significant difference (P < 0.05) between the irradiated samples stored at different temperatures (25 and −25°C).

After 110 storage days, no significant difference (P > 0.05) was observed among treatments. This could be explained if the irradiation effect for storage at room temperature was minimized by the reaction of malonaldehyde with other food substances (Al-Kahtani et al., 1996).

In agreement with our results, Gomes and Silva (2006) suggested that gamma radiation (3 and 4 kGy) increased the TBARS values of mechanically deboned chicken meat in the first days of frozen storage (−18°C). However, at 90 d, both the irradiated and nonirradiated samples showed similar (P > 0.05) levels of TBARS. These authors attributed this result to the tendency of the products of lipid oxidation to rapidly recombine due to their chemical instability, and therefore, TBARS values cannot be predicted up to the end of frozen storage.

The maximum TBARS value found by Gomes and Silva (2006) during 90 d of frozen storage was 1.52 mg of malonaldehyde/kg for mechanically deboned chicken meat irradiated at 4.0 kGy. In our study, the broiler breast fillets were irradiated at 48 kGy and the TBARS values did not exceed 1.42 and 0.98 mg of malonaldehyde/kg in the irradiated samples stored at room temperature and the irradiated samples stored frozen, respectively. The results of the present study suggest that the use of dry ice during the irradiation process combined with frozen storage and use of secondary packaging to prevent light exposure were effective in preventing large variations in malonaldehyde levels during the full storage period.

Although the irradiated samples stored at room temperature showed higher TBARS values than the other treatments up to 110 d, the levels for all treatments were within the limits indicated in the literature for foods with no sensory changes and that are not harmful to the health of consumers (Al-Kahtani et al., 1996; Torres and Okani, 1997; Osawa et al., 2005; Al-Bachir and Othman, 2013).

Based on the results, the preservation methods used in this study were effective to ensure the bacterial quality of the products. The authors believe that the slight physical and chemical changes induced by high-dose irradiation during the entire storage period did not compromise the sensory quality of food. Nevertheless, further studies should be performed to evaluate of free radicals from irradiation process and sensory changes perceived by consumers. Therefore, the use of high-dose irradiation for storage at room temperature may have potential for the preservation of ready-to-eat broiler breast fillets, to provide food that is safe for consumption.

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