GAMMA IRRADIATION PRESERVATION OF CHESTNUT FRUITS: EFFECTS ON COLOR AND TEXTURE

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Abstract

Chestnuts are a seasonal fruit that must be postharvest treated to meet food safety regulations. In this study the effect of gamma irradiation on color and texture of chestnut fruits from a European variety (*Castanea sativa* Miller) was reported. The fruits were subjected to gamma irradiation doses of 0.5, 3 and 6 kGy, with color and texture properties analyzed along a typical commercial period for this fruit after postharvest treatment, at 0, 15 and 30 days of storage. For *L* and *b* color parameters, significant differences ($p < 0.05$) were observed with irradiation dose (ID) only for higher doses of 3 kGy and 6 kGy. Along storage time (ST) significant differences ($p < 0.05$) were observed for fruits interior (half-cutted) after 15 days of storage. Regarding texture, differences on fruits were only detected for chestnuts irradiated with 6 kGy. With this study we can identify the maximum acceptable dose for irradiation processing of these fruits, concluding that gamma irradiation could be a promising alternative technology for postharvest disinfestation of European chestnuts varieties, to meet food safety international trade regulations, not affecting significantly two important parameters for the consumer, the color and texture.

Keywords: Chestnut fruits, food irradiation, color, texture

Introduction

Chestnut fruits world production is about 1.1 million tons, being Portugal the second producer of European varieties (*Castanea sativa* Miller) with about 30 000 ton. From these about 10 000 ton are for exportation, representing an income of 13 MEuros (FAOSTAT, 2010; INE 2010). Chestnuts are a seasonal fruit that must be postharvest treated to meet food safety regulations. Traditionally, the fresh fruits were postharvest fumigated with methyl bromide to meet the international phytosanitary regulations for pest quarantine. However, its use has recently been prohibited in Europe, in March 2010 (EU, 2008), following an international regulation, the Montreal Protocol (UNEP, 2000), existing no or few alternatives to the producers and agro-industry that process this fruit. In this context, irradiation may be a feasible alternative if the food product meets the needed quality parameters after processing.

Food irradiation is a well established technology, approved by international organizations of food (FAO – Food and Agriculture Organization) and health (WHO – World Health Organization), regulated in European Union by the Directive 1999/2/EC (EU, 1999). Gamma irradiation has been studied as preservation technology for many years and it is now approved for several food products (EU, 2009) and irradiation doses till 10 kGy presents no hazard for the consumer (FAO/IAEA/WHO, 1981). A recent report from E.U. Scientific Commission recommends that each irradiated food requires an individual evaluation, as processing and storage generalizations are not possible (EC, 2003). Generally, irradiation doses are classified in three groups: for insects' disinfestation, lower than 1 kGy; for decontamination and reduction of patogenic microorganisms, 1 to 10 kGy; and for sterilization, higher than 10 kGy (Molins, 2001). In fruits, gamma irradiation may change some sensorial parameters, namely color or texture, which can cause the product rejection by the consumer (Pérez *et al.*, 2009).

Studies in gamma irradiated chestnuts on color parameters have been done mainly in Asian varieties, but not for texture (Antonio *et al.*, 2012). However, Asian and European varieties are different, namely in size and flavor (Vossen, 2000). As far as we know, this is the first time that the influence of gamma irradiation on color and texture of European varieties is reported.

Materials and methods

Samples

Chestnut fruits (*Castanea sativa* Miller) samples, harvested in November 2010, were obtained from an industrial unit with different European varieties and ready for marketing. The fruits were divided in four groups to be exposed to the radiation doses of 0, 0.5, 3 and 6 kGy - being 0 kGy the non-irradiated, the control sample. Each group was dimensioned for the experimental chamber, containing 35 chestnuts (approximately 350 g), with 2 batches for each dose. After irradiation, the samples were stored at 4 ºC, being the color and texture monitored during a typical commercial period from postharvest treatment to marketing, at 0, 15 and 30 days.

Irradiation

The irradiations were performed in a Co-60 experimental equipment, with a total activity of 267 TBq (7.2 kCi) in November 2010 (Gravatom, model Precisa 22, from Graviner Manufacturing Company Ltd., U.K.), as described in a previous study (Antonio *et al.*, 2011). To estimate the dose for the irradiation positions, a dosimetric characterization of the gamma chamber was done using a sensitive radiation chemical solution, Fricke dosimeter, based on an oxidation process of ferrous ions to ferric ions in acidic aqueous solution by ionizing radiation. After irradiation, the dose and dose rate was estimated following the standard (ASTM E1026, 1992) and the procedure described by Antonio *et al.* (2011). During the irradiation process, four routine dosimeters (Amber Perspex batch V, from Harwell co., U.K.) sensitive in the 1 to 30 kGy range, were used to monitor the process for the higher doses (3 and 6 kGy). For the lower dose (0.5 kGy) it was used the known dose rate, previously obtained with the standard Fricke dosimeter. The samples were rotated up side down (180^o) at half of the time, to increase the dose uniformity. The Amber Perspex dosimeters were read in a UV-VIS spectrophotometer (Shimadzu mini UV 1240) at 603 nm, two readings for each, to estimate the dose according to a previous calibration curve.

Axial dimensions

The axial dimensions of the fruits were determined measuring the length (L), width (W) and thickness (T) of three chestnut fruits from each batch at each time point, using a digital calliper with precision of 0.01 mm. The arithmetic and geometric diameters, as well as the sphericity, were calculated using the equations (1), (2) and (3) (Mohsenin, 1978).

Arithmetic diameter: $D_a = (L + W + T)/3$ (1)

Geometric diameter $D_g = (L \times W \times T)^{1/3}$ (2)

Sphericity $\Phi = (L \times W \times T)^{1/3} /(max\ [L,W,T])$ (3)

Fruit's density

To calculate the fruit density five chestnut fruits randomly chosen from each irradiation dose were weighted on an electronic balance to an accuracy of 0.0001 g (Balance ABS 220-4, KERN & Sonh GmbH, Germany). The displaced volume of each chestnut fruit in toluene was determined following the procedure described by Yildiz et al. (2009). The density was calculated by the ratio of mass by the volume.

Color

For color, Hunter parameters (*L*, *a*, *b*) were measured using a colorimeter (Konica Minolta model CR400, Japan), calibrated with a white tile, using C illuminant and diaphragm aperture of 8 mm. The measurements were made on the fruit after hand peeling (whole peeled fruit) and after cutting the fruits by the middle (fruits interior). The color of chestnuts was measured in three different points, for each dose and at each time point.

Texture Analysis

For texture analysis it was used a TA–Hdi Texture Analyser (Stable Microsystems, UK) in compression mode, with a probe of 2 mm diameter (SMS P/2), load cell of 50 kg and test velocity of 0.83 mm s^{-1}. The distance for the probe was set at 22 mm to guarantee that it crossed completely the fruits. A sub-sample of chestnuts, randomly chosen, of each dose was taken at 0, 15 and 30 storage days. After hand peeling, the fruits texture was determined for each, registering the maximum value for the force of penetration.

Statistical analysis

All results were analyzed using the "*Mathematica*" software (version 8, Wolfram Research Inc., USA). A 2-way ANOVA, with "irradiation dose" (ID) and "storage time" (ST) as the main factors, followed by a *Tukey* means comparison at a 5% significant level was performed. When IDxST interaction was detected a means comparison was performed for irradiated and stored samples with non-irradiated and non-stored samples, for each single factor (Montgomery, 2001).

Results

Irradiation doses

The estimated value for the dose rate was 0.80 kGy h^{-1} with an average uniformity dose ratio, D_{max}/D_{min}, of 1.12, which was in conformity with the good practices for food irradiation (EU, 1999). After irradiation processing and dosimeters reading, the estimated doses were 0.50 ± 0.10, 2.92 ± 0.09, 5.62 ± 0.93 kGy, for the irradiated samples. For simplicity, 0.5, 3 and 6 kGy is used along the text.

Physical characteristics

The axial dimensions, arithmetic and geometric diameters, and sphericity as well the mass and density of irradiated chestnut fruits, are presented in Table 1.

Table 1. Physical characteristics of chestnut fruits (*Castanea sativa* Mill.)

m (g)	W (cm)	L (cm)	T (cm)
9.28 ± 1.30	2.82 ± 0.10	3.17 ± 0.21	1.76 ± 0.25
ρ (g cm^{-3})	D_a (cm)	D_g (cm)	Φ
1.14 ± 0.13	2.58 ± 0.19	2.50 ± 0.13	0.79 ± 0.05

Mass (m), width (W), length (L), thickness (T), density (ρ), arithmetic (D_a) and geometric diameters (D_g,), sphericity (Φ).
The results are expressed as mean ± std. dev (n = 15).

The chestnut fruits used in the present study presented similar widths (2.82 ± 0.10) and lengths (3.17 ± 0.21), indicating that the fruits were almost round. The thickness was smaller than the former parameters (1.76 ± 0.25), explaining the sphericity values less than one obtained (0.79 ± 0.05).

Color

The effect of irradiation on chestnut fruits color was measured for each dose after 0, 15 and 30 days of storage at refrigerated conditions after postharvest treatment. The registered Hunter *L*, *a* and *b* parameters is a three-dimensional space for color. In Table 2A and Table 2B we present only the *L* and *b* values for the whole peeled fruit and half-cutted fruit (interior), *a-value* is close to zero (data not shown).

Table 2A. Fruits color parameters (*L*, *b*) of gamma irradiated chestnuts with irradiation dose and storage time.

L-value

	0 days	15 days	30 days
0 kGy	75.15 ± 2.10	75.33 ± 3.98	75.90 ± 1.72
0.5 kGy	75.17 ± 3.63	75.43 ± 1.41	73.72 ± 2.27 *
3 kGy	73.07 ± 3.38	73.00 ± 3.28 *	73.67 ± 3.52
6 kGy	69.90 ± 5.79 *	71.92 ± 3.13 *	74.39 ± 3.92

b-value

	0 days	15 days	30 days
0 kGy	29.60 ± 1.72	28.54 ± 2.15	30.34 ± 2.29
0.5 kGy	29.80 ± 2.32	30.34 ± 2.22	29.21 ± 1.96
3 kGy	29.39 ± 1.18	28.25 ± 2.09	29.20 ± 1.17
6 kGy	26.56 ± 2.25 *	29.62 ± 2.24 #, *	28.83 ± 1.88 #, *

Table 2B. Fruits interior (half-cutted) color parameters (*L* and *b*) of gamma irradiated chestnuts with irradiation dose and storage time.

L-value

	0 days	15 days	30 days
0 kGy	84.67 ± 2.23	84.52 ± 1.96	84.25 ± 2.82
0.5 kGy	84.68 ± 1.96	84.39 ± 1.59	83.38 ± 2.82
3 kGy	85.07 ± 1.72	81.86 ± 2.59 #	84.76 ± 1.49
6 kGy	85.31 ± 1.29	84.38 ± 2.63	83.27 ± 4.52

b-value

	0 days	15 days	30 days
0 kGy	18.80 ± 1.87	18.76 ± 2.50	18.52 ± 2.51
0.5 kGy	18.96 ± 1.30	19.60 ± 0.32	17.50 ± 1.87
3 kGy	19.66 ± 1.62	19.87 ± 2.31	19.08 ± 1.68
6 kGy	17.65 ± 1.87	19.45 ± 1.67 #	19.40 ± 3.23

Values with a superscript, in each row (#) and in each column (*), are significantly different from the non-stored (0 days) or non-irradiated sample (0 kGy), respectively ($p < 0.05$). Results are expressed as mean ± std. dev.

Irradiation dose (ID) and storage time (ST) both affected *L* and *b* color parameters of chestnuts. A statistical analysis for each single factor was performed, and a means comparison for irradiated and stored samples with non-irradiated and non-stored samples, respectively. From the results presented in the tables, storage time (along rows) and irradiation dose (along columns), we could make same considerations. For fruits, significant differences ($p < 0.05$) were observed on *L-value* ("lightness") for the higher dose of 6 kGy at 0 days and for higher storage times at lower doses. For fruits interior, no significant differences were observed in *L-value* with irradiation dose, compared to the non-irradiated samples. For *b-value* ("yellowness") of fruit and fruits interior we did not observed any significant difference for irradiation doses lower than 6 kGy and along storage time up to 30 days. In fruits, for the higher dose of 6 kGy we observed a lowering tendency on *b-value* at 0 and 30 days of storage, maybe due to the stopping of enzymatic processes by the radiation, described by other authors as a ripening delay effect in irradiated fruits (Sabato *et al.*, 2009).

Texture

The texture values, maximum force of probe penetration, for the chestnut fruits subjected to 0, 0.5, 3 and 6 kGy along 0, 15 and 30 days of storage are reported on Table 3.

Table 3. Texture (maximum force, in N) with irradiation dose (ID) and storage time (ST).

ID				
0 kGy	0.5 kGy	3 kGy	6 kGy	p-value (n = 18)
26.3 ± 3.3 [a]	27.4 ± 3.8 [a]	25.1 ± 3.6 [a]	21.9 ± 2.9 [b]	0.0001
ST				
0 days	15 days	30 days	p-value (n = 24)	
25.0 ± 3.0 [a]	25.3 ± 3.6 [a]	25.2 ± 5.1 [a]	0.94	
ST x ID p-value = 0.66				

Values with the same superscript are not significantly different ($p > 0.05$).
The results are expressed as mean ± std. dev.

There's no significant interaction between the factors ST (storage time) and ID (irradiation dose), STxID *p-value* = 0.66, that allows us to make some conclusions regarding each independent factor, presented graphically in whisker-box plots in Figure 1 and Figure 2.

Regarding storage time, no significant differences were detected on texture up to 30 days of storage at refrigerated conditions (Figure 1).

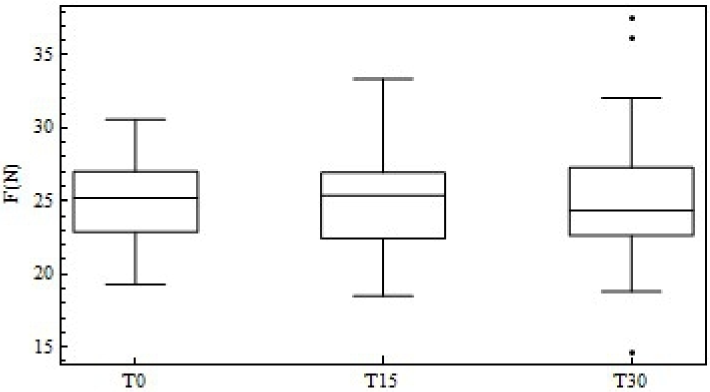

Figure 1. Box plot of fruit texture with storage time.

With irradiation dose, it was observed a significant decrease in chestnut fruits texture only for the higher dose of 6 kGy (Figure 2).

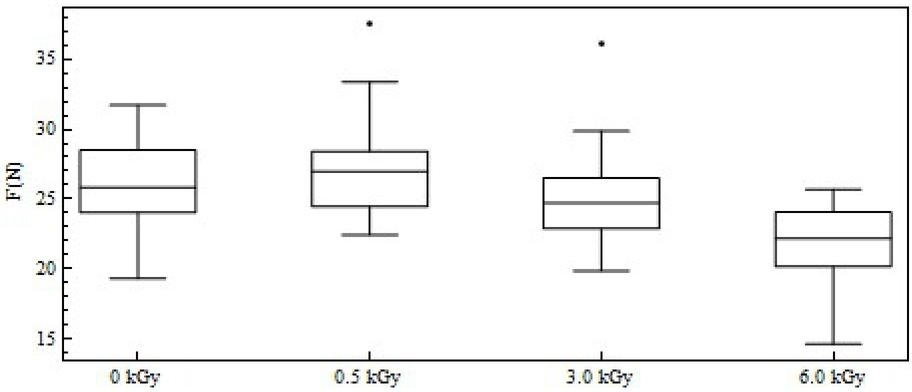

Figure 2. Box plot of fruit texture with irradiation dose.

The softening effect in texture of irradiated fruits may be induced by radiation cell wall breakdown (Gandolph *et al.*, 2007).

Conclusion:

Irradiation postharvest treatment must be validated for each particular fruit. In this study, the effect of gamma irradiation on color and texture of European chestnut fruit varieties, up to 6 kGy and 30 days of storage time, was reported. For *L-value*, significant differences were observed with irradiation on fruits color for the higher dose of 6 kGy after irradiation and only for lower doses at longer storage times. For fruits interior (half-cutted), no significant differences were observed for doses lower than 3 kGy and along storage time, up to 30 days. For the *b* parameter, no significant differences were observed on color for doses lower than 6 kGy and along storage time up to 30 days, for fruits and fruits interior. Regarding texture, changes were observed only for the higher irradiation dose of 6 kGy. With storage time, up to 30 days at refrigerated conditions, it was not observed any significant difference on texture.

With this study it was possible to identify the maximum acceptable dose for irradiation processing of these fruits. The typical doses for quarantine treatment are lower than 3 kGy, so we can conclude that gamma irradiation could be a promising alternative technology for postharvest disinfestation of European chestnuts varieties, to meet food safety international trade regulations, not affecting significantly two important parameters for the consumer, the color and texture.

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References:

Antonio, A.L., Fernandes Â., Barreira J.C.M., Bento A., Botelho M.L., and Ferreira, I.C.F.R. Influence of gamma irradiation in the antioxidant potential of chestnuts (Castanea sativa Mill.) fruits and skins. Food and Chemical Toxicology 49, 2011.

Antonio A.L., Carocho, M., Bento A., Quintana, B., Botelho M.L. and Ferreira, I.C.F.R. Effects of gamma radiation on the biological, physico-chemical, nutritional and antioxidant parameters of chestnuts - A review. Food and Chemical Toxicology 50, 2012.

ASTM E1026: Practice for Using the Fricke Reference Standard Dosimetry System. American Society for Testing and Materials. Annual Book of ASTM Standards, 12.02, Philadelphia, USA, 1992.

EC European Commission Health and Consumer Protection Directorate-General Scientific Committee on Food, Revision of the opinion of the Scientific Committee on Food on the irradiation of food. SCF/CS/NF/IRR/24 Final Report, 2003.

EU Directive 1999/2/EC: On the approximation of the laws of the Member States concerning foods and food ingredients treated with ionizing radiation. Official Journal of the European Communities, L(66/16), 13th March, 1999.

EU Commission Decision concerning the non-inclusion of methyl bromide in Annex I to Council Directive 91/414/EEC and the withdrawal of authorizations for plant protection products containing that substance. Official Journal of the European Union, L(258/68), 26th September, 2008.

EU List of Member States' authorizations of food and food ingredients which may be treated with ionizing radiation. Official Journal of the European Union, C(283), 24th November, 2009.

FAOSTAT Food and Agriculture Organization of the United Nations. Available from: http://faostat.fao.org/site/339/default.aspx, 2011.

FAO/IAEA/WHO Wholesomeness of irradiated food. Report of a Joint FAO/IAEA/WHO Expert Committee. Technical Report Series, 659, World Health Organization, Geneve, Switzerland, 1981.

Gandolph, J. , Shand, A., Stoklosa, A., Ma, A., Weiss, I., Alexander, D., Perchonok, M., and Mauer, L.J. Foods for a Mission to Mars: Investigations of Low-Dose Gamma Radiation Effects. World of Food Science 2, 2007.

INE Portuguese Agricultural Statistics. Instituto Nacional de Estatística I.P., Lisbon, Portugal. http://www.ine.pt. 2011.

Mohsenin N. N. Physical properties of plant and animal materials. Gordon and Breach Sci. Publishers, New York, USA, 1978.

Molins, R. Food Irradiation: Principles and applications. John Wiley & Sons, USA, 2001.

Montgomery D.C. Design and Analysis of Experiments. Wiley & Sons, USA, 2001.

Sabato, S.F., Silva, J.M., Cruz, J.N., Broisler, P.O., Rela, P.R., Salmieri, S. and Lacroix, M. Advances in commercial application of gamma radiation in tropical fruits at Brazil. Radiation Physics and Chemistry 78, 2009.

UNEP. The Montreal Protocol on Substances that Deplete the Ozone Layer. United Nations Environment Programme, 2000.

Vossen, P. Chestnut culture in California. In Publication 8010, Department of Agriculture and Natural Resources, University of California, USA, 2000.

Yildiz M.U., Özcan M.M., Çalisir S., Demir F., Er F. Physico-Chemical properties of wild chestnut (*Castanea sativa* Mill.) fruit grown in Turkey, World Applied Sciences Journal, 6(3), 2009.