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Effect of gamma irradiation on shelf life extension of fresh pasta

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ABSTRACT

The feasibility of extending shelf life of fresh pasta using gamma radiation was evaluated. Microbiological quality and technological and sensorial properties were determined. Commercial gnocchi without chemical preservative was irradiated at doses of 5, 10 and 13 kGy and stored at 7, 15 and 25 °C during 90 days. The 13 kGy dose was effective in reducing the microbial count below the detection limit during storage at 25 °C. The growth of surviving psychrotrophic and mesophilic bacteria and molds and yeasts in pasta irradiated at 5 and 10 kGy was fitted to modified Gompertz and logistic models and kinetic parameters were determined. The gamma radiation did not change the cooking loss but reduced significantly the water absorption. There was no significant difference in the overall impression between control and irradiated samples. Gamma irradiation technology has a great potential to preserve fresh pasta at room temperature for more than 90 days without compromising sensory properties.

1. Introduction

Fresh pasta is a product not submitted to a drying process, with a high moisture content and water activity of approximately 0.96, which favors the growth of many spoilage and pathogenic microorganisms. Preservation of this product requires refrigerated storage and in some cases it is necessary the addition of chemical preservatives and vacuum packaging or modified atmosphere (Del Torre et al., 2004; Resta and Oliveira, 2013; Sanguinetti et al., 2016; Sousa et al., 2016). Besides microbiological quality and safety, long shelf life and sensory characteristics (appearance, color, aroma and flavor) are of most importance to pasta consumers. Therefore, pasta quality attributes including cooking loss, water absorption and firmness must also be considered (Özyurt et al., 2015; Sanguinetti et al., 2015).

Food irradiation has been used to increase the shelf life and safety of several products, reducing losses and occurrence of foodborne diseases (FDA, 2016). Radiation causes DNA and/or protein damage and the generation of free radicals due to radiolysis of the water, which are toxic to cells, leading to bacterial death (Daly, 2009; Trudeau et al., 2012). Free radical can also interact with macronutrients (proteins, lipids and carbohydrates) and with minerals, modifying physical-chemical and sensory characteristics of the food (Bashir and Aggarwal, 2016; Ben Mustapha et al., 2014; Damodaran et al., 2008; Najafabadi et al., 2017; Ocloo et al., 2014; Shi et al., 2015).

Dry products such as spices and pasta are irradiated without significant damage, however, foods with a high moisture content can suffer significant losses in organoleptic properties (development of off-flavors, discoloration and losses of firmness), making it impossible to use gamma radiation to increase the shelf life (Silvestre et al., 2017).

This work aimed to evaluate the use of gamma radiation in order to improve microbiological quality of fresh pasta (gnocchi) during storage at refrigerated and room temperature and the effect on physical, chemical and sensory characteristics.

2. Material and methods

2.1. Fresh pasta

Fresh vacuum-packed gnocchi were purchased in a local market (São Paulo, Brazil) and stored at 7 °C until use. The pasta was produced with the following ingredients: wheat flour enriched with iron and folic acid, potato, egg, vegetable fat, salt and monosodium glutamate. The

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gnocchi label composition per 100 g was: 30 g of total carbohydrate, 4.1 g of protein, 2.7 g of total fat and 150 mg of sodium.

2.2. Irradiation process

The day before the irradiation, the original gnocchi package (with no more than one week of shelf life) was opened, and 30 g (6 units) were repacked in polyethylene bags in the presence of oxygen and refrigerated at 7 °C. Control samples (non-irradiated) were similarly repacked. The Multipurpose Gamma Irradiation Facility equipped with cobalt-60 radiation sources (Radiation Technology Center, IPEN, Brazil) was used to perform the gamma irradiation on samples in Styrofoam boxes at 7 °C, by two-faces stationary irradiation method (Santos and Vasquez, 2015). The irradiation doses 5 (5.2 ± 0.2), 10 (9.8 ± 0.6) and 13 (13.3 ± 0.3) kGy were obtained at a dose rate of 5 ± 1 kGy h^{-1} and measured with Amber Perspex 3042 dosimeters (Harwell Dosimeters, UK).

Both, the control and the irradiated samples were stored at 7 ± 1 °C, 15 ± 1 °C and 25 ± 1 °C during 90 days for the microbiological and physicochemical analysis. The irradiation process was repeated in four independent trials (n = 4).

2.3. Microbiological analysis

Total aerobic mesophilic and psychrotrophic bacteria, and molds and yeasts were determined.

Samples of 10 g were diluted with 90 mL of sterilized saline solution (0.85%) and homogenized for 60 s at 230 rpm on Stomacher 400 (Seward, England). Serial decimal dilutions were performed with the same diluent.

For molds and yeasts enumeration, 0.1 mL of diluted samples was spread-plate in duplicate on Potato Dextrose Agar medium (PDA CM0139, Oxoid LTD, UK) acidified with L (+) tartaric acid PA (ACS, LabSynth, Brazil) to pH 3.5 and incubated at 25 ± 1 °C for 5 days (APHA, 2001). Similarly, for enumeration of mesophilic and psychrotrophic bacteria, 1 mL of diluted samples was pour-plate in duplicate on Plate Count Agar (PCA CM0325, Oxoid LTD, England) and incubated at 36 ± 1 °C for 48 ± 2 h and at 7 ± 1 °C for 10 days, respectively (APHA, 2001).

Analyzes were performed immediately after irradiation and on days 3, 10, 17, 24, 31, 38, 45, 59, 73 and 87 of storage.

2.4. Cooking procedure

The gnocchi cooking procedure was adapted from Alessandrini et al. (2010). A sample of 30 g of pasta was placed in 90 mL of boiling water (1:3) for 5 min, drained for 4 min and cooled at room temperature (~25 °C) for 20 min before analyzing water absorption, color and texture.

This procedure was performed in triplicate for each sample on days 4, 18, 30, 60 and 90 of storage.

2.5. Physicochemical analysis

2.5.1. Proximate composition

Three samples of non-irradiated gnocchi were analyzed for moisture (AOAC 926.07) and ash (AOAC 925.11A) according to the Official Methods of Analysis of AOAC (AOAC, 2011). The content of protein (AACC 46–13) and fat (AACC 30–25) were determined following the American Association of Cereal Chemists (AACC) (AACC, 1995). Total carbohydrate was calculated by difference (Yokoyama et al., 1997). For each sample, analyzes were carried out in triplicate for moisture and ash, and repeated five times for protein and fat.

2.5.2. Water activity and pH

Water activity (Aw) of raw gnocchi (non-irradiated) and irradiated samples during storage were determined using the Decagon AquaLab 3TE equipment (Decagon Devices, Inc., Pullman, Washington, USA). The pH was determined only for the non-irradiated gnocchi (AOAC 940.23) using a pH meter (mPA210, MS Tecnopon Instrumentação, Piracicaba, BR) (AOAC, 2011). The analyzes were performed in triplicate.

2.5.3. Cooking quality

Equations (1) and (2) (Köksel et al., 1996; Özyurt et al., 2015; Tudorica et al., 2002) were used to determine the water absorption and cooking loss. The analyzes were performed in triplicate only on the fourth day of storage.

$$\text{Water absorption}(\%) = \frac{weight_{cooked\ gnocchi}(g) - weight_{raw\ gnocchi}(g)}{weight_{raw\ gnocchi}(g)} x100 \tag{1}$$

$$\text{Cooking loss}(\%) = \frac{weight_{dry\ residue}(g)}{weight_{raw\ gnocchi}(g)} x100 \tag{2}$$

2.5.4. Texture analysis

A texture analyzer (TA.XT2i Upgrade, Stable Micro Systems Ltd., Surrey, UK), equipped with a 30 kg load cell, was used to evaluate the firmness (kN) of the gnocchi, irradiated or not, after cooking.

In addition, an aluminum probe (diameter 90 mm x thickness 5 mm) at a work platform model HDP/90 was used. The distance between the probe and the platform was set at 20 mm, test speed was 2.0 mm s^{-1}, post-test speed was 10.0 mm s^{-1} and the sample was compressed at 80% as recommended by the equipment manufacturer. This method is in accordance with some studies that evaluated the texture in gnocchi and potato cubes (Alessandrini et al., 2010; García-Segovia et al., 2008; Sanguinetti et al., 2015).

Three cooked gnocchi units were placed on the platform, and the compression test was carried out in triplicate for each sample, immediately after irradiation and on days 4, 18, 30, 60 and 90 of storage.

2.5.5. Color measurement

A ColorQuest XE colorimeter (Hunter Lab Inc., Reston, VA, USA) and EasyMatchQC software version 4.77 were used to evaluate the color of cooked and uncooked gnocchi, irradiated or non-irradiated.

The gnocchi color was determined using the CIELab system, Illuminant D65, angle 10°, where the parameters L*, a* and b* were obtained (Bashir and Aggarwal, 2016; Najafabadi et al., 2017).

The total color difference was calculated using Equation (3) and the non-irradiated sample at the first day of storage at 7 °C was the reference color.

$$\Delta E^* = \sqrt[2]{\Delta L^2 + \Delta a^2 + \Delta b^2} \tag{3}$$

The tests were performed in quadruplicate, immediately after irradiation and on days 7, 15, 30, 60 and 90 of storage for raw gnocchi and 4, 18, 30, 60 and 90 of storage for cooked gnocchi.

2.6. Mathematical model and data analysis

Experimental microbiological data were assigned in the USDA Integrated Pathogen Modeling Program (IPMP) 2013 (Huang, 2013). The data were fitted using a logistic model (Equation (4)) (Fang et al., 2013, 2012), suitable for growth curve without lag phase; and the modified Gompertz model (Equation (5)) (Zwietering et al., 1990).

$$y(t) = y_0 + y_{max} - ln\{\exp(y_0) + [\exp(y_{max}) - \exp(y_0)]exp(-\mu_{max}t)\} \tag{4}$$

$$y(t) = y_0 + (y_{max} - y_0)\ exp\left\{-exp\left[\frac{\mu_{max}\ e}{y_{max} - y_0}(\lambda - t) + 1\right]\right\} \tag{5}$$

Where t is the storage time [h]; y_0, y_{max} and $y(t)$ is the natural logarithm of the cell concentration [ln CFU g^{-1}] over time: initial, maximum and t, respectively; μ_{max} is the specific growth rate [h^{-1}]; λ is the duration of lag phase [h] and e is the Euler's number.

The fitting and the accuracy of the predict models were evaluated using the statistical indices: Mean Square Error (RMSE) (Equation (6)), coefficient of determination (R^2) (Equation (7)), accuracy factor (A_f) (Equation (8)) and bias factor (B_f) (Equation (9)) (Barnston, 1992; Huang, 2016; Lee et al., 2015; Longhi et al., 2018; Ross et al., 2000).

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{n-p}} \quad (6)$$

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2} \quad (7)$$

$$A_f = 10^{\frac{\left[\sum_{i=1}^{n}\left|\log\left(\frac{\hat{y}_i}{y_i}\right)\right|\right]}{n}} \quad (8)$$

$$B_f = 10^{\frac{\left[\sum_{i=1}^{n}\log\left(\frac{\hat{y}_i}{y_i}\right)\right]}{n}} \quad (9)$$

Where y_i is the observed values in the experiment at time i; $\hat{y}_i$ is the predicted values by the model at time i; $\bar{y}$ is the average value of the observations in the experiment; n is the number of experimental data and p is the number of parameters of the model.

2.7. Sensory evaluation

Non-irradiated and irradiated (10 and 13 kGy) fresh gnocchi were subjected to the acceptance test with monadic presentation (one sample served at a time, and all attributes rated for that sample) using a nine-point hedonic scale ranging from 9 (extremely like) to 1 (extremely dislike) for each sensory characteristic. The samples, stored under refrigeration, were evaluated 5 days after the irradiation treatment.

Gnocchi was prepared according to Silva et al. (2016). The samples were cooked as described previously and served warm with tomato sauce, as they are commonly eaten and presented in a monadic form. The samples were presented randomly.

One hundred and twenty-six (126) untrained consumers (52% women; age: 18–51 years) evaluated color (sample presented without tomato sauce), aroma, texture, flavor and overall impression in a sensory analysis laboratory with individual booths (Azzeh and Amr, 2009; Li et al., 2011; Özyurt et al., 2015; Sanguinetti et al., 2016; Tomac et al., 2017).

2.8. Experimental design and statistical analysis

The experiments were repeated in four independent trials (the irradiation process was repeated four times) and the results were expressed as mean ± standard deviation. The data were analyzed by ANOVA (General Linear Model) and means were compared using Tukey's multiple range tests. t-Student test was used to compare the lag phase parameter. Sensorial data were analyzed using ANOVA (two-way analysis of variance) and Duncan's test. Statistical analysis was performed using Minitab® 16.1.1 Statistical Software (Minitab Inc., State College, PA, US) at a significance level of 5%.

3. Results and discussion

3.1. Pasta characterization

The result of the proximate composition of the commercial gnocchi was similar to that of the packaged label. Moisture, ash, protein, fat and carbohydrate contents were: 57.4 ± 1.8%, 1.27 ± 0.08%, 4.65 ± 0.14%, 0.97 ± 0.08% and 35.7 ± 1.7%, respectively. The water activity was 0.975 ± 0.001 and the pH value was 5.1 ± 0.3.

3.2. Microbiological assessment

Fresh gnocchi showed a high count of mesophilic and psychrotrophic bacteria and molds and yeasts before the irradiation, 8.5 ± 0.3 log CFU g^{-1}, 8.4 ± 0.3 log CFU g^{-1} and 4.4 ± 0.2 log CFU g^{-1}, respectively. Irradiation at 5 kGy significantly ($p < 0.05$) decreased mesophilic and psychrotrophic counts by 6.7 log CFU g^{-1} and 6.6 log CFU g^{-1}, respectively, while the reduction in molds and yeasts was 2.0 log CFU g^{-1}. The higher doses, 10 and 13 kGy reduced counts below the detection limit (1.0 log CFU g^{-1} for mesophilic and psychrotrophic bacteria and 2.0 log CFU g^{-1} for molds and yeasts).

Similarly, initial reductions of 2.95 log CFU g^{-1} in the number of molds and yeasts in fresh cannelloni stuffed with ricotta irradiated at 4 kGy were obtained by Narvaiz et al. (2003). Ben Mustapha et al. (2014), also observed a decrease in more than 4.9 log CFU g^{-1} and 2.4 log CFU g^{-1} on mesophilic bacteria and molds and yeasts, respectilely, in Tunisian millet flour irradiated at 5 kGy.

During storage, no growth was observed on irradiated samples at 13 kGy stored at 7, 15 and 25 °C and at 10 kGy, refrigerated at 7 °C, for 87 days. However, samples irradiated at 5 kGy and the control (non-irradiated), maintained at 15 and 25 °C, showed visible deterioration at the 10th day. When those samples were stored at 7 °C, visible spoilage by molds was observed at 24th day. Although the initial populations of mesophilic and psychrotrophic bacteria in gnocchi irradiated at 10 kGy were less than 1 log CFU g^{-1}, they increased to 6.1 ± 0.7 log CFU g^{-1} and 6.4 ± 0.4 log CFU g^{-1}, respectively, after 10 days at 25 °C. Molds and yeasts also increased to 5.2 ± 0.6 log CFU g^{-1} in the same period and temperature (Fig. 1).

The higher the radiation dose, the deeper the DNA and/or protein damage to microorganism cells; and the closer to the optimum growth temperature the product is stored, the faster the cells can repairs the damage (Marques and Da Costa, 2013; Trudeau et al., 2012). When the gnocchi irradiated at 10 kGy was stored at 25 °C (favorable temperature for growth of microorganisms), there was a faster recovery of mesophilic and molds and yeast when compared to those stored at 15 °C. Moreover, psychrotrophic bacteria could not growth in gnocchi irradiated at 10 kGy stored at 7 and 15 °C (Fig. 1).

The modified Gompertz model or Logistic model was fitted to experimental sets of data of samples that showed growth of microorganisms during storage (Fig. 1). The estimated parameters and statistical indices are shown in Table 1. The values of y_0, y_{max} and $y(t)$ obtained through the IPMP 2013 program were converted to $\log_{10}$ CFU g^{-1}.

In general, models showed a reasonably good fit to the data. The coefficient of determination (R^2) ranged from 0.723 to 0.991 and the Mean Square Error (RMSE) from 0.324 to 2.502. Ideally predictive models would have A_f and B_f equal to 1 (Ross, 1999). It can be seen in Table 1 that all values of accuracy and bias factors are very close to 1, indicating good models. Bias factor is a measure that indicates whether a model is underestimating or overestimating the growth rates. $B_f > 1$ indicates that the model is dangerous because it provides longer generation times than observed, potentially leading to underestimated predictions. On the other hand, $B_f < 1$ indicates that a model is generally safe and conservative, indicating an overestimated model (Ross, 1999; Ross et al., 2000).

The lag phase was observed only in samples irradiated at 10 kGy and varied between 77 to 82 h (approximately 3 days) for mesophilic bacteria with no significant ($p > 0.05$) difference between storage temperature. For molds and yeasts the lag phase increased significantly ($p < 0.05$) from 81 to 138 h when temperature was reduced to 15 °C. On the other hand, the dose of 13 kGy caused damage so deep that cells were unable to recover their DNA and multiply again. The dose of 5 kGy caused little damage to the DNA structure, allowing cells to repair the damage more easily, and no lag phase was observed. Non-irradiated microorganisms also did not show a lag phase. The presence of lag phase at higher irradiation dose was also observed by Tomac et al. (2013) for psychrotrophic bacteria in squid rings. Samples irradiated at

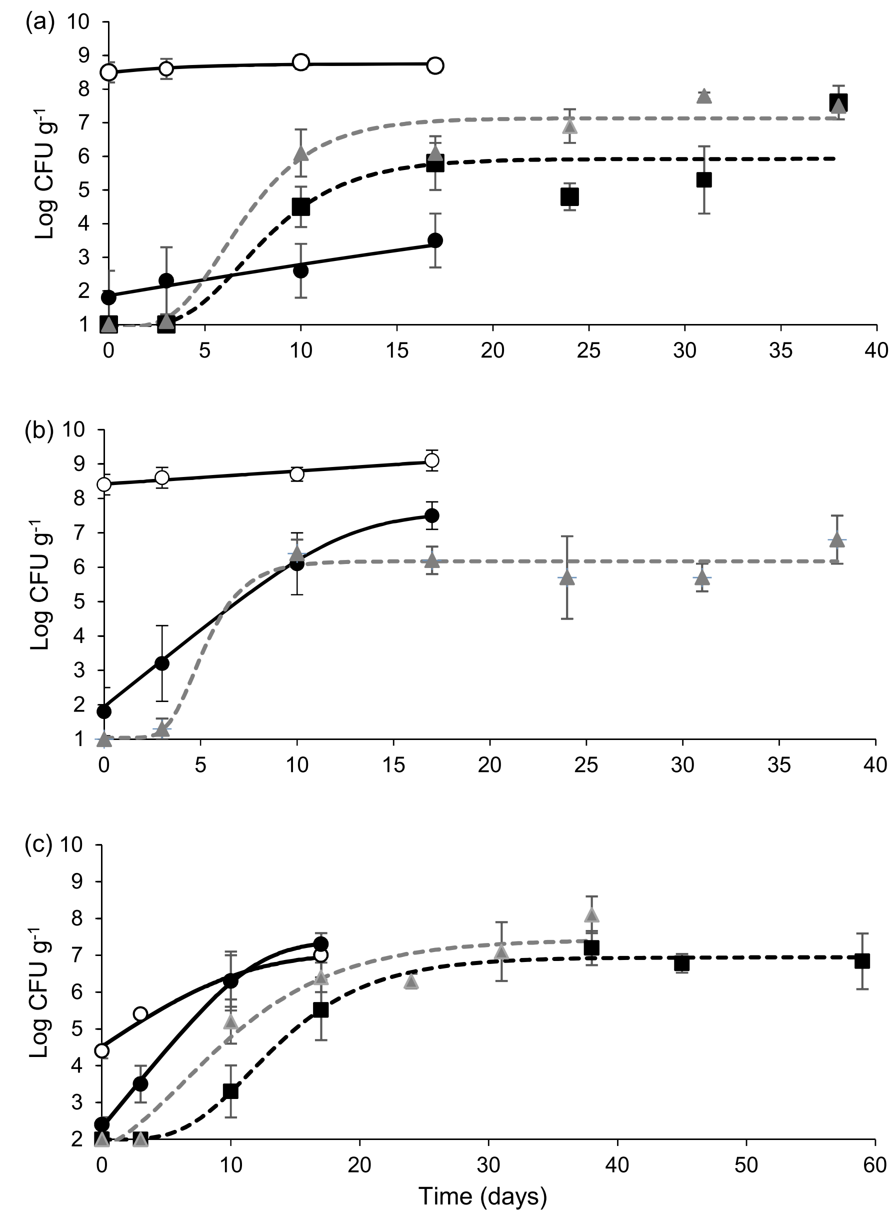

Fig. 1. Counts of (a) aerobic mesophilic bacteria, (b) aerobic psychrotrophic bacteria and (c) molds and yeasts in fresh gnocchi subjected to the following treatment: 0 kGy–7 °C (○); 5 kGy–7 °C (●); 10 kGy–15 °C (■) and 10 kGy–25 °C (▲); fitted by the models: (—) logistic model and (···) modified Gompertz model, for 59 days. Data are mean (n = 4) ± standard deviation.

Table 1
Values of the estimated parameters y_0 [$\log_{10}$ CFU g^{-1}], y_{max} [$\log_{10}$ CFU g^{-1}], λ [h] and μ_{max} [h^{-1}] and the statistical indexes *RMSE*, B_f, A_f and R^2 of the models that best fit each growth curve to the experimental data.

Microorganism	Treatment	Fitted model	Estimated parameters				Statistical indexes			
			y_0	y_{max}	λ	μ_{max}	*RMSE*	B_f	A_f	R^2
Mesophilic	0 kGy-7 °C	LM[a]	$8.7^{A} \pm 0.1$	$8.9^{A} \pm 0.1$	–	$0.014^{B} \pm 0.012$	0.324	1.004	1.009	0.723
	5 kGy-7 °C	LM	$1.9^{B} \pm 0.8$	$3.5^{C} \pm 0.6$	–	$0.010^{B} \pm 0.001$	1.376	0.987	1.191	0.812
	10 kGy-15 °C	MG[b]	$0.9^{B} \pm 0.1$	$5.8^{B} \pm 0.9$	$82^{A} \pm 16$	$0.049^{AB} \pm 0.016$	2.502	0.971	1.154	0.854
	10 kGy-25 °C	MG	$0.9^{B} \pm 0.1$	$7.1^{B} \pm 0.2$	$77^{A} \pm 13$	$0.073^{A} \pm 0.032$	1.336	0.997	1.095	0.975
Psychrotrophic	0 kGy-7 °C	LM	$8.4^{A} \pm 0.3$	$9.2^{A} \pm 0.3$	–	$0.006^{B} \pm 0.003$	0.487	0.997	1.017	0.842
	5 kGy-7 °C	LM	$1.9^{B} \pm 0.9$	$7.5^{B} \pm 0.3$	–	$0.042^{B} \pm 0.011$	1.629	1.034	1.186	0.948
	10 kGy-25 °C	MG	$1.0^{B} \pm 0.0$	$6.2^{B} \pm 0.1$	72 ± 9	$0.140^{A} \pm 0.036$	0.970	1.006	1.060	0.974
Molds and yeasts	0 kGy-7 °C	LM	$4.4^{A} \pm 0.1$	$6.6^{A} \pm 0.4$	–	$0.030^{A} \pm 0.004$	0.657	1.004	1.031	0.956
	5 kGy-7 °C	LM	$2.4^{B} \pm 0.2$	$7.3^{A} \pm 0.0$	–	$0.036^{A} \pm 0.008$	1.050	1.009	1.072	0.991
	10 kGy-15 °C	MG	$2.0^{C} \pm 0.1$	$7.1^{A} \pm 0.3$	$138^{A} \pm 49$	$0.033^{A} \pm 0.008$	1.166	1.035	1.054	0.938
	10 kGy-25 °C	MG	$1.9^{BC} \pm 0.1$	$7.0^{A} \pm 0.8$	$81^{B} \pm 27$	$0.051^{A} \pm 0.024$	1.432	1.002	1.080	0.946

- Parameter nonexistent in Logistic model. A - B, means in a column for the same group of microorganisms that do not share uppercase letters, differ significantly ($p < 0.05$).

[a] Logistic model (no lag phase).

[b] Modified Gompertz model.

higher doses have a lower microbial population and these cells are seriously injured and require more time to repair damage before start to growth.

The increase in temperature storage from 15 to 25 °C in the irradiated samples with 10 kGy increased y_{max} values by 1.3 log CFU g^{-1} for mesophilic bacteria, however the difference was not significant ($p > 0.05$). The predicted y_{max} for mesophilic and psychrotrophic bacteria were smaller in irradiated samples, regardless of storage temperature. On the other hand, y_{max} for molds and yeasts, in samples irradiated at 5 kGy and 10 kGy, did not differ significantly ($p > 0.05$) from the control sample. For samples irradiated at 10 kGy, the maximum specific growth rate (μ_{max}) increased with higher storage temperature for mesophilic bacteria and mold and yeast, although differences were not significant ($p > 0.05$).

3.3. Water activity, water absorption, cooking loss, firmness and color measure

Besides microbiological quality, technological parameters are very important for evaluation of gnocchi self-life. The water activity of the control and irradiated samples remained constant (0.975 ± 0.03) regardless of temperature and storage time (data not shown), being in agreement with other authors (Alessandrini et al., 2010; Del Torre et al., 2004; Sanguinetti et al., 2016).

Irradiation significantly decreased ($p < 0.05$) the fresh gnocchi ability to retain water during cooking (Fig. 2). This could be attributed to the destruction of crystalline ordering granules in potato and wheat starch by irradiation, which change the gelatinization process and decrease the susceptibility to water absorption (Bhat and Karim, 2009). According to Azzeh and Amr (2009) doses above 5 kGy cause partial damage to the structure of the gluten network that loses its ability to retain water. In addition, some studies have shown that the higher the dose of radiation applied to carbohydrates, the greater the depolymerization (Bao and Corke, 2002; Bashir and Aggarwal, 2016; De Kerf et al., 2001). For some samples a negative water absorption was observed, which means no water absorption and a loss of solid content during cooking. A reduction of water absorption was also observed by Oliveira et al. (2014) in pasta (talharim) irradiated with 20 kGy.

The percentage of cooking loss during the 5 min of cooking of the fresh gnocchi with 4 days of storage ranged from 1.5% for the control sample stored at 7 °C to 2.1% for samples irradiated at 13 kGy and

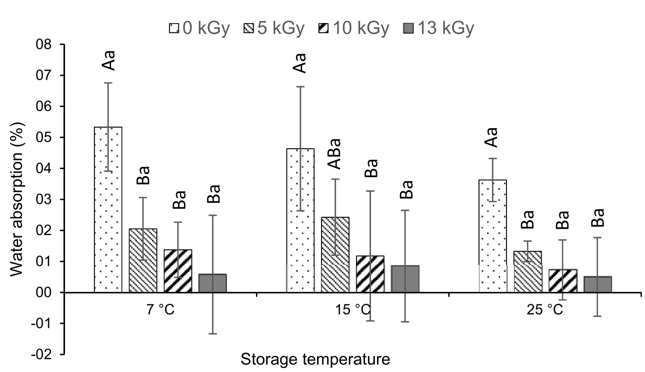

Fig. 2. Water absorption of the gnocchi (control and irradiated) stored at 7, 15 and 25 °C, with 4 storage days. A - B, means that do not share uppercase letters, for different radiation doses at the same temperature storage, differ significantly ($p < 0.05$); a - c, means that do not share lowercase letters, for different storage temperature at the same radiation dose, differ significantly ($p < 0.05$). Data are mean ($n = 4$) ± standard deviation.

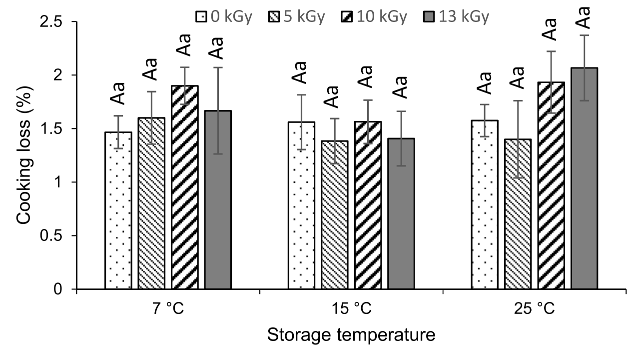

Fig. 3. Cooking loss during gnocchi cooking at three storage temperatures and all radiation doses with 4 storage days. A; a: means that share lower or uppercase letters, for the same storage temperature and radiation dose, does not differ significantly ($p > 0.05$). Data are mean ($n = 4$) ± standard deviation.

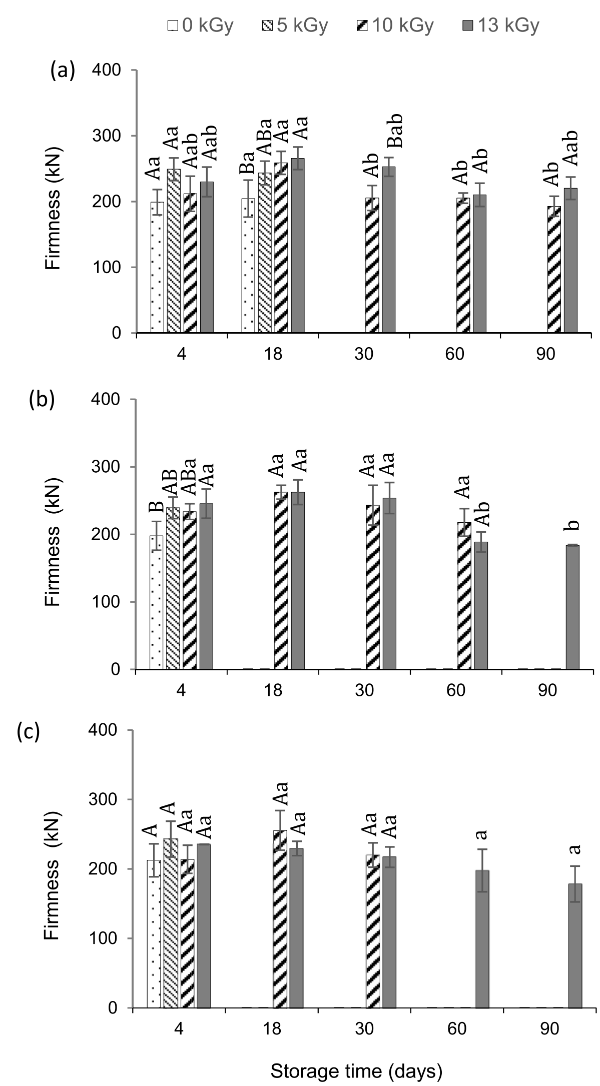

Fig. 4. Firmness of gnocchi (control and irradiated), stored at 7 (a) 15 (b) and 25 °C (c). A - B, means that do not share uppercase letters, for the same time and temperature storage, differ significantly ($p < 0.05$); a - b, means that do not share lowercase letters, for the same storage temperature and radiation dose, differ significantly ($p < 0.05$). Data are mean ($n = 4$) ± standard deviation.

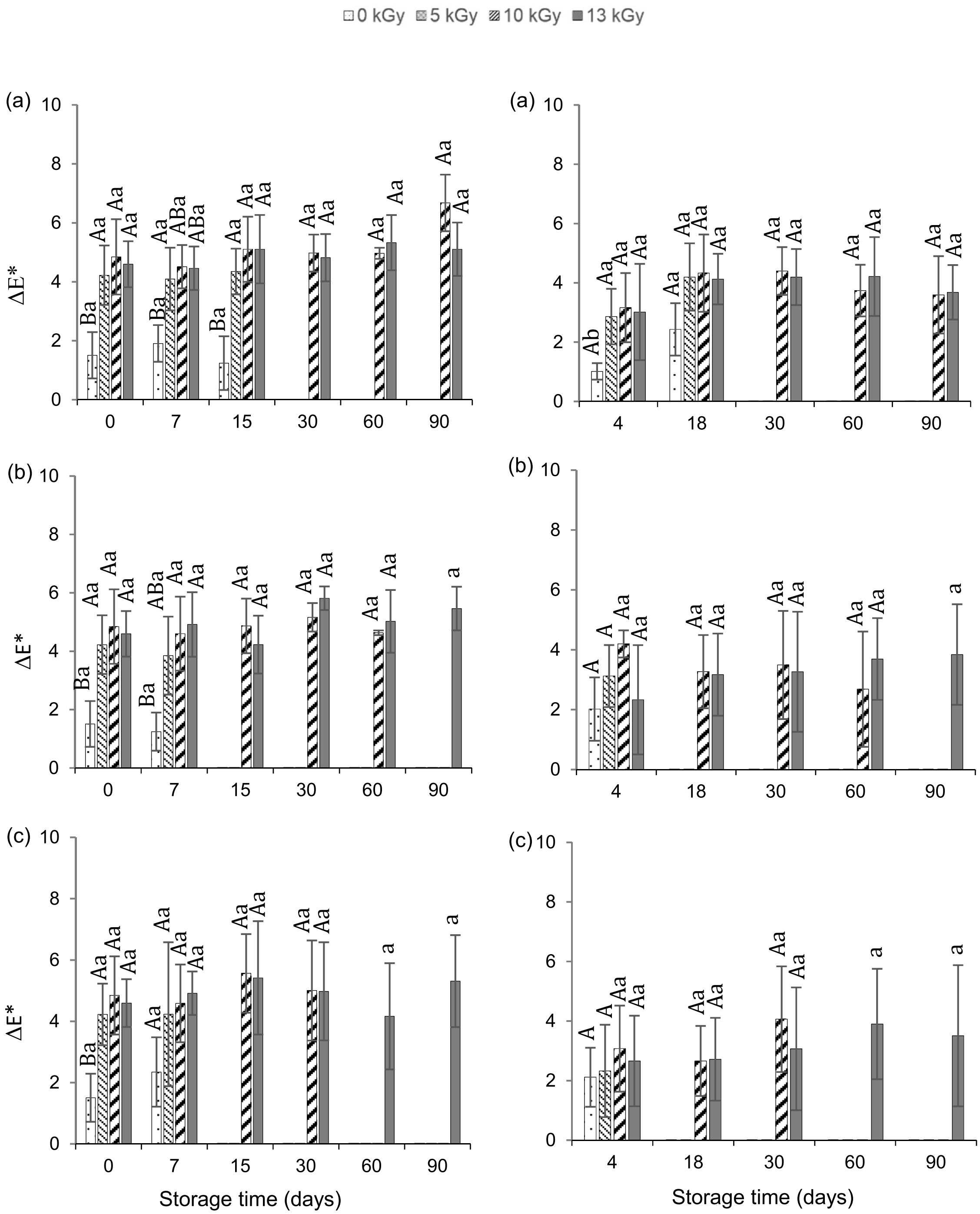

Fig. 5. ΔE* values of the raw (left) and cooked (right) gnocchi samples stored at 7 (a), 15 (b) and 25 °C (c), during 90 days. A - B, means that do not share uppercase letters, for the same time and temperature storage, differ significantly ($p < 0.05$); a, means that share lowercase letters, for the same storage temperature and radiation dose, does not differ significantly ($p > 0.05$). Data are mean ($n = 4$) ± standard deviation.

stored at 25 °C. However, the differences were not significant ($p > 0.05$) (Fig. 3). These values are similar to those found by Alessandrini et al. (2010) which obtained a cooking loss for irradiated gnocchi between 0.2% and 1.7%. On the other hand, Azzeh and Amr (2009) reported an increase in cooking loss in lasagna irradiated at doses between 2.5 and 10 kGy. This could be explained by starch degradation to dextrins, maltose and glucose, which are soluble in water and more difficult to entrap in gluten network resulting in an increase in water soluble residues.

After cooking, there was a significant difference in firmness between the control and the irradiated sample at 13 kGy only on the 4th day of storage at 15 °C; and between the control and irradiated samples at 10 and 13 kGy on the 18th day of storage at 7 °C (Fig. 4). The increase in firmness may be related to the decrease in water absorption of irradiated samples. When considering the texture of the cooked samples over the storage time, a significant reduction of the firmness of the 10 kGy irradiated samples were observed after 30 days when stored at 7 °C and of samples irradiated at 13 kGy after 60 days when stored at 7 °C and 15 °C ($p < 0.05$).

Regarding to raw gnocchi color, irradiation significantly ($p < 0.05$) increased ΔE* in relation to non-irradiated gnocchi in approximately 3 units. ΔE* values above 2.3 units indicate visual

Table 2
Means of the scores attributed by the 126 testers for each evaluated attribute. The analysis was carried out 5 days after the irradiation treatment.

Attribute	Radiation dose		
	Control	10 kGy	13 kGy
Color	7.6^a	7.3^b	7.3^b
Aroma	7.3^a	7.2^a	7.2^a
Texture	7.1^a	7.1^a	6.8^a
Flavor	7.3^a	7.1^a	6.9^a
Overall impression	7.4^a	7.2^a	7.1^a

a - b, means that do not share lowercase letters, 0;0.05). Data are mean ($n = 126$).

difference from the control sample (Becherini et al., 2017; Inam et al., 2017; Mahy et al., 1994). After cooking the gnocchi, the control sample showed lower ΔE* values, especially when stored at 7 °C, however this difference was not significant ($p > 0.05$) (Fig. 5).

3.4. Sensory evaluation

Sensory analysis was performed with gnocchi irradiated at 10 kGy and 13 kGy and with non-irradiated samples (Table 2).

High doses of radiation are expected to affect the gnocchi's sensory quality, making them different from the standard. For this reason, the test was carried out by individually, evaluating the degree of acceptance of each sample and not the difference between them. It is worth mentioning that the results do not indicate qualitative differences between samples, but the degree of acceptance by the final consumer.

The color was the only attribute that showed a significant difference ($p < 0.05$) between the control and the irradiated samples at 10 and 13 kGy. Although the other attributes did not differ significantly ($p > 0.05$), it was possible to verify a slight reduction of the mean score with the increase in irradiation dose. It was expected a significant reduction in acceptability of irradiated samples as observed by others studies that irradiated lasagna (Azzeh and Amr, 2009) and chiffon cakes (Sirisoontaralak et al., 2017) at a dose of 10 kGy. However, even using higher doses of radiation (13 kGy), in our study, the acceptance of irradiated gnocchi was similar to control gnocchi. Some consumers attributed higher scores for the irradiated samples and justified their scores by stating that the gnocchi did not taste like flour.

4. Conclusion

Despite the high water content of fresh pasta (gnocchi), the use of gamma radiation at 13 kGy was effective to maintain shelf stability of gnocchi (without chemical preservative and modified atmosphere) at room temperature (25 °C) for 90 days with no loss of sensorial quality (overall impression) and cooking quality (color and texture of cooked gnocchi), guaranteeing a good microbiological quality. When refrigeration was combined as an additional method of preservation, the dose of 10 kGy was enough to obtain the same result.

CRediT authorship contribution statement

Marcella Cassares: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing - original draft. **Natalia L. Sakotani:** Investigation, Validation. **Leo Kunigk:** Conceptualization, Writing - review & editing, Funding acquisition. **Pablo A.S. Vasquez:** Resources, Writing - review & editing. **Cynthia Jurkiewicz:** Conceptualization, Methodology, Validation, Formal analysis, Writing - review & editing, Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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