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Physico-chemical and sensory evaluation of potato (*Solanum tuberosum* L.) after irradiation

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ABSTRACT

This work evaluated the effects of ionizing radiation on the physico-chemical and sensory characteristics of the potato cultivar Ágata (*Solanum tuberosum* L.), including budding and deterioration, with the end goal of increasing shelf life. For this, four groups of samples were harvested at the maturation stage. Three of them were separately exposed to a Co-60 source, receiving respective doses of 0.10, 0.15 and 2.00 kGy, while the non-irradiated group was kept as a control. All samples were stored for 35 days at 24 °C (± 2) and at 39% relative humidity. The following aspects were evaluated: budding, rot, loss of weight, texture, flesh color, moisture, external and internal appearance, aroma, soluble solids, titratable acidity, vitamin C, protein, starch and glucose. The results indicated that 0.15 kGy was the most effective dose to reduce sprouting and post-harvest losses, under the conditions studied.

Key words: conservation, irradiation, potato, spoilage, storage.

INTRODUCTION

Potato (*Solanum tuberosum* L.) is the third most important food crop in the world after rice and wheat (FAO 2010). In addition to its culinary versatility, the potato has the advantage of being a low-cost product, so it is available to all social classes (Filgueira 2003).

Today, this vegetable is the most important food in terms of volume of consumption and economic value. For example, in Brazil, the potato, along with the onion and tomato, are the most economically viable, in terms of volume produced and income generated (Costa et al. 2007). In 2010, Brazil produced a total of 3,459,183 tons of potatoes, with 8.5% of this total being produced in the northeast region, mostly in the states of Paraíba and Bahia, the latter with 290,680 tons per year (Agrianual 2011).

The Ágata cultivar is a variety originating from Holland created by crossing the cultivars Böhm52/72 and SIRCO. This cultivar has become the most widely planted cultivar in Brazil because of its characteristics of productivity and due to its visual acceptance by consumers with regards to the external aspects of this vegetable (ABBA 2010).

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Despite all of the attractive features that encourage its cultivation, the potato is the subject of various biodegradation processes during its cultivation, harvest, transport and storage, caused by pest attacks, micro-organisms and budding. To minimize these types of losses, different processes of conservation, such as gamma irradiation, have been employed (Prado et al. 2008).

Irradiation improves food preservation and is a process where fruits and vegetables, already packaged or in bulk, undergo a controlled amount of radiation. However, dose levels of radiation useful for improving food shelf life can adversely affect their sensory quality (Rocha and Sousa 2007).

In this context, this study was designed to evaluate the effects of gamma radiation on the physico-chemical and sensory characteristics of the potato cultivar Ágata, especially studying the effects of sprouting and spoilage during storage.

MATERIALS AND METHODS

Collection and Preparation of Samples

Potatoes, cultivar Ágata, were harvested at full physiological maturity for a period of approximately ten days and were commercially obtained in the city of Recife-Brazil and taken to the Laboratory of Post-harvest at the Regional Center of Nuclear Sciences (CRCN/NE). Samples were selected based on weight (± 100 g for each sample) and the absence of mechanical damage.

Experimental Procedures

The samples were packed in polyethylene bags (low density) and were irradiated at the Laboratory of Ionizing Radiation Metrology of the Nuclear Energy Department, (UFPE-Brazil) using a ^{60}Co source Gammacell (dose rate: 4,658 kGy / h, model 220 - MDS Nordion Excel) at doses of 0.10, 0.15 and 2.00 kGy. These doses were chosen according to the recommendations of the Food and Drug Administration-USA concerning the use of radiation for treatment of food (FDA 1995).

A total of 120 tubers were selected for the experiment. From this total, 40 tubers were divided into 4 groups (each containing 10 specimens), with one group kept as the control and the other three being exposed separately to 0.10, 0.15 and 2.00 kGy to evaluate sensory and percentage weight loss analyses. For physico-chemical analyses, the remaining 80 tubers were divided into 4 groups with 5 tubers for each dose of irradiation: zero (control), 0.10, 0.15 and 2.00 kGy.

After irradiation, all of the potatoes were stored at a temperature of 24 °C (± 2) with 39% relative humidity for 35 days. During this period, control and irradiated groups were evaluated every seven days for sprouting, rotting and weight loss percentages. Samples targeted for physical and chemical analyses were peeled, packed in low density polyethylene bags and stored at -18 °C.

Affective Sensory Comparative Analyses

The affective sensory comparative method was performed according to the methods of Reis and Minim (Reis and Minim 2006), with the participation of 40 untrained volunteers who were aged 18 or over and who described the general characteristics of external and internal appearance as well as the aroma of each specimen. These observations were recorded using a nine-point scale, varying from 1 (poor) to 9 (excellent).

For the analysis of the external appearance, the evaluators (volunteers) pointed out which samples they preferred. For this, potatoes were distributed in styrofoam trays that were numbered with three different digits and were evaluated in individual booths. Using this methodology, it was possible to score the level of acceptability for each dose studied.

Weight Loss (%) and Pulp Texture

Weight loss was evaluated every seven days during storage by the difference of the initial and final weights of each tuber.

The pulp texture was evaluated at the end of storage using a penetrometer (Tr-Turoni, Forlì-Italy) with an 8-mm diameter flat probe. The analysis was performed with two readings that were evenly distributed in the middle parts of the 80 tubers for a total of 160 measurements.

PHYSICO-CHEMICAL ANALYSES

Physico-chemical analyses were based on routinely used standard methods at the Laboratory of Bromatology at the Academic Center of Vitória de Santo Antão (CAV/UFPE) and are presented in Table I.

The physico-chemical analyses were performed with shredded pulp obtained using a household blender, with two replicates per sample as described below.

Color of flesh

For the evaluation of the flesh color, a colorimeter was used (Minolta model CR- 300, the operating system D65 illuminant and standard observer 2). Readings were taken across the entire pulp, and the results were expressed using the color parameters L* (lightness pulp), a* (changes from red a+ to green a-) and b* (changes from yellow b+ to blue b-).

Humidity (%)

The moisture content was measured using the gravimetric method, and the weight loss of the samples was measured after heating at 105 ºC to achieve a constant weight. Two replicates per sample were performed.

Soluble solids (°Brix)

The soluble solids were determined for the pulp using a refractometer (ATAGO Model PZO RR11, No. 20700, 0-35 Brix, temperature compensated to 20 °C).

Titratable acidity (%)

Titratable acidity (%) was determined by visual titration with 0.1 N NaOH solution until there was a change to pink in the color of the solution, due to the addition of a phenolphthalein indicator.

Vitamin C (mg/100g)

The main reactant in the determination of vitamin C content was 2-6 phenolphthaleins. The results were expressed in mg of ascorbic acid per 100 g of pulp.

Starch (%)

Starch was determined in the remaining portion of the sample by titrating with a correction factor of 0.90.

Sugar reducer (glucose - %)

Glucose was determined in the filtered sample by titrating with a correction factor of 0.95.

TABLE I
References used to analyze the physico-chemical parameters.

REFERENCE WORKS	ANALYZED PARAMETER			
IAL - Instituto Adolfo Lutz (1985)	Soluble solids (°Brix)		Titratable acidity (%)	
IAL - InstitutoAdolfo Lutz (2005)	Humidity (%) **012/IV method**	Starch (%) **043/IV method**	Sugar reducer (Glucose %) **038/IV method**	Total Protein (%) **037/IV method**
Carvalho et al. (1990)	Vitamin C (mg/100 g)			
McGuirre (1992)	Color of flesh (L*, a*,b*)			

L* (lightness pulp), a* (changes from red a+ to green a-) and b* (changes from yellow b+ to blue b-).

Total protein (%)

Total protein was measured using an acid-based digestion of organic matter followed by Kjeldahl distillation, and nitrogen was subsequently dosed by titration. The value of nitrogen was multiplied by the conversion factor of 6.25.

Statistical analyses

Statistical analyses were performed using the statistical software BioStat 5.0. For the physicochemical factors, data were submitted to one way ANOVA followed by Tukey's post hoc test. For the analyses related to texture and percentage cumulative weight loss, ANOVA was used for paired samples (Gomes 2002). The non-parametric Mann Whitney test was used for comparative evaluation of the affective sensory analysis. The analyses were performed at a significance level of 5%.

RESULTS AND DISCUSSION

Percentage of Potatoes with Sprouting and Rot

It was observed that all potatoes in storage irradiated with doses of 0.10 and 0.15 kGy showed a slower sprouting than control samples and, subsequently, sprouting ceased. Samples irradiated with 2.00 kGy showed no sprouting and had dry and dark spots that remained throughout storage.

Control samples showed 15% rot after the first seven days, while samples that received doses of 0.10 and 0.15 kGy showed 5% rot after 14 days and remained with this percentage until the end of storage. Samples irradiated at 2.00 kGy showed a higher percentage of rot, with 55% at the end of storage (Fig.1).

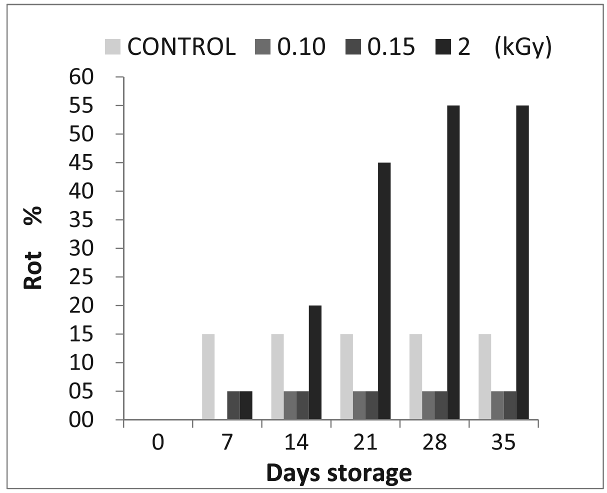

Figure 1 - Percentage of rot as a function of the applied dose in potato cultivar Ágata following 35 days of storage at 24 ºC (± 2).

Affective Sensory Comparative Analysis

Sensory analysis of the external appearance of tubers after 35 days of storage revealed that potatoes subjected to doses of 0.10 and 0.15 kGy were not significantly different (p> 0.05) and received the highest scores. The marks awarded for the internal appearance of tubers subjected to doses of 0.10 and 0.15 kGy were higher than those of the control and those treated with a dose of 2.00 kGy. Statistical analysis showed no significant difference (p> 0.05) between these samples. It was observed that tubers submitted to the 2.00 kGy dose exhibited a less desirable appearance. This result indicates that although the dose of 2.00 kGy compromised the external appearance of the potatoes, much more than their internal appearance. For the flavor of the tubers, there was little interference of radiation in this sensory characteristic, with no significant differences between the values for the doses studied.

When evaluators where asked which samples they would buy, according to the general outward appearance of the tubers, 70% said they would buy the samples subjected to a dose of 0.15 kGy, while only 10 and 30% would buy the control samples and those undergoing the 0.10 kGy dose (Table II), respectively. It is important to note that no reviewer chose samples that received a dose of 2.00 kGy, which can be attributed to the presence of rot in the tubers.

Acceptability Index

According to Teixeira et al. (1987), for a product to be accepted, it must have an acceptability

TABLE II
Consumer choice percentage for the external appearance of the potato cultivar Ágata after 35 days of storage at room temperature 24 ºC (± 2) as a function of the applied dose.

DOSE (kGy)	*CHOICES*	*%*
zero	**4**	**10**
0.10	**12**	**30**
0.15	**28**	**70**
2.00	**0**	**0**

index equal to or greater than 70%. The external appearance (Fig. 2) of the tubers after 35 days of storage revealed that only potatoes that received doses of 0.10 and 0.15 kGy, with emphasis on the dose 0.15 kGy, had acceptable indexes, with values of 71.94 and 79.72%, respectively (Fig. 2a). The result regarding the acceptability of the internal appearance revealed that tubers irradiated with 0.10 and 0.15 kGy were also the only ones that showed acceptability values of 70.27 and 73.88%, respectively (Fig. 2b). Acceptability of the flavor was the unique feature where all of the doses studied had acceptable content (Fig. 2c).

COLOR OF FLESH

L * values near 70 indicate a good brightness of pulp (Silva et al. 2008), and these values were found for the control samples and those subjected to the dose of 0.15 kGy. Mathew et al. (2008), who studied the effects of gamma radiation on the color and texture characteristics of tomatoes (subjected to doses of 0, 1, 2, 3 and 4 kGy and stored for 21 days at 12 °C and 90 - 95% RH), reported that the values of L * declined during storage and that there were no significant differences (p <0.05) between doses.

The parameter a* had negative average values. There was no significant difference between the

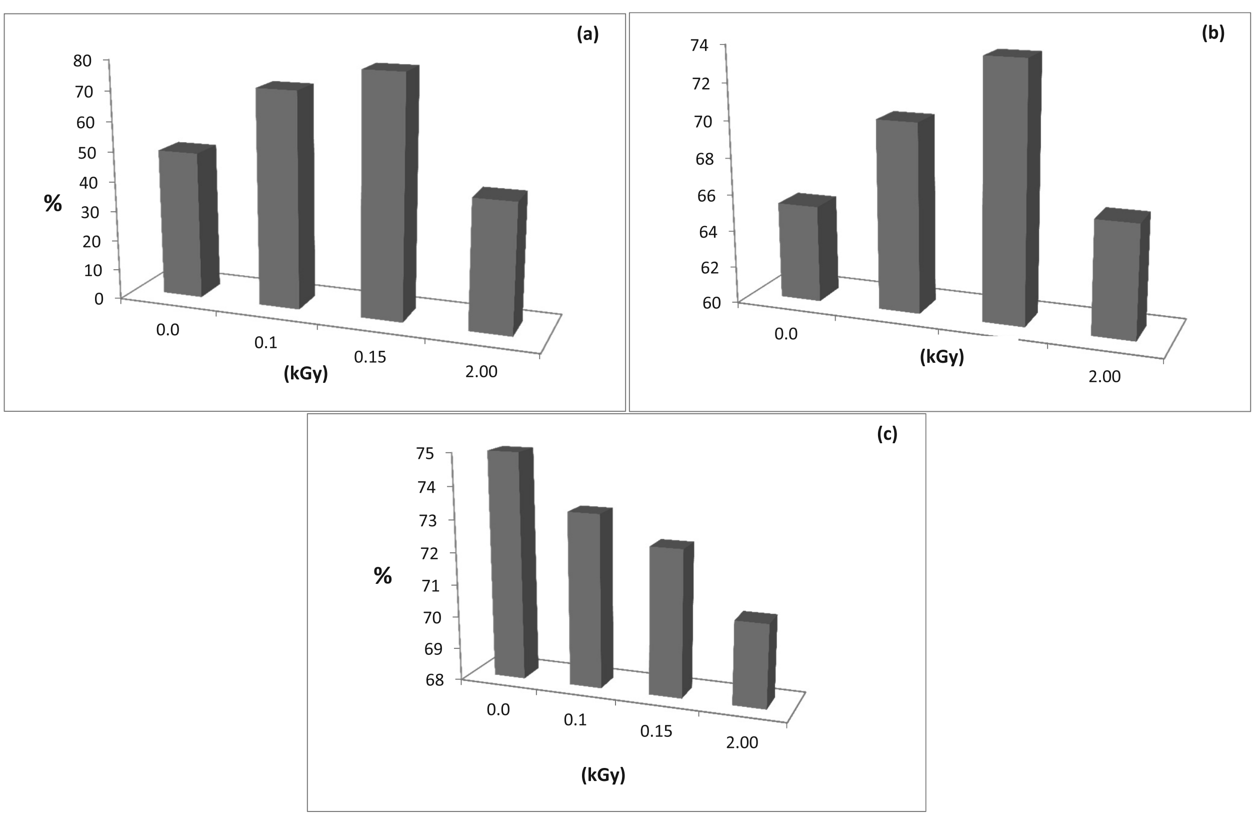

Figure 2 - Percentage of consumer acceptance for external appearance (**a**), internal appearance (**b**) and flavor (**c**), as function of the applied dose in potato cultivar Ágata after 35 days of storage at room temperature 24 ºC (± 2).

control and irradiated samples at doses of 0.10 and 0.15 kGy; however, the tubers subjected to the 2.00 kGy dose were significantly different ($p < 0.05$) from the control and the other doses. These results are in agreement with those indicated by Lima et al. (2001), who found a significant decrease in the total color difference (ΔE) with increasing radiation dose among carrots (cultivar Nantes) irradiated with doses of 0.25, 0.50, 0.75 and 1.0 kGy. For the b* values, it was observed that the control and those irradiated with 2.00 kGy reached the highest averages, which can be explained by the greater degree of maturity of the tubers.

Moisture Contents (%)

Samples irradiated at 0.10 and 0.15 kGy had higher moisture contents, which contributed to a greater conservation of tubers, and were significantly different ($p < 0.05$) compared with the controls (Fig. 3). According to Molins (2001), there is a tendency for reduction in water content with increasing dose of radiation, and this can be explained by the boost of radiolysis of water as dose increases. This author also states that lower moisture is expected at higher doses when compared to non-irradiated samples. According to Park et al. (2007), another explanation is that the slight heating of the samples during the radiation process would certainly increase the rate of evaporation of the water contained in the sample.

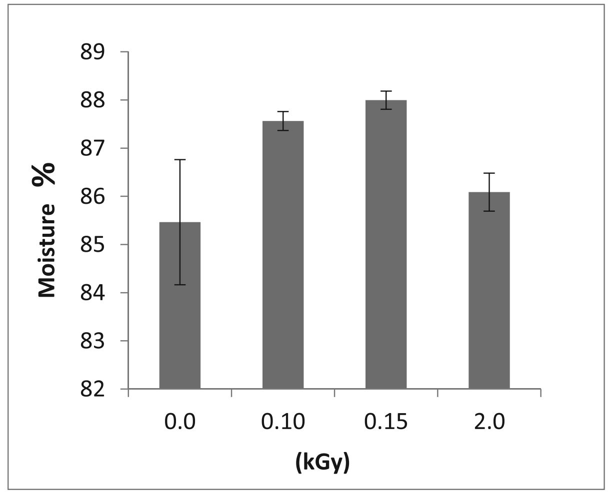

Figure 3 - Percentage of moisture as a function of the applied dose in potato cultivar Agata after 35 days of storage at 24 °C (± 2).

Percentage of Cumulative Weight Loss

A higher percentage of cumulative (19.55 ± 6.07%) weight loss was observed in the samples irradiated at 2.00 kGy, which was significantly different ($p < 0.05$) than the other doses. This result contributed to greater wrinkling and a less desirable external appearance of these samples. These results are in agreement with the analysis performed by Lu et al. (2012), who found that the storage time coupled with increasing dose resulted in greater weight loss of the tubers.

Rezaee et al. (2011) evaluated tubers of the cultivar Agria at doses of 0.05, 0.10 and 0.15 kGy for 10, 30 and 50 days after harvest and at temperatures of ± 8 and ± 16 °C and noted that tubers with the doses 0.10 and 0.15 kGy had a significantly decreased weight loss at both temperatures. According to Chachin and Iwata (1981), depending on the intrinsic and extrinsic characteristics of the tuber, changes may occur on the membrane function of irradiated tubers, which increases the permeability causing increased breathing.

Pulp Texture (kgf)

Samples subjected to a dose of 2.00 kGy had lower values for the texture of the flesh (7.42 ± 0.24 kgf) and were significantly different compared with the other treatments (Fig. 4a). Akter and Khan (2012) evaluated the effects of gamma radiation on the quality of tomatoes and also found that there was a greater loss of firmness at higher doses (0.50 and 0.70 kGy). In contrast, Lima et al. (2001) studied the effect of gamma radiation on carrots and found no significant difference in firmness.

Determination of Soluble Solids and Titratable Acidity (%)

Potatoes that received the 0.15 kGy dose had a lower amount of soluble solids (Fig. 4b). According to Chitarra and Chitarra (2005), the amount of

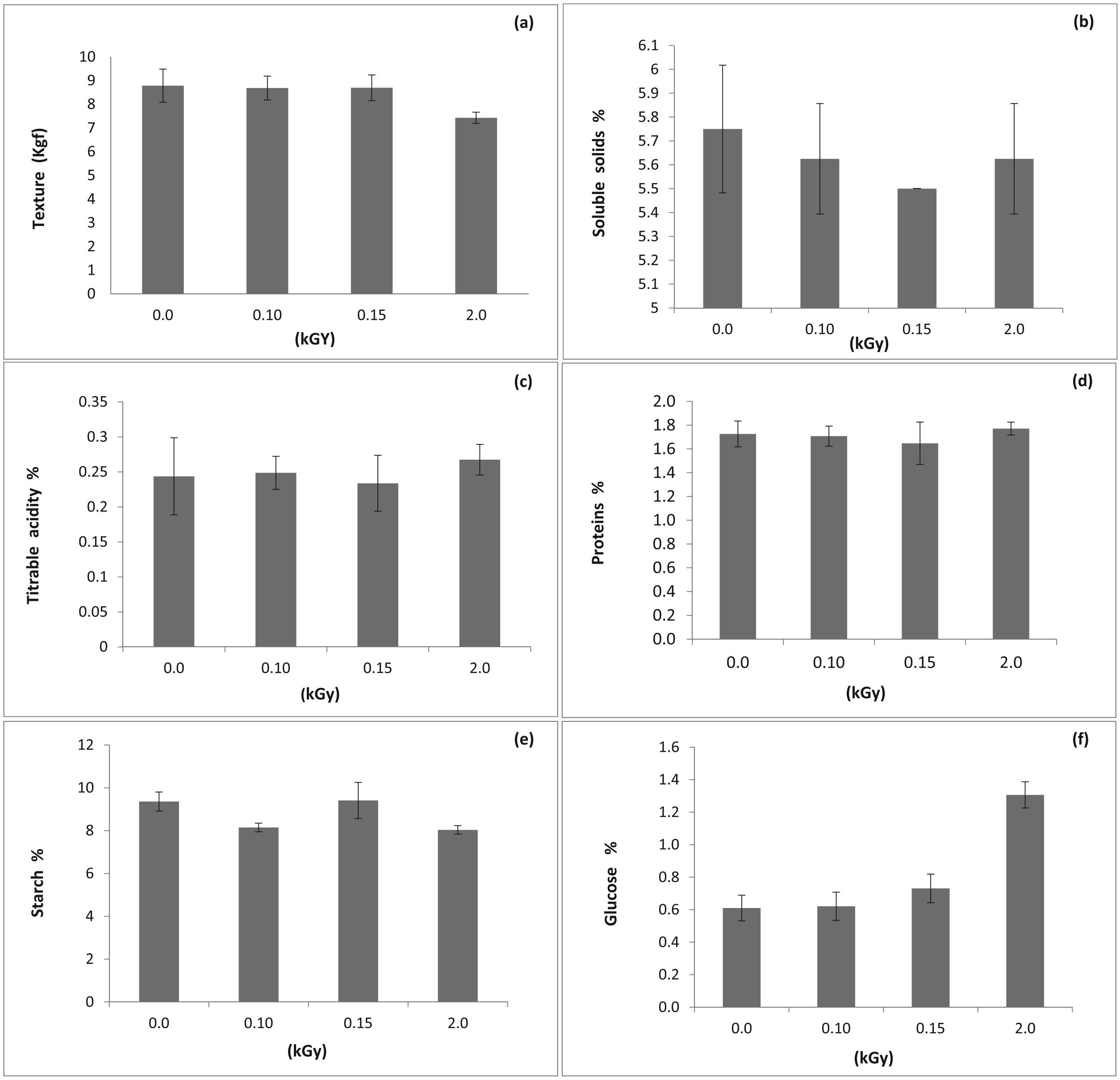

Figure 4 - Percentage values as a function of the applied dose of the texture (**a**), soluble solids (**b**), titratable acidity (**c**), proteins (**d**), starch (**e**) and reducing sugar into glucose (**f**) in potato cultivar Ágata after 35 days of storage at room temperature 24 °C (± 2).

soluble is lower when vegetables are less mature, and the content of soluble may vary according to the cultivar, the degree of maturation and the climate. Fugita (2011), in post-harvest studies for the fruit Mana cubiu (*Solanum sessiflorum* Dunal), with different doses of gamma irradiation (0.0, 0.2, 0.4, 0.6 and 0.8 kGy conservation), under different storage temperatures (24, 6, 8 and 10 °C), found that there was no significant difference between the overall averages of soluble solids for treatments applied at different temperatures.

There was little variation in the analysis of titratable acidity, with no significant effect observed ($p > 0.05$) between the different doses studied (Fig. 4c). Similar results were found by Oliveira et al. (2006) with irradiated guavas, and Prakash et al. (2002) with tomatoes treated with different doses of gamma radiation. Calore and

Vieites (2003) found that the use of post-harvest gamma radiation to treat peach cultivar Biuti did not influence the acidity of the samples up to a dose of 0.1 kGy. These authors also reported that radiation did not cause a delay in the ripening of the fruit. Lima et al. (2001) evaluated the effect of previously hyphenated gamma irradiation on physical and chemical characteristics of the carrot cultivar Nantes and found that the values obtained for acidity showed an increase in acid oxidation of irradiated carrots (at the 5% significance level).

Amount of Ascorbic Acid (Vitamin C) and Protein Percentage

The mean values of ascorbic acid obtained for the control samples and those irradiated at 0.15 kGy were higher (2.1 mg/100 g), with no statistically significant differences between doses. Lee and Kader (2000) found that doses of 1.0 kGy had no significant effect on the vitamin C content of various fruits and vegetables. In contrast, Rezaee et al. (2013) studied the effect of post-harvest gamma radiation on the potato cultivars Agria and Marfona at doses of 0.05 and 0.10 kGy and observed an increased loss of ascorbic acid at higher doses, such as 0.10 kGy for the cultivar Agria.

Wang and Chao (2003) studied the effects of gamma radiation on the quality of dried potato under different doses (0.0, 2.00, 4.00 and 6.00 kGy), and found that there was a decrease in vitamin C content with increasing dose of radiation.

Little variation occurred in the percentage of variable protein, and there were no significant differences between the control samples and those that were irradiated (Fig. 4d). Nouri and Toofanian (2001) also observed that there were no significant differences in the total protein content between control and irradiated tubers of potatoes. Additionally, Costa et al. (2013) evaluated the effect of gamma radiation on growth inhibition of aflatoxigenic fungi on peanuts at doses of 6, 9, 12 and 15 kGy and observed that the amount of protein in the samples did not vary considerable and that radiation did not significantly influence protein.

Starch and Sugar Reduction (%)

Tubers subjected to a dose of 0.15 kGy showed a higher percentage of starch, which was significantly different than samples irradiated at 0.10 and 2.00 kGy (Fig. 4e). Yu and Wang (2007) reported that gamma radiation has been considered to be a method of starch modification, which can generate free radicals able to break glycosidic linkages, changing large molecules into smaller fragments.

Lu et al. (2012) analyzed three varieties of potato irradiated with 0.1 kGy and stored for 5 months at 8 ºC and found that the radiation caused a slight degradation of starch after three months of storage, in addition to also increasing and it also increased the content of total glucose in two varieties of potato. The authors also stated that the crystallinity of starch decreased significantly in all irradiated tubers.

Chung and Liu (2010), who analyzed the molecular structure and physico-chemical properties of starch in the potato cultivar Frederiction 8 and the white bean cultivar AC compass, irradiated with doses of 10 and 50 kGy at 20 °C, observed through scanning electron microscopy (SEM) and polarized microscopy that some granules of starch in potatoes and beans were destroyed by gamma radiation and that the breach was much greater in the higher dose of 50 kGy.

There was a gradual increase in the percentage of reducing sugar to glucose with increasing radiation dose (Fig. 4f). Braun et al. (2010), comparing the physico-chemical characteristics of potato cultivars Asterix and Atlantic cultivar with Ágata, found that the potato cultivar Ágata showed higher reducing sugars in relation with the others (9.34 g reducing sugar per 100 g of dry matter). Ezekiel et al. (2007) studied the effects of gamma radiation on three cultivars of potato and verified that there was further degradation of starch with the highest dose of 0.50 kGy, which generated a higher concentration of sugars.

Gökman et al. (2007), studied the effects of controlled atmosphere storage and doses of 50 and 200 Gy on components of tubers of the potato cultivars Agria and Russet Burbank during a six month period at 9 °C (± 1) and observed that there was a gradual decrease in reducing sugars with increasing irradiation dose.

CONCLUSIONS

Based on the methodology performed in this work, 0.15 kGy was the most efficient radiation dose for the preservation of samples of the potato cultivar Ágata. This dose did not change either the nutritional or the sensory properties and contributed to an increase in the shelf life of samples. Considering the chronic problem of hunger and malnutrition in developing countries, where sprouting and spoilage greatly decreases food productivity, this methodology of irradiation of potato could contribute to reduce losses between field and table.

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RESUMO

Este trabalho avaliou os efeitos da radiação ionizante sobre as características físico-químicas e sensoriais de batata inglesa da cultivar Ágata (*Solanum tuberosum* L.), incluindo brotamento e a deterioração, com o objetivo final de aumentar a vida de prateleira. Para isso, quatro grupos de amostras foram colhidos na fase de maturação. Três destes grupos foram separadamente expostos a uma fonte de Co-60, recebendo respectivas doses de 0,10, 0,15 e 2,00 kGy, enquanto que o grupo não irradiado foi mantido como controle. Todas as amostras foram armazenadas durante 35 dias a 24 ° C (± 2) e a 39% de umidade relativa. Os seguintes aspectos foram avaliados: brotamento, podridão, perda de peso, textura, cor da polpa, umidade, aparência externa e interna, aroma, teor de sólidos solúveis, acidez titulável, vitamina C, proteínas, amido e glicose. Os resultados indicaram que a dose de 0,15 kGy foi a mais eficaz para reduzir a germinação e perdas pós-colheita, sob as condições estudadas.

Palavras-chave: conservação, irradiação, batata, deterioração, armazenamento.

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