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Effect of ionizing radiation on traditional and bacon *"farofa"*

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ABSTRACT

Seasoned "farofa" is a typical Brazilian dish made with toasted cassava flour. It is known that ionizing radiation is widely employed to improve food products extending its shelf life. In this context, this work analyzes the effects of ionizing radiation on the rheological and physicochemical properties of bacon (BF) and traditional (TF) "farofa". The samples were obtained from local markets (São Paulo/Brazil) and irradiated in the electron beam accelerator of Nuclear and Energy Research Institute (IPEN/CNEN-SP, São Paulo, Brazil) in doses of 1, 5 and 10 kGy, and analyzed on the first, fifteenth and thirtieth storage day. The results showed that the irradiated TF and BF samples displayed acidic pH throughout the storage period, regardless of dose increase. The different irradiation doses did not significantly affect (Tukey test $p > 0.05$) the water activity, keeping the products in the safe range. The colorimetric analysis, also showed no significant difference ($p \geq 0.05$) among the samples and ionizing radiation doses, indicating that the yellowish coloration remained stable throughout the experiment. After the thirtieth day, the moisture of the TF and BF samples ranged from 7.06% to 9.75%. Irradiation had a significant impact on the viscosity profile and texture characteristics of the "*farofa*", such as hardness, cohesiveness, and the springiness at 5 and 10 kGy.

1. Introduction

Cassava (*Manihot esculenta Crantz*) is one of the most important food crops in the world, playing an important role in Food Security in developing countries (FAO, 2018). In Brazil, the greater applicability of cassava in food products comes especially through its derivatives, such as starches (fermented and unfermented) and cassava flour. The cassava flour is the product obtained from cassava peeled roots that are washed, grounded, and slightly roasted (ANVISA, 2011). It's an important carbohydrate source presenting, starch, fibers, and some minerals such as potassium, calcium, phosphorus, sodium, and iron (Broca et al., 2016; Taco, 2011).

Moreover, cassava flour is frequently present in Brazilians daily meals, being considered part of the culture as a regional dish, with the additional advantage of presenting low cost, and is considered of easy elaboration (Cereda, 2005; Damiani et al., 2011; Sá et al., 2017). In particular, seasoned toasted cassava flour also called "*farofa*" is the result of the addition of condiments during the cassava flour production process (Cereda and Vilpoux, 2003; Ferreira Neto et al., 2005).

Regarding extension shelf life and food preservation, the food irradiation technology is considered a promising alternative for food processing, as it provides food safety with guaranteed nutritional quality (Ehlermann, 2016; Silva et al., 2010). Furthermore, the ionizing radiation applied in different doses to food can improve its technological properties and reduce insect infestations (IAEA, 2015; Teixeira et al., 2018).

Indeed, after the application of any food preservation techniques, it is important to analyze whether the technological quality and the important characteristics of the food have been maintained. In the food industry, an important factor to consider is these techniques effects during storage. For this reason, this study aimed to evaluate the effects of ionization radiation in bacon (BF) and traditional (TF) "farofa" on the rheological and physicochemical characteristic such as moisture, pH, water activity, color, viscosity, and texture during thirty days.

2. Material and methods

2.1. Samples

"*Farofa*" (traditional and bacon) were purchased at a local market in São Paulo, Brazil. The "*farofa*" from different batches were homogenized and transferred to polyethylene packs of 100 g each and

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analyzed after first, fifteenth and thirtieth storage day.

2.2. Samples irradiation

The sampling procedure was carried out using two different batches, which were divided into 4 polyethylene packs (100 g and 1 cm thickness), for each type of "farofa" according to was presented in 2.1 item. The irradiation process was carried out at the Energy and Nuclear Research Institute - IPEN/CNEN (São Paulo, Brazil) in an electron beam accelerator (IBA Industrial Inc., Edgewood, NY, USA), at room temperature with applied doses of 1.0; 5.0 and 10.0 kGy (dose rate 3.99 kGy/s, energy: 1.5 MeV, beam current: 1.0 mA, tray speed 6 m/min), related dose per pass in the tray (1 kGy). The Alanine pellet and Alanine Blister (Aerial) dosimeter were used to measure radiation dose.

2.3. Instrumental analysis

2.3.1. Colorimetric analysis

The instrumental analysis of the color was performed using the Minolta Chroma Meter color model CR200b digital, according to the AACCI method 14–22.01 (AACCI, 2010), with configuration for the parameters L * (black/white, 0 to 100), a * (intensity of positive = red/negative = green) and b * (intensity of positive = yellow/negative = blue), chroma C * (saturation or color intensity), and Hue angle (amount of color in which red-purplish = 0°, yellow = 90°, green blue = 80° and blue = 270°). Twenty random readings of the samples were performed. The results were expressed in CIELab, which is the most used system for the evaluation of color measurement in foods (HunterLab, 2008).

2.4. Pasting properties

The pasting properties of the irradiated "farofa" were measured using a Rapid Viscosity Analyzer, model RVA - 4500 from Perten Instruments (Warriewood, Australia) using Thermocline for Windows software, version 3. The analysis was performed at the Institute of Food Technology (Campinas, Brazil). Samples were analyzed in triplicates, using the suspension of samples (2.5 g of "*farofa*" in 25 mL of water), corrected for 14% moisture. The scheduling was performed according to the methodology described by Pereira and Leonel (2014), with time/temperature 50 °C for 1 min, heating from 50 °C to 95 °C at a rate of 6 °C/min, pulp maintenance at 95 °C per 2 min and 30 s and cooling at 95 °C to 50 °C at a rate of 6 °C/min. The viscosity was expressed in Rapid Visco Unit (RVU).

2.5. Texture analyzer

The Hardness (g), Springiness (g), Cohesiveness of the gel samples were determined using a TA-XT2i texture analyzer (Stable Micro Systems, Haslemere, GBR), version 6.10, and 7.10, held at the Institute of Food Technology (Campinas, Brazil). The gel obtained from the RVA analysis was kept in its aluminum cup, the temperature of 23 °C until its complete cooling, and gel readings were carried out. The pre-test, test, and post-test velocities were respectively 0.5 mm/s, 1.0 mm/s, and 10 mm/s, with a 5 mm sample penetration distance, using an acrylic probe cylindrical of P20 (AACCI, 2010).

2.6. Water activity (a_w)

Water activity (a_w) was measured in triplicate at a temperature of (25 °C ± 1 °C) on the Aqualab, 4 TE Duo digital apparatus (AOACI, 1992; ASTM, 2002).

2.7. Determination of pH

For pH determination, 10 g of "*farofa*" were dispersed in 90 mL of deionized water and the suspension stirred for 30 min, according to the analytical standards of the Adolfo Lutz Institute (Instituto Adolfo Lutz, 2008). After the stirring process stopped, the pH was measured immediately as the pH meter of the Kasvi model benchtop (São José do Pinhais/Brazil).

2.8. Moisture content

"*Farofa*" moisture content was measured according to AACCI, 2010 method 44-15.02. The moisture was determined on a Denver Instrument heat balance, model IR-35 (NY, USA), 3 g of the "*farofa*" were weighed and evenly spread on the scale plate, using an infrared heat source the sample was heated to a temperature of 130 °C until reaching its specific moisture. The result was expressed as a percentage.

2.9. Statistical analysis

The GraphPad Prism software (version 7.0), was used for statistical treatment and preparation of tables and graphs. The samples data were measured in triplicates. The comparison between the treatments administered was performed by analysis of variance (ANOVA), with a significance level of $p < 0.05$ and the treatments that differ by the Tukey test (Banzatto and Kronka, 2013; Mead et al., 2017).

3. Results and discussion

3.1. Colorimetric analyses

Color is a very important feature for consumer acceptance, and therefore for the food industry since appearance is frequently associated to food quality. In the case of food irradiation, color is one of the physical properties of food that may be changed after the radiation processing. According to Hruskova and Machova (2002), storage also may have a strong influence on the discoloration of some products.

The colorimetric analyses indicate that all "farofa" (TF and BF) presented no significant difference ($p \geq 0.05$) when compared to the same type of "farofa" and irradiation dose in different storage days. All parameters (L*, a*, b*, C, and h) followed the same trend. These results showed that the "farofa" irradiation process was positive, since the color remained stable during processing, using different irradiation doses.

Lustosa et al. (2010) obtained similar results on mixtures of cassava flour and casein. Their results showed high values of L * (80.36–77.63), chromaticity coordinate a* positive (3.17–2.68). Sousa (2013), studied seasoned "farofa" during ninety days and identified that there was a significant difference in L * between the first day (81.1 ± 0.77) and thirtieth (102.9 ± 0.12) day.

In general, the colors of the flours are mainly related to their composition (carotenoids, proteins, fibers), and by chemical reactions that occurred during processing (caramelization, Maillard e.g.) (ICTA, 2013).

For this reason, bacon and traditional "farofa" presented parameters L* (brightness) and a* (redness) in different ranges. The L* ranged from 74.71 to 76.17 for BF and 79.45 to 82.26 for TF. These values were expected since BF has bacon on its composition and presents a brown color, contributing to the darkening of the "farofa". The same occurred for the a* or redness, with values of 6.56–7.05 for BF, while for TF it was almost 50% lower, varying 2.73 to 3.55 (see Table 1).

3.2. Pasting properties

According to Camargo et al. (2008), the viscosity properties evaluation of the paste in the viscoamilograph can be determined by two factors: the degree of swelling of the granules and the dissolution resistance from the heat in fragmentation by mechanical agitation. Properties of irradiated and non-irradiated "farofa" paste (traditional

Table 1
Bacon and Traditional farofa (non-irradiated and irradiated) colorimetric analysis for thirty days of storage.

Dose (kGy)	Storage	Parameters				
		Bacon "*farofa*" (BF)				
		L*	a*	b*	C*	h
Non-irradiated	1	76.03 ± 0.76[a]	6.91 ± 0.44[a]	31.91 ± 0.89[a]	32.65 ± 0.92[a]	77.78 ± 0.66[a]
	15	76.13 ± 0.90[a]	6.89 ± 0.27[a]	32.45 ± 0.92[a]	33.17 ± 0.87[a]	78.01 ± 0.68[a]
	30	76.17 ± 0.77[a]	6.85 ± 0.30[a]	31.93 ± 1.05[a]	32.65 ± 1.02[a]	77.89 ± 0.70[a]
1	1	75.72 ± 0.71[a]	6.87 ± 0.31[a]	31.60 ± 0.81[a]	32.34 ± 0.82[a]	77.73 ± 0.51[a]
	15	75.74 ± 0.82[a]	7.05 ± 0.28[a]	30.98 ± 1.39[a]	31.78 ± 1.33[a]	77.18 ± 0.91[a]
	30t	75.47 ± 0.84[a]	7.01 ± 0.26[a]	31.97 ± 0.86[a]	32.73 ± 0.84[a]	77.64 ± 0.53[a]
5	1	75.19 ± 0.86[a]	6.86 ± 0.34[a]	30.99 ± 0.99[a]	31.74 ± 0.96[a]	77.52 ± 0.78[a]
	15	75.58 ± 0.89[a]	6.96 ± 0.36[a]	30.95 ± 1.14[a]	31.72 ± 1.11[a]	77.32 ± 0.78[a]
	30	74.89 ± 1.11[a]	6.87 ± 0.39[a]	31.38 ± 0.92[a]	32.13 ± 0.93[a]	77.65 ± 0.64[a]
10	1	74.71 ± 0.96[a]	6.56 ± 0.22[a]	30.24 ± 0.59[a]	30.94 ± 0.59[a]	77.76 ± 0.41[a]
	15	75.28 ± 0.92[a]	6.69 ± 0.32[a]	30.38 ± 1.12[a]	31.11 ± 1.13[a]	77.57 ± 0.55[a]
	30	75.16 ± 0.06[a]	6.99 ± 0.36[a]	30.32 ± 0.69[a]	31.11 ± 0.67[a]	77.02 ± 0.73[a]
Traditional "*farofa*" (TF)						
Non-irradiated	1	81.79 ± 0.61[a]	2.97 ± 0.16[a]	29.49 ± 0.62[a]	29.64 ± 0.62[a]	84.26 ± 0.31[a]
	15	82.26 ± 0.74[a]	2.75 ± 0.24[a]	29.05 ± 0.69[a]	29.18 ± 0.69[a]	84.59 ± 0.46[a]
	30	81.80 ± 0.62[a]	2.72 ± 0.24[a]	29.49 ± 0.78[a]	29.61 ± 0.78[a]	84.74 ± 0.47[a]
1	1	80.89 ± 0.65[a]	3.14 ± 0.31[a]	28.61 ± 0.64[a]	28.79 ± 0.62[a]	83.73 ± 0.72[a]
	15	80.72 ± 0.81[a]	3.24 ± 0.23[a]	28.61 ± 0.77[a]	28.80 ± 0.76[a]	83.54 ± 0.56[a]
	30	80.59 ± 0.79[a]	3.18 ± 0.22[a]	28.92 ± 0.58[a]	29.09 ± 0.58[a]	83.73 ± 0.43[a]
5	1	79.45 ± 0.69[a]	3.55 ± 0.67[a]	27.45 ± 2.73[a]	27.68 ± 2.52[a]	82.63 ± 3.19[a]
	15	80.26 ± 0.74[a]	3.34 ± 0.21[a]	27.85 ± 0.66[a]	28.05 ± 0.64[a]	83.17 ± 0.51[a]
	30	80.24 ± 0.66[a]	3.32 ± 0.19[a]	28.22 ± 0.71[a]	28.42 ± 0.72[a]	83.29 ± 0.35[a]
10	1	78.45 ± 0.59[a]	3.36 ± 0.15[a]	27.01 ± 0.67[a]	27.22 ± 0.67[a]	82.91 ± 0.36[a]
	15	79.64 ± 0.90[a]	3.21 ± 0.19[a]	26.69 ± 0.76[a]	26.88 ± 0.76[a]	83.15 ± 0.41[a]
	30	79.81 ± 0.90[a]	3.25 ± 0.52[a]	26.89 ± 1.06[a]	27.08 ± 1.07[a]	83.11 ± 1.06[a]

[1] Mean value followed by their standard deviation. Means followed by the same letter in the columns do not differ statistically from each other by the Tukey test ($p > 0.05$).

and bacon) during the storage period are shown in Table 2. Electron beam radiation influenced decreased the binding properties of both "farofa" types in a dose-dependent manner(see Table 3).

Pasting temperature provides a minimum temperature indication required to cook a given sample. Both samples did not differ statistically (Tukey $p < 0.05$) regardless of dose and storage.

Peak viscosity is the highest viscosity achieved during heating at 95 °C and indicates the water-holding capacity of the starch. TF and BF non-irradiated had the highest peak viscosity during storage. Moreover, TF presented higher results than BF. Among irradiated samples, both TF and BF at 1 kGy presented a better performance during storage than other doses. The variation of peak viscosity among doses are associated with the swelling power of starch and the rate of disruption of the starch granules.

In this study, the starch swelling power decreased in a dependent increase dose manner (Corke et al., 1997). Also according to Peroni et al. (2006), a low peak viscosity is mainly due to the change in the amylose content, lipids, phosphorus, and size of the starch granule. This Peak viscosity is often correlated with final product quality, and also indicates the viscous load likely to be encountered after cooking.

Final viscosity was the paste viscosity upon cooling at 50 °C. TF and BF non-irradiated showed the highest final viscosity followed by TF and BF 1 kGy. The starch granules do not experience a good restructuring of starch molecules and retrograded at 5 kGy and 10 kGy compares to 1 kGy.

Final viscosity also measured the ability of the starch to form a viscous paste after cooking and cooling (Shafie et al., 2016). Thus, 1 kGy dose was more suitable than other doses and had less influence at the abundance of amylopectin in "farofa" and the formation of the number of intermolecular hydrogen bridges that lead to gel formation at low temperatures (Silva et al., 2008).

A considerable decrease in viscosity breakdown and setback in both "farofa" were observed. Results also found by Barroso and del Mastro (2019) with arrowroot starch treated with ionizing radiation in a source of cobalt-60, with doses of 5 kGy, 10 kGy, and 15 kGy. Low breakdown viscosity is associated to low hydration, swelling power, and high shear resistance of starch, whereas a high breakdown indicate a low paste stability, brittleness of the granules, and the tendency to starch retrogradation. (Barroso and del Mastro, 2019; Corke et al., 1997).

TF and BF irradiated samples present a stable starch paste. Comparatively, TF 1 kGy had significant differences in breakdown viscosity among first (4.5 ± 0.1A) and fifteenth (3.0 ± 0.1B), the thirtieth day (3.4 ± 0.1B). BF had significant differences only first (3.5 ± 0.0A) and fifteenth (4.6 ± 0.2B).

Setback viscosity indicated a starch retrogradation tendency after gelatinization and cooling at 50 °C. Comparatively, TF 1 kGy had a lower setback viscosity than BF 1 kGy during storage. Viscosity changes while cooling were mainly due to amylose molecular reassociation, and low setback viscosity indicates a low rate of starch retrogradation (Shafie et al., 2016). Finally, TF and BF irradiated samples presented starch retrogradation stable data.

3.3. Texture analyzer

Ionizing radiation can modify physical properties such as springiness, hardness, and cohesiveness of food. Hardness is defined as the

Table 2
Viscosity results of traditional and bacon "*farofa*" irradiated compared with non-irradiated.

Storage	Dose (kGy)	TF				
		Peak Visc (RVU)	Breakdown (RVU)	Final Visc (RVU)	Setback (RVU)	Pasting Temp (°C)
1	Non-irradiated	54.39 ± 0.7^{aA}	19.25 ± 0.6^{aA}	111.41 ± 1.0^{aA}	76.27 ± 0.2^{aA}	75.64 ± 0.2^{aA}
	1	20.80 ± 0.5^{bA}	4.50 ± 0.1^{bA}	33.25 ± 0.4^{bA}	16.94 ± 0.6^{bA}	75.63 ± 0.1^{aA}
	5	5.66 ± 0.1^{cA}	1.27 ± 0.1^{cA}	7.22 ± 0.2^{cA}	2.83 ± 0.1^{cA}	75.62 ± 0.1^{aA}
	10	3.11 ± 0.0^{dA}	0.97 ± 0.1^{dA}	3.44 ± 0.0^{dA}	1.3 ± 0.1^{dA}	75.62 ± 0.4^{aA}
15	Non-irradiated	44.52 ± 1.7^{aB}	18.00 ± 0.4^{aA}	102.36 ± 0.6^{aB}	75.83 ± 1.8^{A}	75.62 ± 0.2^{aA}
	1	16.97 ± 0.3^{bB}	3.05 ± 0.1^{bB}	30.14 ± 0.5^{bB}	16.22 ± 0.4^{aA}	75.62 ± 0.3^{aA}
	5	4.75 ± 0.1^{cA}	1.42 ± 0.0^{cA}	5.41 ± 0.1^{cB}	2.1 ± 0.1^{cA}	75.62 ± 0.3^{aA}
	10	3.00 ± 0.4^{dA}	0.97 ± 0.2^{cA}	3.41 ± 0.3^{dA}	1.4 ± 0.1^{dA}	75.62 ± 0.1^{aA}
30	Non-irradiated	46.41 ± 1.6^{aC}	20.30 ± 0.8^{aC}	110.89 ± 1.8^{aA}	84.78 ± 1.1^{aB}	75.62 ± 0.2^{aA}
	1	16.47 ± 0.4^{bB}	3.38 ± 0.1^{bB}	30.44 ± 0.1^{bB}	17.36 ± 0.2^{bA}	75.62 ± 0.3^{aA}
	5	4.38 ± 0.1^{cA}	1.47 ± 0.0^{cA}	4.67 ± 0.0^{cB}	1.75 ± 0.1^{cA}	75.62 ± 0.2^{aA}
	10	2.30 ± 0.1^{dA}	0.86 ± 0.0^{dA}	2.67 ± 0.0^{dA}	1.22 ± 0.0^{dA}	75.62 ± 0.3^{aA}
BF						
1	Non-irradiated	34.69 ± 0.8^{aA}	17.44 ± 0.3^{aA}	98.36 ± 2.1^{aA}	81.11 ± 2.2^{aA}	75.62 ± 0.2^{aA}
	1	13.91 ± 0.4^{bA}	3.47 ± 0.0^{bA}	35.75 ± 0.6^{bA}	25.30 ± 0.3^{bA}	75.62 ± 0.1^{aA}
	5	4.44 ± 0.3^{cA}	0.38 ± 0.1^{cA}	6.22 ± 0.3^{cA}	2.16 ± 0.1^{cA}	75.62 ± 0.1^{aA}
	10	2.97 ± 0.1^{dA}	0.27 ± 0.0^{cA}	4.36 ± 0.0^{dA}	1.66 ± 0.1^{dA}	75.62 ± 0.4^{aA}
15	Non-irradiated	32.05 ± 1.4^{aB}	16.58 ± 1.0^{aB}	97.75 ± 2.7^{aA}	82.27 ± 2.8^{aA}	75.62 ± 0.2^{aA}
	1	14.27 ± 0.1^{bA}	4.55 ± 0.2^{bB}	36.08 ± 0.2^{bB}	26.36 ± 0.2^{bA}	75.62 ± 0.3^{aA}
	5	4.50 ± 0.2^{cA}	0.41 ± 0.1^{cA}	5.97 ± 0.2^{cA}	1.88 ± 0.1^{cA}	75.62 ± 0.3^{aA}
	10	2.44 ± 0.1^{dA}	0.33 ± 0.0^{cA}	3.39 ± 0.0^{dA}	1.27 ± 0.0^{dA}	75.62 ± 0.3^{aA}
30	Non-irradiated	31.58 ± 0.6^{aB}	16.86 ± 0.3^{aB}	94.89 ± 2.6^{aB}	80.16 ± 2.2^{aA}	75.62 ± 0.1^{aA}
	1	12.19 ± 0.2^{bB}	3.44 ± 0.0^{bA}	30.69 ± 0.6^{bB}	21.94 ± 0.4^{aB}	75.62 ± 0.2^{aA}
	5	3.72 ± 0.0^{cA}	0.27 ± 0.0^{cA}	5.63 ± 0.1^{cA}	2.25 ± 0.0^{aA}	75.62 ± 0.4^{aA}
	10	2.33 ± 0.0^{dA}	0.30 ± 0.0^{cA}	3.36 ± 0.0^{dA}	1.33 ± 0.0^{aA}	75.62 ± 0.2^{aA}

[1]RVU – Rapid Visco Unit.
[2]For each parameter, different small letters in the same column mean statistical difference by the Tukey test ($p > 0.05$) of the same storage day.
[3]For each parameter, different capital letters on the same column mean statistical difference by the Tukey test ($p > 0.05$) of dose during storage.
[4]Mean values followed by their standard deviation.

Table 3
Bacon and Traditional samples water activity quantification after ionizing radiation process.

Doses (kGy)	Traditional "*farofa*"			Bacon "farofa"		
	Storage			Storage		
	1	15	30	1	15	30
0	0.42 ± 0.02^{aAB}	0.49 ± 0.16^{aA}	0.39 ± 0.02^{aB}	0.52 ± 0.02^{abAB}	0.50 ± 0.01^{aA}	0.53 ± 0.00^{acB}
1	0.45 ± 0.00^{aA}	0.43 ± 0.02^{aA}	0.42 ± 0.01^{aA}	0.51 ± 0.02^{abA}	0.51 ± 0.01^{aA}	0.50 ± 0.01^{bA}
5	0.43 ± 0.08^{aA}	0.43 ± 0.00^{aA}	0.44 ± 0.00^{aA}	0.51 ± 0.01^{abAB}	0.52 ± 0.00^{bA}	0.50 ± 0.01^{bB}
10	0.36 ± 0.01^{bA}	0.43 ± 0.01^{aA}	0.44 ± 0.01^{aA}	0.51 ± 0.02^{bA}	0.52 ± 0.00^{bA}	0.52 ± 0.00^{cA}

[1] Mean value followed by their standard deviation.
[2]For each parameter, different small letters in the same column mean statistical difference by the Tukey test ($p > 0.05$) of the same storage day.
[3]For each parameter, different capital letters on the same line mean statistical difference by the Tukey test ($p > 0.05$) of dose during storage.

peak force during the first compression cycle required to produce a certain deformation at a given distance. In this study, the average hardness of TF 10 kGy was 20.9 ± 1.0; 21.4 ± 2.6; 20.8 ± 1.35 for the first, fifth and thirtieth storage day, respectively. Meanwhile, the mean of the BF - 10 kGy sample was 23.8 ± 0.2; 21.7 ± 1.5; 21.8 ± 0.03 on the first, fifteenth and thirtieth days, respectively. Comparatively, the hardness of the TF and BF samples presented no significant difference in the doses of 10 kGy during storage (Tukey $p < 0.05$).

Springiness is how well a product physically springs back after it has been deformed during the compression. Thus, a perfectly resilient material would exhibit a springiness value of 1.0 whereas a totally non-resilient material would exhibit a springiness value of 0.0. Also, if the springiness is high more mastication energy in the mouth is required (Kazemzadeh, 2019; Shafiur Rahman and Al-Mahrouqi, 2009). As shown in Fig. 1, only non-irradiated and TF 1 kGy samples presented results near 1.0 during all storage periods. On the other hand, TF 10 kGy and BF results presented 0.0 springiness. Indicating that doses higher than 1 kGy can be decreased farofa springiness.

Cohesiveness indicates the strength of internal bonds of the food considered, the rate a food can be deformed before it ruptures (Radoĉaj et al., 2011) and the ability of the product to hold together (Chandra and Shamasundar, 2015). If the structure of the sample is completely destroyed on the first compression its ratio is zero, but if the sample is perfectly elastic and not damaged the ratio is 1.0. At TF 1 kGy and 5 kGy, a significant decrease (Tukey $p > 0.05$) in cohesiveness was observed during storage, and after the fifteenth day, the BF 5 kGy and BF 1 kGy sample result was 0.0.

3.4. Water activity analysis (a_w)

Certainly, water activity analysis in the food processed by ionizing radiation is extremely important since it is related to the amount of free water in food and "radiolysis" phenomenon effects (Fanaro et al., 2015, 2014) which produces hydroxyl radicals that interact with the organic molecules present in food (Kwon et al., 2014).

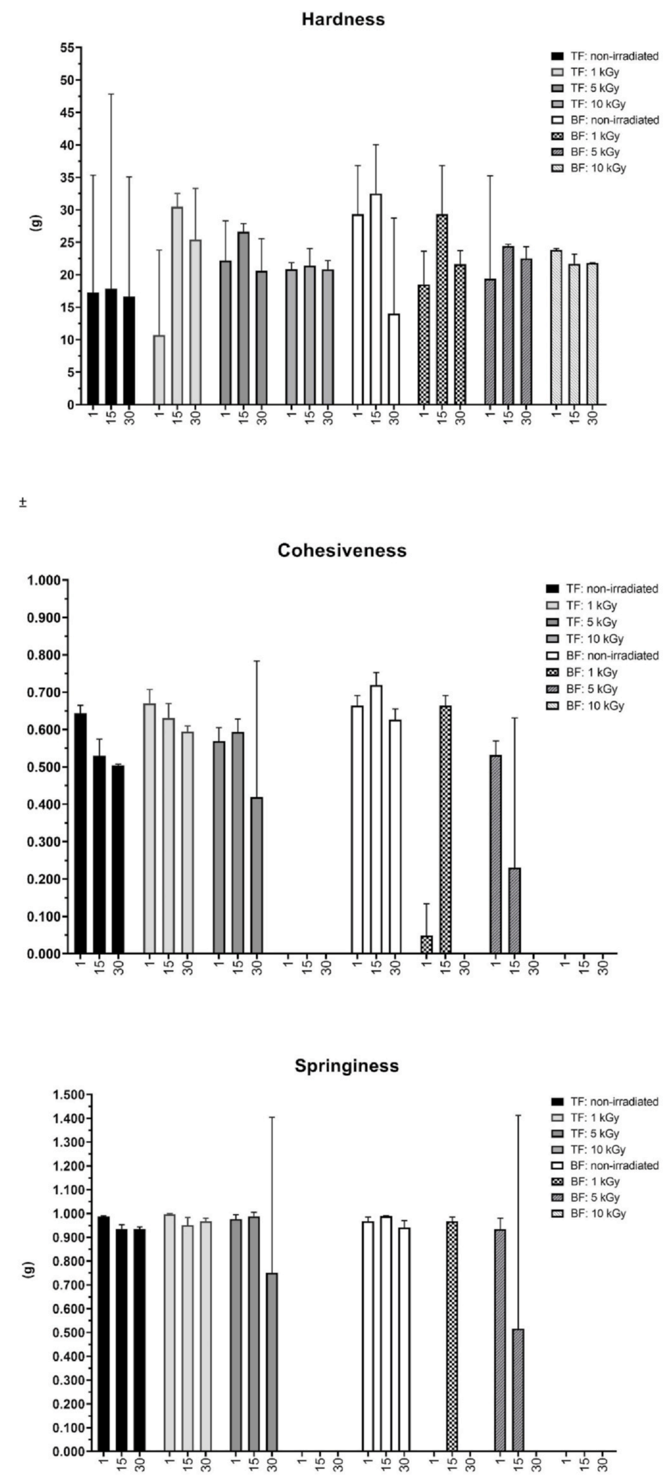

Fig. 1. Comparison of Hardness, Cohesiveness, Springiness of bacon, and traditional “farofa” during storage at 1, 5, and 10 kGy.

Evaluating the TF 10 kGy sample results, it is possible to see these effects because there was a significant reduction in Aw on the first day compared with other doses, possibly as a consequence of the radiation's ability to separate glycosidic bonds promoting the decomposition of macromolecules causing loss of free water (Manupriya et al., 2020).

The BF results showed a_w values ranging from 0.48 to 0.53. BF showed a significant difference in the dose of 5 kGy, which the Aw value obtained after the thirtieth day differed significantly from the other periods (first and fifteenth).

From the standpoint of food microbiological safety, all the farofa (TF and BF) presented values below the minimum value (0.60 aw) for microorganisms’ development in dehydrated food, and also bacteria development (Aw = 0.90), yeast (Aw = 0.80) mold (Aw = 0.60), halophilic bacteria (Aw = 0.65) osmophilic yeast (Aw = 0.62) (Chisté et al., 2006).

3.5. Moisture content

Moisture content (Table 4) is directly related to “farofa” quality and texture, being considered a relevant microbiology stability factor during storage (Ferreira Neto et al., 2005).

Bacon and Traditional samples presented results of 6.66%–9.75%. According to the cassava flour specific legislation, TF and BF are within the limit allowed by Brazilian regulation (maximum of 13%) (ANVISA, 2011).

Agúndez-Arvizu et al. (2006) report that the effect of gamma irradiation of 1 kGy, did not change the moisture content of wheat flour and Hammad et al. (2017) evidenced in their study that 5.0 kGy irradiation during 9 months storage did not cause greater changes in this parameter. In this study, TF irradiated samples had no significant difference ($p < 0,05$) during storage. And TF ranged from 7.64% to 7.75% and BF 8.72%–8.84% on the thirtieth day.

3.6. Determination of pH

Regarding the value obtained for pH as can see in Fig. 2, the TF and BF samples analyzed showed values above 4.5 and did not present significant differences ($p > 0.05$) when compared to the dose and storage period.

According to Souza et al. (2008), foods can be classified as a low acid (pH > 4.5), acid (4.5–4.0), and high acid (< 4.0). In this case, all the samples analyzed in the study were considered to have low acidity, a similar result found in the study by Dias and Leonel (2006) in dry cassava flour that showed values above 4.5.

4. Conclusion

After the physicochemical and rheological property analysis, we conclude that traditional (TF) and Bacon (BF) cassava “farofa” color results presented no significant difference when compared to non-irradiated samples, and the original yellowish color was maintained during storage. After ionizing radiation process, water activity analysis for all samples ranged 0.37 aw - 0.56 aw and moisture content in 6.66%–9.75%, pH approximates to 4.5 (acid), within the standard established for this kind of product. Considering viscosity results, 5 kGy and 10 kGy cannot be applied as a dose for both “farofa” viscosity improvement since those doses induce a decrease of paste properties. The hardness in both “farofa” samples presented no significant difference at 5 kGy and 10 kGy. During storage, doses higher than 1 kGy presented lower cohesiveness and springiness on traditional and bacon samples. In conclusion, 1 kGy presented better results analysis than 5 kGy and 10 kGy and can be applied successfully to traditional and bacon “farofa".

CRediT authorship contribution statement

Ana Paula Nunes de Sá: Conceptualization, Methodology, Writing - original draft, Formal analysis. **Bianca Guimarães Negrão:** Data curation, Formal analysis, Validation, Writing - review & editing. **Elizabeth Harumi Nabeshima:** Writing - review & editing, Resources. **Amanda C. Ramos Koike:** Visualization, Investigation. **Anna Lucia C.H. Villavicencio:** Supervision, Resources, Writing - review & editing.

Table 4
Moisture Content of "farofa" after ionizing radiation process during storage.

	Traditional "*farofa*"			Bacon "farofa"		
	Storage			Storage		
Doses (kGy)	1	15	30	1	15	30
0	7.58 ± 0.07[aA]	7.30 ± 0.04[abB]	7.06 ± 0.02[aC]	9.15 ± 0.48[abA]	9.59 ± 0.20[aA]	9.75 ± 0.62[aA]
1	6.77 ± 0.10[bA]	7.54 ± 0.17[bB]	7.64 ± 0.14[bcB]	8.74 ± 0.48[aA]	9.16 ± 0.05[aA]	8.72 ± 0.06[bA]
5	6.72 ± 0.13[bA]	7.14 ± 0.16[aB]	7.47 ± 0.10[bC]	9.09 ± 0.28[abA]	9.39 ± 0.06[aA]	8.85 ± 0.49[bA]
10	6.66 ± 0.17[bA]	7.17 ± 0.12[aB]	7.75 ± 0.02[cC]	9.72 ± 0.26[bA]	9.59 ± 0.06[aA]	8.84 ± 0.04[bB]

[1] Mean value followed by their standard deviation.
[2]For each parameter, different small letters in the same column mean statistical difference by the Tukey test ($p > 0.05$) of the same storage day.
[3]For each parameter, different capital letters on the same line mean statistical difference by the Tukey test ($p > 0.05$) of dose during storage.

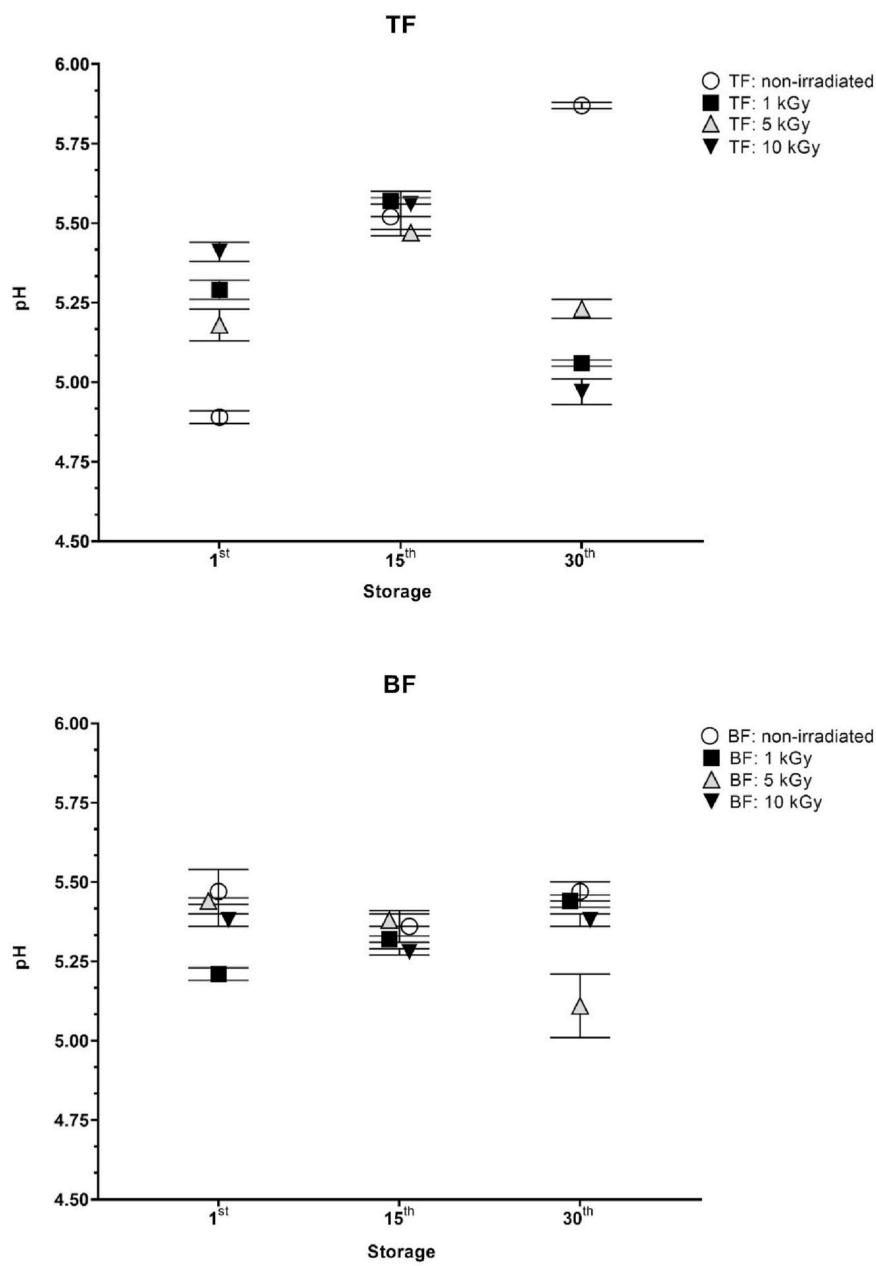

Fig. 2. pH results of traditional and bacon "farofa" non-irradiated and irradiated during thirty storage day.

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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