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Physical properties of irradiated red pitaya (*Hylocereus costaricensis*) during storage

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Abstract: This study evaluated the impact of gamma irradiation on some physical properties of red pitaya (*Hylocereus costaricensis*) during two periods of refrigerated storage. For this purpose, pitaya fruits were irradiated with doses of 1.0 and 3.5 kGy and compared with non-irradiated samples for up to 14 days. The results indicate that irradiation significantly influenced the texture and color of the fruit. For a dose of 1.0 kGy, it had the greatest effect on the elasticity of the peel, while 3.5 kGy better preserved the initial color. In terms of total solids (°Brix), the samples irradiated at 3.5 kGy showed the highest initial values, stabilizing over the storage period. In addition, water activity (aw) remained high in all samples, with no significant differences between the irradiated and non-irradiated doses, suggesting a high microbiological risk without irradiation-induced changes. These results showed that gamma irradiation of pitaya fruit can be effective in maintaining pitaya quality during storage, although lower doses have more beneficial effects on certain properties. Further studies are needed to explore the effects of irradiation on other characteristics and to further extend the shelf life of the fruit.

Keywords: red pitaya, Food irradiation, storage time, texture and color.

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Propriedades físicas da pitaya vermelha (*Hylocereus costaricensis*) irradiada durante sua estocagem

Resumo Neste estudo, foi avaliado o impacto da irradiação gama sobre algumas propriedades físicas da pitaya vermelha (*Hylocereus costaricensis*) durante dois períodos de armazenamento refrigerado. Frutos foram irradiados com dose de 1,0 kGy e 3,5 kGy e comparados com amostras não irradiadas durante um perido de 14 dias. Os resultados indicaram que a irradiação influenciou significativamente a textura e a cor da fruta. A dose de 1,0 kGy mostrou maior efeito na elasticidade da casca, enquanto 3,5 kGy preservou melhor a cor inicial da fruta. Em relação aos sólidos totais (°Brix), as amostras irradiadas com uma dose de 3,5 kGy apresentaram os maiores valores iniciais, estabilizando-se ao longo do tempo de estocagem. A atividade de água (a_w) permaneceu alta em todas as amostras, sem diferenças significativas entre as doses de irradiação e a não irradiada, sugerindo risco microbiológico elevado sem alterações induzidas pela irradiação. Conclui-se que a irradiação pode ser eficaz para manter a qualidade da pitaya durante o armazenamento, embora dose mais baixas apresentem efeitos mais benéficos em certas propriedades. Estudos adicionais são necessários para explorar os efeitos da irradiação em outras características e prolongar ainda mais a vida útil da fruta.

Palavras chave: pitaya vermelha, irradiação de alimentos, tempo de estocagem, textura e cor.

1. INTRODUCTION

Worldwide, the consumption of exotic fruits has attracted consumers and among them is the red pitaya, also known as the dragon fruit, which comes from the tropical forests of Central and South America, India and Malaysia and is one of a vast group of exotic fruits with good marketing potential [1].

The pitaya fruit has nutritional and functional characteristics that make its cultivation considered promising [2]. Both the pulp and the peel are an important source of fiber with attractive digestive attributes. Their physical and chemical characteristics can vary from species to species due to high genetic diversity [3]. In addition, research carried out on pitaya reveals the presence of bioactive compounds, including phenolic compounds such as flavonoids, which contribute to the fruit's antioxidant capacity [4, 5]. The beneficial effects of these compounds are related to the prevention of degenerative diseases such as colon cancer and diabetes, the reduction of bacterial infections, and cardiovascular diseases [6]. In addition, red pitaya has the betalain group of phenolic compounds, which are divided into betaxanthins (yellow color) and betacyanins (violet color) [7, 8].

The food industry is facing great pressure to become more sustainable. Innovative technologies such as food irradiation for food safety are a greener alternative to more energy-intensive thermal processes [9], and efforts must be made to expand their use to avoid significant economic losses due to damaged or contaminated food and save thousands of lives [10]. Ionizing radiation, due to its high energy, is capable of penetrating matter, ionizing atoms, breaking chemical bonds and causing damage to biological tissues. On the other hand, the use of ionizing radiation has innumerable applications that have various benefits for society and individuals. Irradiation with ionizing radiation is a technique used in food preservation that consists of exposing food, packaged or not, and the aim of this process is to increase the shelf life of food by reducing the natural losses caused by physiological processes (sprouting, ripening and ageing) [11]. This technique can also be used to eliminate insects, pathogenic bacteria, viruses, fungi and yeasts, without causing damage to the food, making it safe for the consumer [12].

As for post-harvest, the pitaya is a tropical fruit that deteriorates relatively easily under ambient conditions, and as a result, the post-harvest shelf life is short, approximately 6 to 8 days under natural conditions. Storage temperature and time influence the physiological processes of the pitaya, increasing the useful life of the fruit, especially at a temperature of 8 °C, which resulted in better quality [13, 14].

The aim of this study was to evaluate the physical properties (texture, color, and water activity) in the post-harvest preservation of red-fleshed pitaya fruits during refrigerated storage after being subjected to different doses of gamma radiation in order to preserve nutritional quality and promote greater food safety, and also to identify the best doses of radiation in fresh pitaya to extend shelf life.

2. MATERIALS AND METHODS

The samples were obtained from the CEAGESP (Companhia de Entrepostos e Armazéns Gerais de São Paulo) wholesale market. The fruit was randomly selected and free of mechanical damage, and transported to the LADAI (Laboratório de Análise e Detecção de Alimentos Irradiados) of the CTR (Centro de Tecnologia das Radiações) of IPEN/CNEN-SP (Instituto de Pesquisas Energéticas e Nucleares). The red pitaya boxes were irradiated (doses of 1 and 3.5 kGy) in the Multipurpose Irradiator with a dose rate of 9.111kGy/h (IPEN/CNEN-SP). The control and irradiated samples were analyzed after 7 and 14 days of storage. The texture was analyzed using a Stable Micro Systems TA-XT2 texturometer with a compression capacity of 50 kg and a test speed of 50 mm/s. Irradiated and control samples' color was analyzed using a CR-400 colorimeter (Konica Minolta). The results were expressed by the CIELAB space (Commission Internacionale de L'Eclairage), and nine random readings of the samples were performed for each dose of gamma irradiation. The results were expressed in CIELAB and CIE L*C*h color space which are the most used systems for the evaluation of color in food. The parameters L* (brightness), a* (red/green) and b* (yellow/blue intensity) were obtained [13]. Chroma C* (saturation or color intensity), and Hue angle (amount of color in which red-purplish = 0°, yellow = 90°, green = 180°, blue = 270°, and black = 360°). Soluble solids were obtained by direct reading on a digital refractometer, according to AOAC method no. 932.12 (2002) [15]. The water activity was performed using an AquaLab 4TE model equipment, with ten readings for each dose. The results were analyzed using the program GraphPad Prism (version 8.0), which was also used for the elaboration of tables and graphs. The comparisons among the data were performed using two-way ANOVA, with a statistical significance limit of by Tukey test ($p < 0.05$).

3. RESULTS AND DISCUSSIONS

Table 1 shows the strength and elasticity properties of the non-irradiated and irradiated peel for storage times of 7 and 14 days. It can be seen that for the same storage time (7 days), the strength property showed a reduction of close to 67 and 28% for doses of 1.0 and 3.5 kGy, respectively, while for 14 days, there was also a reduction of 4 and 39%, respectively. For the elasticity property, there was an increase of 43 and 4 for doses of 1.0 and 3.5 kGy when compared to non-irradiated, for the same storage time (7 days). For 14 days, there was an increase of 107 and 69% for 1.0 and 3.5 kGy, respectively. These results suggest that the lower dose of 1.0 kGy had a greater influence than the dose of 3.5 kGy on elasticity, indicating that high doses can damage characteristics that favor the preservation of pitaya during the storage process.

Table 1: Texture of irradiated pitaya.

Dose (kGy)	Storage (days)	Skin Strength (g)	Elasticity (mm)
Non-irradiated	7	950 ± 30*	3.0 ± 0.5
	14	760 ± 20	2.39 ± 0.13
1.0	7	312 ± 4	4.2 ± 0.6
	14	728 ± 21	4.9 ± 1.4
3.5	7	679 ± 27	3.1 ± 0.6
	14	462 ± 30	4.0 ± 1.2

*Mean and SD.

Table 2 shows the results for the color properties of pitaya as a function of storage time and irradiation dose. The luminosity range (L*) of the pitaya indicated that the lowest value was for a dose of 1.0 kGy, with a storage time of 7 days (29.8). For the positive a* parameter (coloration close to red), the same result was observed for the 1.0 kGy dose, showing the lowest intensity, while for 3.5 kGy it was observed that for 7 days there was no difference with the non-irradiated and for 14 days a reduction. This last result suggests that the higher dose of irradiation preserves this parameter during the 7-day period, but fails to maintain the same characteristics after 14 days. Similar results were observed for the other parameters (b*, C* and h°). In general, it can be seen that irradiation with a dose of 1.0 kGy had a reduction in the intensity and tone of the color, which was more evident for the shortest storage time (7 days). This result suggests that after 14 days, the fruit itself is able to regain some of its color, as if recovering from the irradiation process. For 3.5 kGy, the characteristics were also preserved at 7 days, but at 14 days there was a reduction in all the color indicators.

Table 2: Color results of pitaya irradiated.

Dose (kGy)	Storage (days)	Color				
		L*	**a***	**b***	**C***	**h°**
Non-irradiated	7	37 ± 4*	43.1 ± 2.2	11.4 ± 1.6	44.6 ± 2.0	14.8 ± 2.4
	14	38.7± 2.5	42.1 ± 2.5	12.6 ± 2.3	44.0 ± 2.4	17 ± 3
1.0	7	29.8 ± 1.8	25.4 ± 2.3	3.7 ± 1.1	25.7 ± 2.3	8.3 ± 2.1
	14	31.4 ± 4	30 ± 4	6.8 ± 2.6	31 ± 4	13 ± 5
3.5	7	39.2 ± 2.1	42 ± 4	10.9 ± 1.5	44 ± 4	15 ± 3
	14	39 ± 3	32.0 ± 2.4	7.8 ± 1.8	33.0 ± 2.3	14 ± 3

L* (Luminosity), a* (red/green), b* (yellow/blue), C* (chroma), h (hue angle), *Mean and SD.

Table 3 shows the results of total solids (°Brix) of pitaya stored for 7 and 14 days, comparing non-irradiated and irradiated samples at 1 kGy and 3.5 kGy. It can be seen that for the storage time (7 days) the irradiated samples showed a significant increase in total solids compared to the non-irradiated samples. The 3.5 kGy dose resulted in the highest °Brix value (14.1), followed by 1.0 kGy (13.8) and non-irradiated (10.9). For the analysis by treatment (non-irradiated), at 7 days, the non-irradiated samples showed a value of 10.9. At 14 days, there was a significant increase in total solids to 12.8 indicating that the natural ripeness of the fruit contributed to the increase in °Brix during storage. The differences are statistically significant, as indicated by the different letters (a, b) in Tukey's test. For the storage time (day 14) the non-irradiated samples showed an increase in total solids (12.8), equaling the values of the samples irradiated at 3.5 kGy (12.8), while the sample irradiated at 1.0 kGy kept °Brix relatively constant (13.0). There was no statistically significant difference between the groups during this storage period, indicating that the initial irradiation has a greater effect in the first few days of storage, but this difference tends to diminish over time. For the analysis by treatment (1.0 kGy), irradiation at 1.0 kGy resulted in a value of 13.8 at 7 days, higher than that of the non-irradiated samples in the same period. At 14 days, the value remained stable at (13.0), suggesting that the 1.0 kGy dose was effective in maintaining total solids levels during storage. For the analysis by treatment (3.5 kGy), the samples showed the highest initial °Brix value (14.1) at 7 days. At 14 days, the value decreased slightly to 12.8, leveling out at that of the non-irradiated and 1.0 kGy irradiated samples, suggesting that the higher dose may have stabilized the total solids content, but with a slight decrease over time.

Table 3: Total solids (°Brix) in non-irradiated and irradiated samples during storage time.

Storage (days)	Dose (kG)		
	Non-irradiated	**1.0**	**3.5**
7	10.9 ± 0.3^{aA*}	13.8 ± 0.2^{bB}	14.1 ± 0.2^{bB}
14	12.8 ± 0.2^{bC}	13.0 ± 0.2^{bC}	12.8 ± 0.2^{bC}

*ANOVA and Tukey's test (p<0,05).

Table 4 shows the results of the water activity at the pitaya samples, showing that they remained stable during 14 days of storage. The critical point for food is 0.6-0.7 aw, since below this range it is difficult for microorganisms to grow. aw affects the rate of chemical reactions such as the oxidation of lipids, the hydrolysis of proteins, the degradation of vitamins, and biochemical reactions [16]. It should be noted that the value is higher than 0.976, which indicates a high aw and greater susceptibility to the growth of microorganisms due to the amount of free water available, showing the microbiological risk and the need to apply packaging temperature and storage as additional prevention methods. In addition, the irradiated samples did not show a significant difference compared to the control, nor to the storage time, even though there was an interaction between the radiolysis of the water.

Table 4: Water activity (aw) results from 14 days after irradiation.

Storage (days)	Water activity (aw)		
	Non-irradiated	**1.0 kGy**	**3.5 kGy**
7	0.99 ± 0.011^{aA*}	0.98 ± 0.002^{aA}	0.98 ± 0.002^{aA}
14	0.98 ± 0.001^{aA}	0.98 ± 0.004^{aA}	0.98 ± 0.004^{aA}

*Lower case letters (different doses) and upper-case letters (storage time).

4. CONCLUSIONS

The results of the texture analysis suggest that a dose of less than 1.0 kGy had a greater influence on elasticity than a dose of 3.5 kGy. In addition, the irradiation influences the color of pitaya fruit, which is affected by storage time. The irradiated samples initially showed a significant increase in total solids compared to the non-irradiated samples, especially at the 3.5 kGy dose. However, over the storage time, the values tend to stabilize, with the irradiated samples showing less variation in total solids compared to the non-irradiated ones. Irradiation can therefore be effective in maintaining fruit quality during storage. Despite these results, further studies are needed to identify the effects of irradiation on other properties, where it can be significantly beneficial for preserving properties and compounds, as well as increasing the shelf life of this fruit.

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CONFLICT OF INTEREST

All authors declare that they have no conflicts of interest.

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