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Effect of quarantine treatments on the carbohydrate and organic acid content of mangoes (*cv*. Tommy Atkins)

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ABSTRACT

Brazil is one of the largest mango producers and the third largest mango exporter worldwide. Irradiation treatment and its commercial feasibility have been studied in our country to make it possible to develop new markets and, consequently, to compete with the major exporters of mangoes, Mexico and India. This work was designed to compare irradiation treatment with the hot water dip treatment in mangoes *cv*. Tommy Atkins for export and to verify that the main attributes for acceptance, color and texture, as well as carbohydrate and organic acid contents, were maintained. In this study, the fruit was divided into groups: control, hot water dip-treated (46 °C for 90 min), and irradiation-treated at doses of 0.4 kGy and 1.0 kGy. The fruit was stored at low temperature (11 °C ± 2) for 14 days and then at room temperature (23 °C ± 2) until the end of the study. The results indicated that the fruit given a dose of 1.0 kGy remained in a less advanced stage of ripening (stage 3) throughout the storage period, but experienced a greater loss of texture in the beginning of the experiment. It was noted that only the control group had higher levels of citric acid and succinic acid on the last day of the experiment. There were no significant differences in the total sugar content between any treatment groups. Gamma radiation can be used as a quarantine treatment and does not interfere negatively with the quality attributes of mangoes.

1. Introduction

Brazil is the third largest exporter of mangoes after Mexico and India (FAO, 2007). Because Brazil is able to produce mangoes during a period of short supply (September–March), the Brazilian mango, especially *cv*. Tommy Atkins, sells for the highest price in the international market during this time. However, this situation may change because other countries are also seeking to extend their production periods. Brazil needs to take measures to provide fruit with better quality and uniformity that could reach new markets (Pimentel et al., 2000).

For this reason, the postharvest control of quarantine insect pests and shelf life extension have been studied extensively, especially for tropical fruits (Lacroix and Vachon, 1999). Mangoes for export need specific treatments to meet the phytosanitary requirements for the disinfestation of potential pests. The most conventional treatment used to comply with the requirements of the US and European markets is the thermal treatment (hot water dip or vapor treatment) (Cintra et al., 2003).

In this context, several studies show that the irradiation treatment ensures the control of insect pests and, depending on how it is applied, delays ripening, which makes it a quarantine treatment (Sabato et al., 2009; Follett, 2001; Gagnon et al., 1993). On fruit exported to the United States, the radiation dose commonly used for irradiation treatment to control fruit flies and other insects of concern during quarantine is 400 Gy, which is below the maximum applied dose of 1 kGy required by the US FDA. There is a noteworthy trend by exporters toward the use of irradiation technology instead of the conventional hot water dip treatment. For instance, in 2007, India signed an agreement with the United States to export irradiated mangoes (APHIS, 2007). It is estimated that India will increase its exports to the US by approximately 1.25%. In the same year, Mexico was approved by the USDA to apply irradiation as a quarantine treatment, becoming the second country to export irradiated mangoes to the United States (BENEBION, 2007). Brazil has expressed interest in this market, carrying out several studies on the irradiation of mangoes for commercial purposes (Caruso, 2009; Sabato et al., 2009). These studies contributed to the initial experiments on the quality of irradiated mangoes harvested at different maturation stages as well as on the effect of a combined treatment (irradiation with hot water dip). Studies conducted by Sabato et al. (2009) indicated that the use of irradiation (0.25 kGy and

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0.75 kGy doses) is significant in maintaining the quality of fruit in maturity stages 2 and 3 during the export process. Moreover, Caruso (2009) concluded that the combined treatment (irradiation with hot water dip) showed satisfactory results, confirming the synergistic effect. To complement these studies, this work aimed to compare the application of irradiation with the hot water dip treatment in mangoes *cv*. Tommy Atkins for export and to verify that the main attributes for acceptance: color, texture, as well as carbohydrate and organic acid content, were maintained.

2. Materials and methods

Mangoes (*cv*. Tommy Atkins) were supplied by Timbaúba Agrícola from Petrolina, Recife (Northeast region of Brazil). The mangoes were harvested at stage 3 (50% green and 50% red) according to the scale of maturity proposed by Empresa Brasileira de Pesquisa Agropecuária—Embrapa (2004). The mangoes arrived at the Radiation Technology Center of the Instituto de Pesquisas Energéticas e Nucleares (IPEN-CNEN/SP) within 6 days of harvest. Travel from Petrolina to São Paulo was made according to export procedures: by airplane, at room temperature and in closed paper packaging. The subsequent stages of maturity were determined subjectively according to the degree of skin color as proposed by Embrapa (2004): stage 1 (100% green), stage 2 (75% green and 25% dark red), stage 3 (50% green and 50% red), stage 4 (25% green and 75% red) and stage 5 (25% yellow and 75% red).

2.1. Treatments

The mangoes were cleaned with 1% chlorinated water for 5 min and divided into four groups: control group; hot water dip treatment; and irradiation doses of 0.4 kGy and 1.0 kGy.

The fruit was submersed in hot water for 90 min at 46 °C and then cooled to 21 °C, in accordance with the US regulations required for importation of mangoes (International Standards for Phytosanitary Measures—ISPM, nos. 1–24).

The fruit was irradiated in a Multipurpose Cobalt-60 source (90000 Ci) belonging to IPEN-CNEN/SP (developed by our own in house technology). The 0.4 kGy dose was chosen to comply with the international requirement for disinfestation (based on US regulations, USFDA, 2007). The 1.0 kGy dose represents the maximum dose that would be obtained in a commercial facility when the minimum dose (disinfestation dose) is delivered. In this case, the dose uniformity ratio (D_{max}/D_{min}) of the commercial gamma source was reported to be 2.5. Dosimetry was conducted using Gammachrome YR batch 64 dosimeters.

2.2. Storage and sampling

Before treatment (day 0), six mangoes were selected at random. After treatment, all of the fruit was kept at 11 °C ± 2 in an acclimatized chamber (85% UR) for 14 days. After this period, the fruit was kept at room temperature (23 °C ± 2 and 70% RH) until the end of its shelf life (equivalent to approximately 10 days of cold storage). These conditions were established to simulate the conditions of export from Brazil to distant countries.

The fruit was sampled on days 1, 7 and 14 (during the acclimatization period) and on days 17, 22 and 24 (during environmental storage). Each sample, containing 6 mangoes per treatment, was submitted for skin color and texture analysis. Based on these analyses, four mangoes with similar texture and degree of ripening (skin color) were selected to compose the sample for subsequent analyses. These mangoes were peeled, sliced, submersed immediately in liquid nitrogen and stored at −80 °C until required for analysis. Each assay was conducted in triplicate using the homogenized pulp of these four mangoes.

2.2.1. Texture

The texture was measured by a texturometer (Stable Micro Systems), model TA-TX2i, fitted with a penetration probe (N/2). Texture was expressed in Newtons (N).

2.2.2. Organic acids

The extraction of organic acids was carried out in triplicate with deionized water (ratio 190 1:2 m/v). Each sample was processed in a Potter-type homogenizer (in an ice bath) for 1 min and centrifuged at 10,000 g for 10 min at 4 °C. The organic acids in the supernatant were analyzed by HPLC-DAD, according to the method used by Amorós et al. (2003).

2.2.3. Carbohydrate content

The starch content of the pulp tissue was determined enzymatically as described by Cordenunsi and Lajolo (1995). Soluble sugars were extracted three times with 80% ethanol at 80 °C. After centrifugation, the supernatants were mixed, and the ethanol was evaporated under vacuum using a speed-vac system. The soluble sugar content was analyzed by HPLC with pulse amperometric detection (HPLC-PAD-Dionex, Sunnyvale, CA, USA), using a PA1 column (Dionex, Sunnyvale, CA, USA) in an isocratic run with 18 mM NaOH for 25 min. The total soluble sugar content was determined as the sum of the glucose, fructose and sucrose values. The analysis was conducted in triplicate.

2.3. Statistical analysis

The results were evaluated with the analysis of variance (ANOVA) method, and the significant differences were identified by the Tukey test at 5% significance using Statistica version 5.1.

3. Results and discussion

3.1. Stage of maturity

Independent of the treatment, storage at 11 °C (up to 14 days) allowed the skin color development of the mangoes to occur slowly and gradually, making them suitable for consumption until day 24 of storage. This is likely to have occurred due to the low temperature, which decreases the ripening process and prolongs shelf life.

At day 22, the mangoes irradiated with a dose of 1.0 kGy were still in less advanced stages of maturity (stages 3–4), while the control group was between stages 4 and 5 of maturity. However, this difference was not observed on day 24 ($p < 0.05$).

The mangoes irradiated with a dose of 1.0 kGy showed no significant differences ($p < 0.05$) during the experiment. This highest dose slowed the skin color development. Reyes and Cisneros-Zevallos (2007) observed that irradiation by electron beam (1.0, 1.5 and 3.1 kGy) did not promote changes in carotenoid levels over a period of 18 days at 15 °C. The authors attributed these observations to the possibility that ionizing radiation inhibited the synthesis of carotenoids. According to Camargo et al. (2007), this may happen during irradiation due to the formation of free radicals that alter the chlorophyll structure and, consequently, affect the color of the fruit.

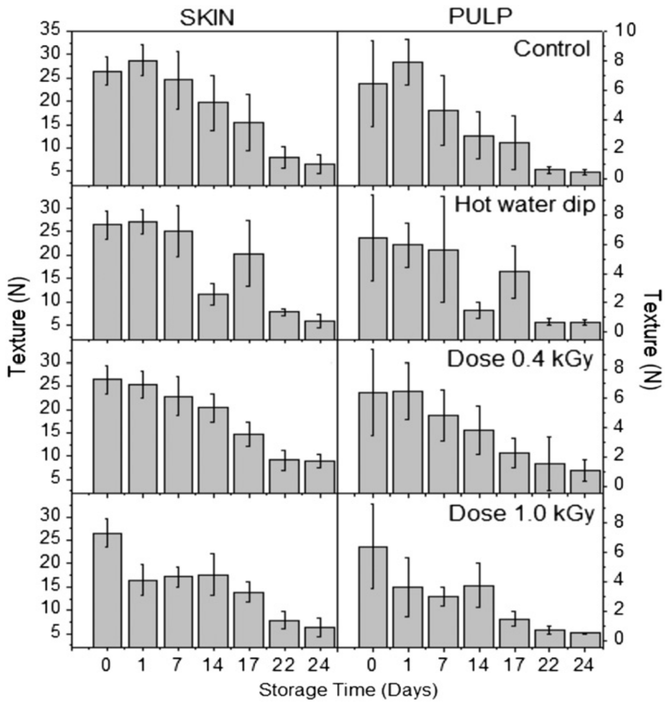

Fig. 1. Effect of each treatment on the texture values of the skin and pulp of mangoes during storage. The values are mean ± standard deviation ($n=6$).

3.2. Texture

The skin and pulp gradually lost their texture throughout the experiment because changes occur in the cell wall structure as the starch degrades during the ripening of the fruit (Awad, 1993).

The texture values of the mango skin in the 1.0 kGy dose group were lower than those in the other treatment groups on day 1. This profile was maintained until day 7 (Fig. 1). The only treatment group that showed greater resistance to penetration was the 0.4 kGy dose group. This group had a loss in texture of approximately 66% during the storage period, while the other groups had a loss of approximately 75%. The same profile was observed in the texture of the fruit pulps (Fig. 1). The 0.4 kGy dose group had an 83% loss in texture during the experiment, while the other groups had a loss of approximately 92%. These results indicate that the use of a 0.4 kGy dose yielded the best texture values throughout the experiment, with a possible delay in the loss of texture. It is probable that the 1.0 kGy dose was too high for application to the fruit, creating stress on the tissue and promoting greater loss of texture. Moreover, the storage of the mangoes at 11 °C minimized the softening process during this period because low temperature slows down the metabolic reactions of the fruit, as shown by Awad (1993). Thus, if the fruit in the 1.0 kGy dose group had not been stored at low temperature, even lower texture values than those observed in this work may have been exhibited. However, the difference in texture observed in the 1.0 kGy dose group did not prevail during the experiment because there were no significant differences ($p<0.05$) between treatments on days 17, 22 and 24. These results indicate that the texture was similar in the ripe fruits, independent of the treatment.

3.3. Organic acids

Organic acids were evaluated on the three main days of storage: unripe fruit (stage 2 and 3) on day 1, intermediate fruit (stage 3) on day 14 and ripe fruit (stage 4) on day 24.

At the beginning of the experiment, the main acids found in all treatment groups were citric acid (~0.015 mg/g) and succinic acid (~0.113 mg/g) (Fig. 2).

During the storage period, for all treatment groups, the citric acid content showed little change until day 14. On the last day of analysis, these levels decreased approximately 73% for the hot water dip group and the two irradiation dose groups.

The succinic acid content increased until day 14 for the hot water dip group and the 0.4 kGy dose group. The control group and the 1.0 kGy dose group showed increases in these levels on only the first day. The control group had the largest increase (~57%) on day 1, followed by the 1.0 kGy dose group, the 0.4 kGy dose group and the hot water dip group, with 43%, 36% and 29%, respectively (Fig. 2). When the fruits were kept at room temperature, a reduction in the levels of succinic acid was observed in all treatment groups on day 24 (Fig. 2). The hot water dip group had the lowest organic acid content, differing significantly ($p<0.05$) from the control group and the 0.4 kGy dose group.

For each treatment group, the total acid content profile was similar to that of succinic acid (Fig. 2). On day 24, all treatment groups exhibited a lower organic acid content because the stage of maturity in fruits was more advanced (stage 4).

3.4. Carbohydrates

The process of starch degradation and soluble sugar accumulation can be observed in Fig. 3. In all groups, there were decreases of more than 87% of the starch content. The 0.4 kGy and 1.0 kGy dose groups had the highest percentage of starch degradation (approximately 98%) followed by the hot water dip and control groups (90%). These results indicate that the radiation process may have an effect on starch degradation in mangoes, although there were no significant differences ($p<0.05$) between groups.

No data on the starch content of irradiated mangoes were found in the literature for comparison with the values obtained in this study.

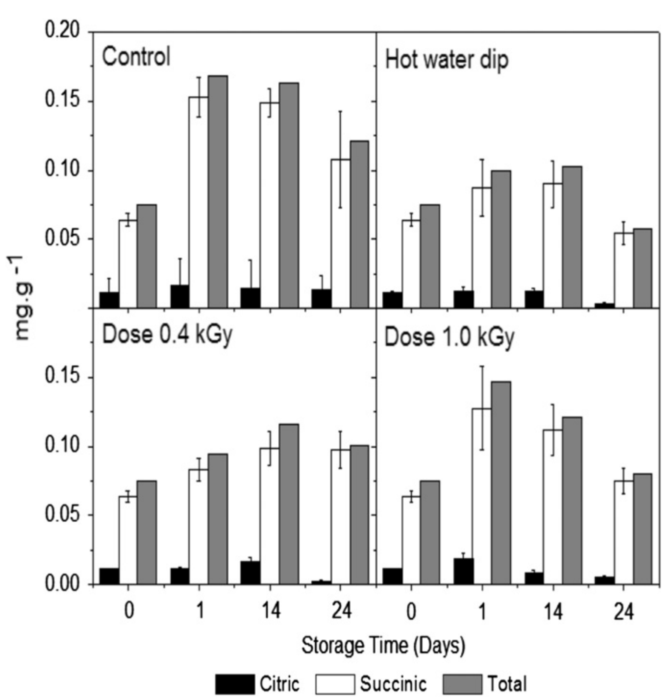

Fig. 2. Effect of each treatment on the organic acid content in mangoes during storage. The values are mean ± standard deviation ($n=3$).

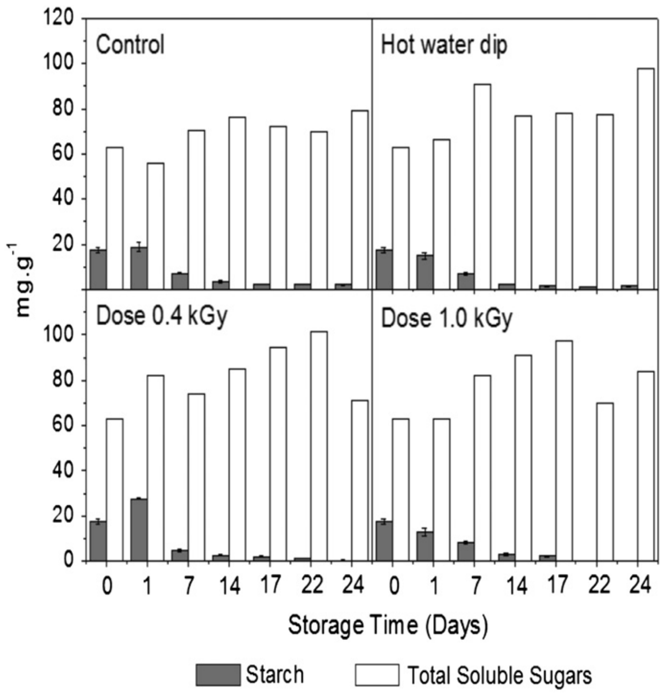

Fig. 3. Effect of each treatment on the content of starch and total soluble sugars during storage. The values are mean ± standard deviation ($n=3$).

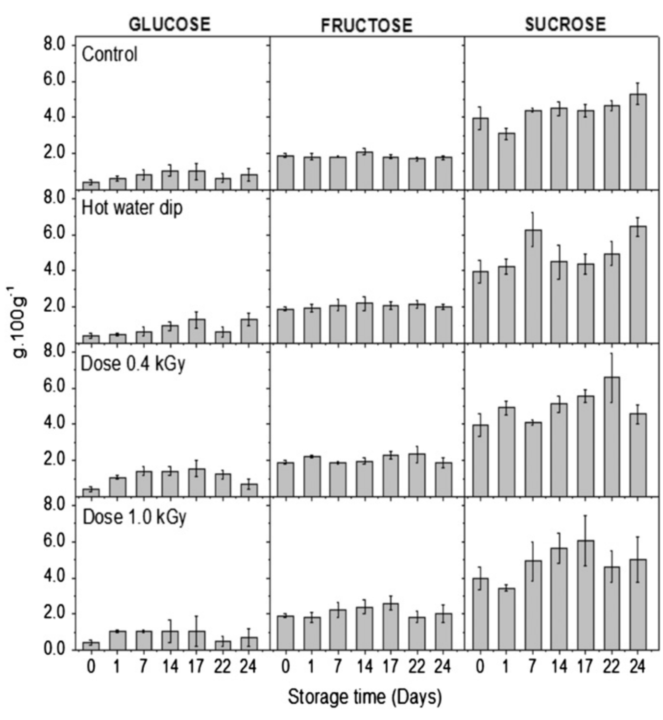

Fig. 4. Effect of each treatment on the content of glucose, fructose and sucrose in mangoes during storage. The values are mean ± standard deviation ($n=3$).

The total soluble sugar content (Fig. 3) increased throughout the experiment for all the groups however, at the end of the experiment, no significant differences ($p<0.05$) in the total sugar content were observed between the groups.

The individual levels of glucose, fructose and sucrose are shown in Fig. 4. Sucrose was the predominant sugar in all groups throughout the storage period, followed by fructose and glucose, respectively. The hot water dip group had a larger increase in glucose of approximately 69%, while the glucose content of the other groups increased by approximately 45%. The same profile was observed for the sucrose content, which again showed an increase in sugar of 40% in the hot water dip group. The 0.4 kGy dose group had the lowest sugar level with about a 15% increase during storage. Fructose levels remained similar throughout the experiment and the hot water dip treatment group was the only one to show an increase at 17%.

Mitchell et al. (1992) observed that mangoes (Kensington variety) irradiated at a dose of 0.3 kGy had higher levels of sucrose compared with those irradiated with a 0.6 kGy dose, which had lower levels. The author concluded that the sucrose content may vary depending on the dose, an observation which was not made in this work because both doses showed similar levels of sucrose. Tinjaca (2005) observed that levels of glucose in irradiated mangoes were greater than those in the control group. The author explains that this increase may be associated with the effect of irradiation on the depolymerization of carbohydrate molecules, such as cellulose and starch, which also induces the degradation of cell membranes and, in turn, promotes the softening of irradiated fruits. This observation could be attributed to the fact that the 1.0 kGy dose group showed texture values that were smaller than those of other treatment groups. Because the glucose content as well as the fructose and sucrose content was similar in all treatments in this work, it was concluded that there was no correlation between the levels of sugars and the loss of texture at the 1.0 kGy dose on days 1 and 7.

The fructose/glucose ratio is usually one in fruits such as banana and papaya (Gomez et al. 1999). However, this was not observed in this study, in which the amount of fructose (0.1 ± 1.895) was higher than glucose content (0.414 ± 0.12) from the beginning of the experiment. Possibly, this is because glucose is used as substrate during the respiration of the fruit, which results in a higher content of fructose.

The proportion of different types of sugars is an important attribute of quality because sugars differ in degree of sweetness. Fructose has a greater degree of sweetness than sucrose, and sucrose is sweeter than glucose. In this work, the glucose content ($\sim$1%) was lower than the fructose content ($\sim$2%), which was lower than the sucrose content (5%). According to these observations, it can be inferred that, in all the groups, the increase in the sweetness of the mango as it ripens may be the result of the increase in and the predominance of two sugars with a greater degree of sweetness (fructose and sucrose).

4. Conclusion

The green color of the fruit irradiated with a dose of 1.0 kGy can be maintained during a long storage period. However, independent of the color, it was observed that other variables such as texture and soluble sugars are not simultaneously influenced. This highest dose did not have a negative effect on the quality of the fruit. A dose of 0.4 kGy produced quality attribute profiles similar to those of the hot water dip group and the control group.

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