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Study of physical–chemical and sensorial properties of irradiated Tommy Atkins mangoes (*Mangifera indica* L.) in an international consignment

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ABSTRACT

Tommy Atkins mangoes from Brazil were sent to Canada after being submitted to a thermal treatment (46.1 °C, 110 min – control) and to a gamma irradiation treatment (doses 0.4 and 1.0 kGy). The fruits were stored at 11 °C during 10 days until the international transportation and kept at an environmental condition (22 °C) during 12 days, where their physical–chemical and sensorial properties were evaluated. Analysis of visual parameters showed that irradiation treatment influenced the maturity index. Mass loss was around 5% for all fruits, from the three treatments, and incidence of end rot was lower for irradiated fruits. Physico-chemical analysis presented some significant differences and irradiated mangoes at 1.0 kGy had lower values than control ones ($p \leqslant .05$) for texture for each day of analysis. Sensory evaluation demonstrated that panelists perceived few differences among treatments.

1. Introduction

Mangoes are attractive fruits due to unique taste well appreciated in different parts of the world. Tommy Atkins variety is the most important and the most exported cultivating in Brazil. As it is a tropical fruit, several cares should be taken to preserve its quality from harvesting until consumption. Disinfestation and shelf life extension have been extensively studied and have a great deal of potential and promise, especially for tropical fruits (Lacroix & Vachon, 1999).

The exportation of mangoes implies specific treatments to attend phytosanitary requirements. The more conventional treatment used in Brazil is thermal treatment (46.1 °C for 90–110 min). Nowadays some Brazilian mangoes exporters are interested in studies representing commercial application of ionizing radiation technology, as there is a trend by some of the great exporters of mangoes in using it instead of conventional ones (APHIS, 2007).

Ionizing radiation can be applied to food for different purposes. Among them, disinfestation is very important considering fruits and their phytosanitary aspects, essential requirement for foreign market. Irradiation is a useful treatment to prevent immature fruit flies from reaching the adult stage, and this has been recommended as the objective of irradiation quarantine treatments against tephritid fruits flies or disinfestation (Hallman, 1999; Moy, 1993). Gamma irradiation is effective to cause damage and even lethal to embryos or insects through disorders of cell walls or direct effect on DNA chains of these pests (Moy, 1977).

When any treatment is applied to mangoes, the concern is not impairing the quality of the fruits, what can be observed through changes in physico chemical properties and sensory aspects. The latter is maybe even more important as the consumer will dictate the market of fresh fruits.

In the literature, few studies consider transportation from distant countries in relation of the quality of mangoes and their acceptance. In general, tropical fruits have been shipped for a long period (normally 15 days at controlled temperature) until delivered in local markets. Lacroix et al. (1993) compared mangoes submitted to irradiation and combined treatment (irradiation plus hot water dip) in studies carried out simultaneously in Thailand and Canada, with good results related to quality of fruits.

Under these considerations, our work consisted in verifying the quality of mangoes, cultivated and harvested in northeast of Brazil, and sent in an international consignment to Canada, representing the transportation of treated fruits to overseas markets. In the scope of this research, the quality of mangoes submitted to gamma irradiation was compared to those thermally treated as control group.

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2. Material and methods

2.1. Fruits, treatments and transportation

Tommy Atkins mangoes were from Petrolina, northeast region of Brazil, harvested at degree 3, in October 7th and sent immediately to Instituto de Pesquisas Energéticas e Nucleares-IPEN (São Paulo, Brazil) where they were treated. The total quantity was around 630 fruits, which were divided in three batches. One of them was submitted to a hot water dip treatment (46 °C during 110 min), that consisted in a control group. The two other groups were irradiated in a Multipurpose Gamma Source (IPEN, São Paulo, Brazil). The delivered doses were 0.4 and 1.0 kGy. The dose of 0.4 kGy was chosen in order to attend the international requirement for disinfestation fruits (based on USA regulations, USDA, 2007). The 1.0 kGy dose represents the maximum dose would be obtained in a commercial facility when the minimum dose (disinfestation dose) is delivered. The dose uniformity ratio (D_{max}/D_{min}) of a commercial gamma source, in this case, was considered as 2.5.

2.2. Storage

After treatment, the mangoes were stored in a conditioned room (11 °C ± 1 and 66.6% RH) until the trip to Canada (October, 17th). Fruits were sent to the Canadian Irradiation Center (CIC, Laval, Canada) by plane at environmental conditions. The storage at CIC was done under environmental conditions (20 °C ± 2; 40% ± 2 RH) and the storage period started on the day of fruits trip from Brazil to Canada (Day 0).

2.3. Mass loss and visual observations

A sample, of 36 mangoes (four boxes), was used for mass loss determination started in Brazil. The visual observations evolving the maturity index of the fruits (35 fruits randomly chosen) were also done. These were evaluated according the following scale: degree 1 (100% green), degree 2 (75% green and 25% dark red), degree 3 (50% green and 50% red), degree 4 (25% green and 75% red) and degree 5 (25% yellow and 75% red). Any presence of defect, rot end and mold was noted during the whole experiment.

2.4. Physico chemical analysis

2.4.1. Sampling

Nine fruits of each treatment were used for each day (of analysis) for all analysis.

2.4.2. Acidity

Titrable acidity was determined by titrating 10 g of fresh pulp with 0.1N of alkali (NaOH) following the AOAC Method 942.15 (AOAC, 1990). Acidity was expressed as% (g / 100 g).

2.4.3. pH

Ten grams of samples were homogenized for pH measurements. A digital pHmeter (Orion, model 420 A) was employed at 25 °C.

2.4.4. Total soluble solids

The content of total soluble solids was determined using samples of fruit pulp with a hand refractometer (Carl Zeiss, Germany), at room temperature (range from 18 to 23 °C).

2.4.5. Ratio (solids/acidity)

The ratio was calculated using the relation between the total soluble solids by acidity.

2.4.6. Texture

For texture measurements, the fruits were peeled (very thin layer) in two different places in the equatorial region of the mangoes. The texture was measured in a handle penetrometer with crossheads of 0.8 cm of diameter. Texture was expressed by kg/cm^2.

2.4.7. Color

Color of the pulp was measured using a Colormet colorimeter (Instrumar Limited St. Johns, NF, Canada). Mango samples were cut longitudinally and the readings were made in the central region of these slices. The system L^*, a^*, b^* was employed, where L^* represented the lightness of the color (for black, $L^* = 0$ and for white, $L^* = 100$). The a^* axis varies from green ($-a^*$) to red ($+a^*$) and the b^* axis varies from blue ($-b^*$) to yellow ($+b^*$).

2.5. Sensory evaluation

The sensorial evaluation was performed with 20 panelists, who tested the color, odor, taste and texture parameters in three fruit samples (control, 0.4 and 1.0 kGy). In addition, each person evaluated the overall appearance judging the whole fruit from consumer point of view. The answers were based on 9 point hedonic scale, being 9 as "like very much" until 1 "dislike very much" (Larmond, 1979). Twelve fruits from each treatment were mixed and delivered into portions.

2.6. Statistics

The results were treated with analysis of variance (ANOVA) and the significant statistical differences were identified by multiple comparison Duncan's test, at 5% significance, using Statistica version 7.0.

3. Results and discussion

3.1. Maturity index and mass loss

The maturity index results showed that the degree 5 was reached at day 5 in the control group for more than 70% of the fruits (Fig. 1). No occurrence in degree 3 at day 7 was observed and all fruits control reached degree 5 in this date. At day 5, around 50% of the irradiated fruits (0.4 and 1.0 kGy) have reached the maturity index 3 and 4. At day 8, these samples were still in less advanced stages of maturity. These results demonstrated that gamma radiation influenced the maturity index when evaluated visually.

Reyes and Cisneros-Zevallos (2007) found similar results during mangoes storage at 15 °C for 18 days and discovered that irradia-

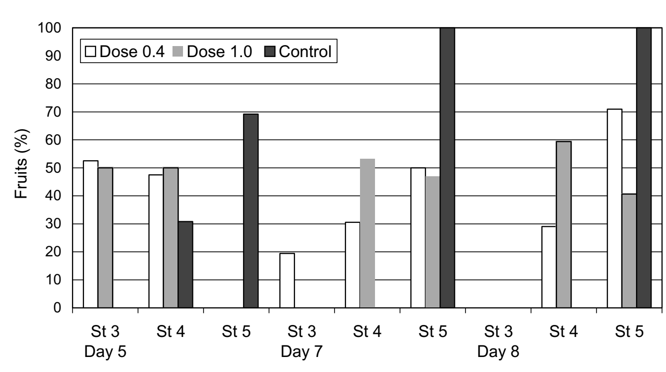

Fig. 1. Distribution of mangoes according the maturity indexes during storage.

tion of mango fruits (⩾1.0 kGy), delayed the ripening index and irradiated fruit's skins remained green after the storage period. Lacroix et al. (1993) observed a significantly delay in ripe skin color for irradiated mangoes compared to control ($p \leqslant .05$).

Mass loss had similar behavior for the three treatments during international transportation and storage (Fig. 2). The control group presented a mass loss slightly higher in day 8, while irradiated fruits at 0.4 kGy had lower value. On day 8, fruits from control, irradiated at 0.4 and at 1.0 kGy presented around 5% of mass loss (5.5%, 5.3% and 5.4%, respectively), that can be related to maturation index.

During the whole experiment, there is no incidence of mold presence in fruits from the three treatments. The random observation of rot end of mangoes in day 8 presented a total of 6.6% for control and 1.6% and 4.7% for irradiated samples at 0.4 and 1.0 kGy, respectively. The level of incidence of this problem was lower for irradiated samples than for control but both treatments was not able to avoid the development of rot end.

3.2. Physico chemical analysis

During storage, pH measurements increased for the three treatments where control fruits presented higher values ($p \leqslant .05$) (Table 1). Statistical differences can be observed for all measurements within treatments and within day of storage. Moreno, Castell-Perez, Gomes, Silva, and Moreira (2006) studied effect of electron beam in mangoes with doses varying from 1.0 to 3.1 kGy and found no pH differences for samples irradiated up to 1.5 kGy.

Acidity results for control samples reduced during the storage with significant difference between days 6 and 8 ($p \leqslant .05$), that can be associated to the metabolism of the fruits (Table 1). A significant different acidity was observed between irradiated fruits treated at 0.4 and 1.0 kGy only at day 8 ($p \leqslant .05$). These results are in accordance with maturity indexes discussed above. Lacroix, Lapointe, Latreille, and Gagnon (1991) observed that acidity of irradiated mangoes was significantly affected during the ripening process and observed a major decrease of acidity between days 12 and 15 of storage ($p \leqslant .05$).

Irradiated mangoes showed highest values in total soluble solids content in day 6 being statistically different from control ($p \leqslant .05$), as can be observed in Table 1. This fact can be associated to the breakage of polysaccharide content of the mangoes by irradiation. Hayashi and Kawashima (1985) studied the effect of ionizing radiation in potatoes tubers at 2.0 kGy and concluded that gamma irradiation brings about various physiological changes that together contribute to the accumulation of sucrose in irradiated potatoes. Doses and storage period had no significant influence ($p > .05$) on total soluble solids content at days 8 and 10. Ornelas-Paz, Yahia, and Gardea-Beja (2007) studied several cultivating of mangoes and found values for total soluble content of Tommy Atkins ranged at 13.6 ± 0.2, that is in agreement with ones of the current paper.

Control samples had an increase trend of ratio values from 54 to 77 and irradiated samples varied from 48 to 73.

Irradiation caused a slightly decrease of texture of mangoes during the storage. However, the values were not statistically significant ($P > .05$) (Table 1). Irradiated mangoes at 1.0 kGy had significant lower values than control samples ($p \leqslant .05$) for each day of analysis. These texture results are in accordance with Moreno et al. (2006) that found a reduction of firmness of mangoes exposed to 1.0 and 1.5 kGy. Tissue texture became progressively less resistant to compression with increasing doses of radiation. This is associated with degradative changes in the middle lamella of plant

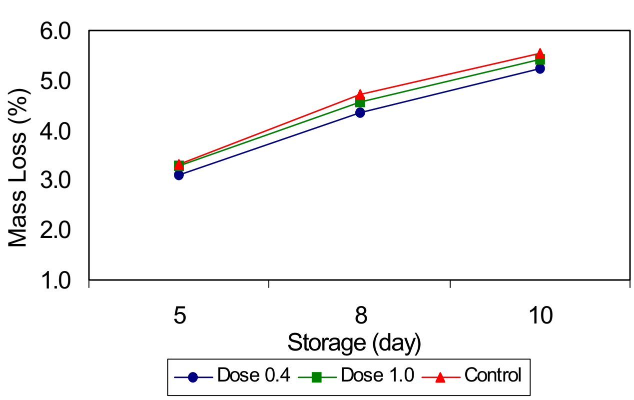

Fig. 2. Mass loss of mangoes during transportation and storage.

Table 2
Results of color parameters of mangoes in function of different treatments during storage

Day	Dose (kGy)	L[a]	a[a]	b[a]
6	Control	65.47 ± 1.43 a, A	13.21 ± 1.61 a, AB	70.71 ± 1.89 ab, A
	0.4	65.70 ± 1.52 a, A	12.93 ± 1.54 a, A	72.36 ± 2.65 b, A
	1	66.12 ± 1.63 a, A	11.49 ± 2.34 a, A	68.18 ± 2.04 a, A
8	Control	66.01 ± 3.12 a, A	11.14 ± 3.80 a, A	69.03 ± 4.17 a, A
	0.4	68.70 ± 3.37 b, B	11.62 ± 1.73 a, A	70.07 ± 3.53 a, A
	1	66.97 ± 1.22 ab, A	11.04 ± 2.19 a, A	69.69 ± 4.21 a, A
10	Control	65.33 ± 2.96 a, A	14.21 ± 1.85 a, B	70.98 ± 6.64 ab, A
	0.4	66.97 ± 2.44 a, AB	13.32 ± 1.96 ab, A	72.77 ± 2.87 b, A
	1	66.20 ± 3.31 a, A	11.04 ± 1.73 b, A	68.14 ± 5.78 a, A

For the same day, means followed by the same lower-case letter are not significantly different ($p \leqslant .05$); for the same dose, means followed by the same capital letter are not significantly different ($p \leqslant .05$).
[a] Standard deviation.

Table 1
Results of physical chemical analysis of mangoes in function of different treatments during storage

Day	Dose (kGy)	Acidity (%)	Total Soluble Solids (°Brix)	pH	Texture (kg/cm^2)
6	Control	0.21 ± 0.02[a] a, A	11.08 ± 0.49 a, A	4.56 ± 0.06 a, A	1.74 ± 0.42 a, A
	0.4	0.18 ± 0.03 a, A	13.17 ± 0.60 b, A	4.43 ± 0.14 b, A	1.56 ± 0.62 ab, A
	1	0.20 ± 0.04 a, AB	12.58 ± 1.07 b, A	4.27 ± 0.15 c, A	1.29 ± 0.49 b, A
8	Control	0.16 ± 0.02 a, B	11.17 ± 0.93 a, A	4.66 ± 0.10 a, B	1.87 ± 0.44 a, A
	0.4	0.17 ± 0.02 a, A	10.92 ± 0.38 a, B	4.49 ± 0.04 b, AB	1.48 ± 0.29 b, A
	1	0.23 ± 0.04 b, A	10.75 ± 0.52 a, B	4.30 ± 0.03 c, A	1.08 ± 0.38 c, A
10	Control	0.14 ± 0.01 a, B	11.00 ± 0.32 a, A	4.83 ± 0.03 a, C	1.38 ± 0.31 a, B
	0.4	0.21 ± 0.03 b, A	10.83 ± 0.52 a, B	4.57 ± 0.01 b, B	1.36 ± 0.29 a, A
7	1	0.19 ± 0.02 b, B	11.00 ± 0.63 a, B	4.42 ± 0.06 c, B	1.04 ± 0.47 b, A

For the same day, means followed by the same lower-case letter are not significantly different ($p \leqslant .05$); for the same dose, means followed by the same capital letter are not significantly different ($p \leqslant .05$).
[a] Standard deviation.

Table 3
Results of sensory evaluation for mangoes in function of different treatments during storage

Day	Dose (kGy)	Color	Odor	Taste	Texture	Overall appearance
7	Control	7.50 ± 1.26 a, A	7.25 ± 1.59 a, A	7.15 ± 1.63 a, A	6.95 ± 1.61 a, A	7.10 ± 1.74 a, A
	0.4	7.70 ± 1.12 a, A	7.15 ± 1.23 ab, A	7.10 ± 1.55 a, A	7.05 ± 1.28 a, A	6.71 ± 2.55 a, A
	1	7.10 ± 1.36 a, A	6.20 ± 1.06 b, A	6.55 ± 1.32 a, A	6.00 ± 2.10 a, A	5.33 ± 2.14 b, A
9	Control	8.00 ± 1.27 a, A	7.82 ± 1.37 a, A	7.36 ± 1.65 a, A	7.68 ± 1.36 a, A	7.47 ± 1.77 a, A
	0.4	7.77 ± 1.40 a, A	6.95 ± 1.05 ab, A	6.64 ± 2.04 ab, A	7.09 ± 1.51 a, A	6.94 ± 1.86 a, A
	1	7.41 ± 0.82 a, A	6.64 ± 1.71 b, A	6.14 ± 1.94 b, A	6.64 ± 1.76 a, A	6.44 ± 1.69 a, A
12	Control	7.70 ± 1.23 a, A	7.75 ± 1.41 a, A	7.50 ± 1.19 a, A	7.25 ± 1.58 a, A	7.20 ± 1.79 a, A
	0.4	7.85 ± 1.90 a, A	7.15 ± 1.35 ab, A	6.95 ± 1.64 a, A	7.15 ± 1.27 a, A	6.55 ± 2.16 a, A
	1	6.15 ± 1.34 b, B	6.65 ± 1.66 b, A	6.75 ± 1.89 a, A	6.30 ± 2.10 a, A	6.53 ± 2.10 a, A

For the same day, means followed by the same lower-case letter are not significantly different ($p \leqslant 0.05$); for the same dose, means followed by the same capital letter are not significantly different ($p \leqslant 0.05$).
*Standard deviation.
On hedonic scale for all parameters a score of 1 = like extremely, 5 = neither likes nor dislikes and 9 = dislike extremely.

cell walls resulting in a lower resistance of the tissues to shear and compression forces (Gagnon et al., 1993). In fact, current results showed that texture values were inversely proportional to the dose of irradiation applied. Other factor that contributes to reduction of texture was the storage temperature. From this point of view, Gagnon et al. (1993) also demonstrated temperature was relevant to quality of mangoes in the experimental part carried out in Thailand (18 °C) where an earlier and more quickly reduction of texture compared to the experiment carried out simultaneously in Canada but in lower storage temperature (15 °C).

Visual observation showed that irradiation fruits presented pulp browning when fruits were in degree 5 of maturity and softer texture, occurring in 1.0 kGy more frequently than in 0.4 kGy. Same effect was observed by Frylinck, Dubery, and Schabort (1987) that observed radiation treatment caused a stress condition in the mangoes which, depending on the dose, may lead to browning of the tissue or necrotic decay.

According to Moreno et al. (2006) and Oufedjikh, Mahrouz, Amiot, and Lacroix (2000), attributed higher absorbed doses might increase the activity of enzymes such as poliphenoxidases and phenylalanine ammonia lyase (PAL). Reyes and Cisneros-Zevallos (2007) have studied that flavonol compounds were mainly observed in irradiated Tommy Atkins (3.1 kGy). They stated that the role of these flavonols may have in the cell is unknown, in part because it is unclear if these compounds were synthesized under the extreme non-common abiotic stress or alternatively were the resultant by-products of a disrupted cellular metabolism due to the excessive irradiation treatment.

Irradiation did not impair the a^* values until day 8 of storage (Table 2). At day 10, only 1.0 kGy irradiated mangoes had a lower a^* values as compared to the control ($p \leqslant .05$). This is in accordance with the maturity indexes where control had more fruits with color of degree 5 using visual observation of skin color. For b^* values, the difference was found at days 6 and 10 where 1.0 kGy irradiated samples were significantly different to 0.4 kGy treated samples ($p \leqslant .05$). L^* value was significantly higher ($p \leqslant .05$) for 0.4 kGy samples at day 8 as compared to the control. Lacroix, Jobin, Beliveau, and Gagnon (1992) found significantly decrease in L^* value at day 15 for control and irradiated samples and at day 20 for combined treatment between hot water dip and irradiation.

3.3. Sensory evaluation

Sensorial tests showed that irradiated samples treated at 1.0 kGy had significantly different color values at day 12 and for odor in all days ($p \leqslant .05$; Table 3). For the taste, the 1.0 kGy treated samples showed lower values as compared to control and 0.4 kGy samples, but a significant difference was observed only at day 9 ($p \leqslant .05$). Irradiation or storage had no influence on texture scores ($p > .05$). These results show that if even firmness decreased (texture results, Table 1), the panelists did not perceived difference in palatability of the pulp (Table 3).

For overall appearance, the 1.0 kGy treated mangoes showed significantly different values ($p \leqslant .05$) as compared to the control and 0.4 kGy treated samples but only at day 7. Lower scores of overall appearance for 1.0 kGy treated mangoes could be related to the comments of panelists where some noted the softness of the fruits. The results obtained for sensory perception showed good consumer acceptability, fact also observed by Lacroix et al. (1992) in studies of mangoes submitted to irradiation and irradiation plus thermal treatment compared to control.

4. Conclusion

Gamma radiation was favorable to mangoes concerning visual observations like mass loss, mold and end rot development. Some delay in maturity indexes was noted when visually evaluated.

Physico chemical analysis showed that gamma irradiation or thermal treatment resulted in similar performances. Main effect was observed in texture measurements where samples irradiated at highest dose had greater reduction. Samples irradiated at 1.0 kGy besides less firmness presented some browning that should be considered for commercial purposes. Even with this observation, irradiated fruits were acceptable as demonstrated by sensory evaluation. From current results, irradiation could be a potential disinfestation treatment comparable to thermal treatment, for international purposes.

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