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Advances in commercial application of gamma radiation in tropical fruits at Brazil

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ABSTRACT

All regions of Brazil are potential areas for growing tropical fruits. As this country is already a great producer and exporter of tropical fruits, ionizing radiation has been the subject of studies in many commodities. An important project has been carried out to increase the commercial use of gamma radiation in our country. Instituto de Pesquisas Energeticas e Nucleares (IPEN)–CNEN/SP together with field producers in northeast region and partners like International Atomic Energy Agency (IAEA), CIC, Empresa Brasileira Pesquisa na Agricultura (EMBRAPA) joined to demonstrate this technology, its application and commercial feasibility. The objective of this study is to show advances in feasibility demonstrate the quality of the irradiated fruits in an international consignment from Brazil to Canada. In this work, Tommy Atkins mangoes harvested in northeast region of Brazil were sent to Canada. The fruits were treated in a gamma irradiation facility at doses 0.4 and 1.0 kGy. The control group was submitted to hydrothermal treatment (46 °C for 110 min). The fruits were stored at 11 °C for 10 days until the international transportation and kept at an environmental condition (22 °C) for 12 days, where their physical–chemical and sensorial properties were evaluated. The financial part of the feasibility study covers the scope of the investment, including the net working capital and production costs.

1. Introduction

Since 2003, India increased mango exportation and assumed second place in the exportation ranking, inverting the position with Brazil. As Brazil is a great producer of mangoes and its territory has several different places to grow this cultivar, any new trend in applying new technologies has to be followed close. Recently, India signed an agreement with USA in order to export irradiated mangoes (APHIS, 2007). Mexico, the largest mango exporter, is setting up a cobalt facility to irradiate mangoes in order to supply the American market. Brazil has demonstrated its interest through a project supported by the International Atomic Energy Agency (IAEA) and the Governmental Foundation of support for research at São Paulo State (FAPESP) approaching two governmental institutions: Instituto de Pesquisas Energeticas e Nucleares (IPEN), EMBRAPA (Empresa Brasileira Pesquisa na Agricultura) and producers in the northeast region. IPEN has carried out several studies on food irradiation application where commercial purposes were the focus. In this work, the main objective was to study the quality of irradiated mangoes during the international consignment from Brazil to Canada and demonstrate its feasibility.

When tropical fruits go to external market as phytosanitary treatments may be necessary. Usually, mangoes to USA and Japan are treated with hot-water dip. This quarantine treatment must be very strict and the conditions consist of immersion of the fruits in a bath at 46.1 °C for 75 min (fruits weighing up to 425 g) or for 90 min (fruits weighing more than 425 g).

Gamma radiation can be applied to fruits in a quarantine treatment. It is a versatile disinfestation treatment that can be used against a wide variety of organisms and is tolerated by many agricultural commodities (Hallman, 2000).

This paper had the objective to determine the advances of the feasibility study and at the same time demonstrated the quality of irradiated fruits in an international consignment from Brazil to Canada.

2. Methodology

Around 630 mangoes were shipped from the northeast region of Brazil to São Paulo (southeast) where they were treated. One third of the fruits were treated with the hot-water dip treatment (46 °C during 110 min) which is the routine treatment for mangoes

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Table 1
Chronology and storage conditions of mangoes during the international consignment.

Data	Description	Conditions
October, 7th	Mango harvest	Mangoes: Tommy Atkins type Harvesting point: 3 Cultivation region: Petrolina, northeast region of Brazil Climate conditions: tropical, semi-arid; annual averages: 26 °C, 50% HR, 450 mm rain
October, 9th	Mangoes treated at IPEN, Brazil	Hot-water dip and irradiation
October, 9–17th	Storage at conditioned chamber	11 ± 1 °C and 66,6% RH
October, 17–18th	Brazil to Canada by air (day 0)	Environmental conditions (airplane temperature)
October, 19th	Fruits arrival at CIC, Canada	Environmental conditions (around 20 °C)
October, 19–30th	Experiment at CIC, Canada	20 °C ± 2; 40% ± 2 RH

sent to external markets. The remaining two thirds of the fruits were irradiated to 0.4 and 1.0 kGy. The 0.4 kGy dose was chosen in order to attend the international requirement for disinfestations' fruits (USDA, 2007). The 1.0 kGy dose represents the maximum dose that would be obtained in an industrial facility when the minimum required dose (0.4 kGy) is delivered, with a dose uniformity ratio (D_{max}/D_{min}) of 2.5.

The chronology, since harvesting, until arrival at the Canadian Irradiation Center (Laval, Canada) as well as the storage conditions of the mangoes are described in Table 1.

2.1. Maturity index

Thirty five fruits from each treatment were chosen randomly and observed visually with the following scale: 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).

2.2. Texture and physical–chemical analysis

Texture was measured on two different places at the equatorial region of the fruits where the skin was peeled in a very thin layer. The measurements were made using a handle penetrometer with crossheads of 0.8 cm of diameter (expressed by kg/cm^2). pH measurements were made in a digital pHmeter (Orion, model 420 A). 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). Replication of the each test consisted of nine fruits from each treatment for each day of analysis.

2.3. Sensory evaluation

Sensory evaluation was carried out in three different dates where 20 panelists gave perceptions about color, odor, taste and texture of the irradiated fruits and control. Each person was asked also to evaluate odor and taste 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.

2.4. Statistics

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

2.5. Feasibility study of cobalt-60 source for mango disinfestations

Once the technical feasibility of the mango irradiation process was established, the potential use in the country depends on the economic feasibility. The specific unit process cost study was carried out correlating capital and operating costs with throughputs. The choice of a multipurpose irradiator model was based on the best suited for the specific needs on mangoes irradiation, taking in account the seasonality of this product and the use of the remaining time for the processing of other agricultural products, spices, medicinal herbs and other products.

The pallet conveyor gamma irradiator with double-rack sources was adopted making it possible to irradiate products stacked on standard transportation pallets, allowing a great throughput and reducing the handling of the product.

Investment consists of the hardware cost of the irradiator, control and transport system, radiation shield, auxiliary equipments, warehouse land and radioactive material. These costs are based on a pallet irradiator already developed and constructed in the country.

- Pallet irradiator (shielding, transport and control system): US$ 1,700,000.
- Warehouse (0,1 ha) and land (0,5 ha): US$ 400,000.
- Cobalt 60 (400.000 Ci): US$ 1,000,000.
- Total of the investment: US$ 3,100,000.
  Operating costs include cost of the investment, salaries, utilities, maintenance, taxes, insurance, cobalt replenishment and others miscellaneous expenses. The depreciation costs were calculated on 20 years amortization of cobalt and buildings, the cost of the money was calculated as 10% of the invested capital.
- Annual cost of investment and amortization: US$ 360,000.
- Salaries (manager, radiation safety officer, operators and handlers): US$ 300,000.
- Utilities, maintenance and taxes: US$ 160,000.
- Replenish of cobalt (13% per annum): US$ 130,000.
  Facility processing cost is equal to annual total operating costs divided by the annual up time of the irradiator that has a performance superior to 8000 h per year.
- Processing costs: US$ 118/h
  Unit processing cost was calculated as the relation of the facility processing cost and the mangoes throughput capacity of the irradiator.

- Throughput of pallet irradiator for mangoes (dose 0.5 kGy and 0.25 as empirical value of the irradiator efficiency): 10 ton/h.
- Unit processing cost for mangoes: US$ 18/ton.

3. Results and discussion

Fruits from the control sample (hot-water dip treated) arrived in Canada in advanced stage of maturity, 69% of the fruits were in stage 5 at day 5 (Table 2). At this day, half of the irradiated mangoes were in stage 3 and half, in stage 4. At day 8, irradiated mangoes were still in less advanced stages of maturity, while 100% of control fruits were in stage 5. This visual observation demonstrated that irradiation slowed maturity of the mangoes. In a similar international consignment, Lacroix et al. (1993) observed a significant delay in ripe skin color for irradiated mangoes compared to control ($p \leqslant 0.05$).

Table 3 summarizes the main results of texture and physical–chemical analysis related to this experiment considering the Canadian storage period.

Texture measurements for mangoes irradiated at 1.0 kGy were lower compared to control ones ($p \leqslant 0.05$) for each day of analysis (Table 3). These findings were observed by other authors (Moreno et al., 2006; Gagnon et al., 1993; Frylinck et al., 1987) that can be associated with degradative changes in the middle lamella of plant cell walls resulting in a lower resistance of the tissues to shear and compression forces (Gagnon et al., 1993). This decay in texture occurred markedly for irradiated mangoes at 1 kGy but not for irradiated ones at 0.4 kGy. Visual observation demonstrated that irradiated mangoes presented browning pulp mainly those in stage 5 of maturity and softer texture, occurring in 1.0 kGy-irradiated mangoes more frequently than in 0.4 kGy.

During the storage, pH measurements increased for the three treatments ($p \leqslant 0.05$) that agreed with the senescence of the fruits, once they get maturity more sweet and less acid are the fruits (Manica et al., 2001). Gamma radiation caused a decrease of pH values for all days of measuring, where mangoes irradiated at higher level (1.0 kGy) had lower pH compared to 0.4 kGy-irradiated mangoes and control ($p \leqslant 0.05$; Table 3). These results are in accordance to maturity indexes observed that reinforces that some delay of maturity occurred to irradiated mangoes.

Total soluble solids contents presented some fluctuations including statistically significant at day 6 for 0.4 kGy-irradiated mangoes but showed no trend (Table 3). Doses and storage period had no significant influence ($p > 0.05$) on total soluble solids content at days 8 and 10. These results are within Brazilian regulation that establish minimum of 11° Brix at 20 °C (Ministério da Agricultura, 2000).

The results of sensory evaluation showed no specific trend or significant differences for the parameters color, texture and overall appearance, indicating good acceptance for irradiated mangos as well as control. The odor rating for 1.0 kGy-irradiated fruits was significantly lower than mangoes treated by hot-water deep (control) for all days of analysis ($p \leqslant 0.05$; Table 4). For the taste, there was statistical significance only in one day of analysis (day 9) for 1.0 kGy-irradiated mango.

Table 3
Physical chemical results of irradiated mangoes and hot-water dip group during the storage time.

Dose (kGy)	Total soluble solids (°Brix)	Texture (Kg/cm^2)	pH
Day 6			
Hot-water dip	11.08 ± 0.49 a, A	1.74 ± 0.42 a, A	4.56 ± 0.06 a, A
0.4	13.17 ± 0.60 b, A	1.56 ± 0.62 ab, A	4.43 ± 0.14 b, A
1.0	12.58 ± 1.07 b, A	1.29 ± 0.49 b, A	4.27 ± 0.15 c, A
Day 8			
Hot-water dip	11.17 ± 0.93 a, A	1.87 ± 0.44 a, A	4.66 ± 0.10 a, B
0.4	10.92 ± 0.38 a, B	1.48 ± 0.29 b, A	4.49 ± 0.04 b, AB
1.0	10.75 ± 0.52 a, B	1.08 ± 0.38 c, A	4.30 ± 0.03 c, A
Day 10			
Hot-water dip	11.00 ± 0.32 a, A	1.38 ± 0.31 a, B	4.83 ± 0.03 a, C
0.4	10.83 ± 0.52 a, B	1.36 ± 0.29 a, A	4.57 ± 0.01 b, B
1.0	11.00 ± 0.63 a, B	1.04 ± 0.47 b, A	4.42 ± 0.06 c, B

For the same day, means followed by the same lower-case letter are not significantly different (p ⩽ 0.05); for the same dose, means followed by the same capital letter are not significantly different (p ⩽ 0.05).

Table 4
Sensory evaluation of irradiated mangoes and hot-water dip group during the storage time.

Dose (kGy)	Odor	Taste
Day 7		
Hot-water dip	7.25 ± 1.59 a, A	7.15 ± 1.63 a, A
0.4	7.15 ± 1.23 ab, A	7.10 ± 1.55 a, A
1.0	6.20 ± 1.06 b, A	6.55 ± 1.32 a, A
Day 9		
Hot-water dip	7.82 ± 1.37 a, A	7.36 ± 1.65 a, A
0.4	6.95 ± 1.05 ab, A	6.64 ± 2.04 ab, A
1.0	6.64 ± 1.71 b, A	6.14 ± 1.94 b, A
Day12		
Hot-water dip	7.75 ± 1.41 a, A	7.50 ± 1.19 a, A
0.4	7.15 ± 1.35 ab, A	6.95 ± 1.64 a, A
1.0	6.65 ± 1.66 b, A	6.75 ± 1.89 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 ($p \leqslant 0.05$).
On hedonic scale for all parameters a score of 1 = dislike extremely, 5 = neither likes nor dislikes and 9 = like extremely.

Table 2
Maturity index of mangoes measured in number of occurrences in each stage of maturity.

Dose (kGy)	Maturity index (% fruits)								
	Day 5			Day 7			Day 8		
	Stage 3[a]	Stage 4	Stage 5	Stage 3	Stage 4	Stage 5	Stage 3	Stage 4	Stage 5
Hot-water dip	0	30.8	69.2	0	0	100	0	0	100
0.4	52.5	47.5	0	19.4	30.6	50.0	0	29.0	71.0
1.0	50.0	50.0	0	0	53.1	46.9	0	59.4	40.6

[a] Stage represents stage of maturity (scale varying from 1 to 5).

4. Conclusion

Current results indicate gamma radiation can be used for export markets with disinfestation purposes. Some concerns related to texture should be taken in account if doses around 1 kGy were delivered. Future studies should consider new packaging to minimize this firmness loss. Other relevant issue covers national efforts in regulations to reduce the disinfestation dose related to our potential plagues and consequently the bilateral agreements establishing lower doses instead of generic minimum dose. This fact is important as it implies directly in the maximum dose that should be delivered in mangoes, and consequently the fruits will have better texture. In terms of cost, the gamma irradiation process is competitive to treat mangoes with quarantine requirements.

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