SENSORY QUALITY AND NUTRIENT COMPOSITION OF THREE HAWAIIAN FRUITS TREATED BY X-IRRADIATION

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ABSTRACT

Papayas, rambutans, and Kau oranges were irradiated at 0 (control) and 0.75 (irradiated) kGy and stored for 2 and 9 days to determine the effect of X-irradiation on objective and sensory quality attributes. Irradiation at 0.25 kGy, as a minimum dose, has been approved as a quarantine treatment for the export of tropical fruits grown in Hawaii. The effects of irradiation and storage on specific sensory attributes were dependent on the specific fruit. Aroma and flavor tended to be more intense in the irradiated fruit. Firmness decreased as a result of irradiation and storage, though significant only in rambutans. The color of the rambutans and oranges were significantly affected by irradiation. Irradiation did not contribute to significant changes in the ascorbic acid and carotenoid contents, pH, titratable acidity, and total soluble solids. Adaptation of X-ray irradiation as a quarantine treatment should enhance the marketability of tropical fruits.

INTRODUCTION

Tropical fruits grown in Hawaii are infested by fruit flies and other pests, resulting in quarantine restrictions for fruit transported to U.S. mainland

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markets. Thermal treatments, such as vapor heat and high-temperature forced air, are approved quarantine procedures, effective in inactivating the insects to prevent potential infestation in nonfruit fly areas. However, these thermal treatments can have serious undesirable effects on quality, including incomplete ripening, lumpiness or hard-core texture (Cavaletto 1989). The successful marketing of tropical fruit on the U.S. mainland requires that the fruit meet the consumer expectations of high quality.

Irradiation provides an effective alternative to thermal treatments as a quarantine treatment for elimination of fruit flies. In comparison to thermal treatments, irradiation is more efficient, requiring less process time, more effective in inactivating larvae, and results in higher product quality (Moy 1985; Moy and Wong 1999; Mermelstein 2000). In 1986, the FDA approved irradiation at a dose limit of 1.0 kGy to treat fresh foods for disinfestation and delayed maturation (FDA 1986). The USDA, in 1997, granted specific approval of irradiation of Hawaii-grown papayas, litchis, and carambolas as a quarantine treatment with a minimum required dose of 0.25 kGy (USDA 1997). Low irradiation doses (less than 1 kGy) are effective in insect deinfestation, sprout inhibition of tubers, and reduced spoilage of tropical fruits. Higher doses (1-6 kGy) are necessary to reduce spoilage and pathogenic microorganisms (Akamine and Moy 1983; Moy 1983, 1985; Kilcast 1994). Because of the nonuniformity in a commercial irradiator, the dose rate absorbed by the fruit may be 2.5 to 3.0 times the target dose.

During irradiation, reactive free radical species are formed through the removal of an electron from water molecules. These radicals react with the DNA of insects and microorganisms to cause their sterility and eventual death (Kilcast 1994). Radiation sources for food preservation include radioactive sources, such as ^{60}Co or ^{137}Cs (γ-irradiation), electron beams or converted X-rays. Electron beam and X-ray as irradiation sources have the advantage of no radiation hazard, a potential problem with γ-irradiation. Gamma rays and X-rays are effective in penetrating bulky packaging materials and food products, while the penetration of electron beams is limited to a maximum of approximately 8 cm into the food (Kilcast 1994; McLaughlin 1999). Generally, the changes in the nutrient composition and overall quality of foods following irradiation are small, but some changes may occur, with sensory characteristics and functional properties of the components affected. These changes occur most frequently at medium and high doses and include initiation of lipid oxidation, decomposition of sulfur amino acids, breakdown of high molecular weight carbohydrates, and partial loss of some vitamins (Urbain 1989; Kilcast 1994).

Irradiation has been evaluated as a treatment for disinfestation and shelf-life extension of several fruits and vegetables, including grapefruit (Moshonas and Shaw 1982, 1984); strawberries (Yu *et al.* 1995; Graham and Stevenson 1997), 14 tropical fruits and vegetables (Mitchell *et al.* 1992); melons (Lalaguna 1998), mangoes (Khan *et al.* 1974; Thomas and Janave 1975; Mitchell *et al.* 1990), stone fruits (Moy *et al.* 1983), oranges (Nagai and Moy 1985; O'Mahony *et al.* 1985), and apples (Bhushan and Thomas 1998). Specific effects of irradiation on composition were dependent on the fruit and irradiation dose, although in general, irradiation did not have an adverse effect on the quality of the fruits. Although a significant amount of research has been conducted on the irradiation of fruits and vegetables, specific research on the effects of irradiation on the quality of papaya, rambutan, and Kau orange is limited. Knowledge of the effects of irradiation on the nutrient, chemical, and sensory characteristics of fruits is important for the acceptance of irradiation by fruit growers, packers, and consumers.

The objectives of this research were to evaluate the effect of converted X-rays on the sensory quality, nutrient and chemical composition, and texture of three Hawaiian fruits, papayas, rambutans, and oranges. The fruit were irradiated at 0 and 0.75 kGy. Although 0.25 kGy is the minimum dose approved by the USDA for quarantine treatment of selected Hawaiian fruit, the dose rates could vary by as much as 3-fold. Thus, in evaluating the effect of irradiation on fruit quality, it is important to expose the fruit to the upper irradiation dose that the fruit may be exposed to during the irradiation treatment. This research was a collaborative project between the University of Hawaii at Manoa and Iowa State University. Identification of a quarantine treatment that has minimal adverse effects on sensory and nutritional quality of the fruit should greatly enhance the marketing of these fruits in the U.S. mainland.

MATERIALS AND METHODS

Fruit Source and Treatment

Papayas (cv. UH Rainbow), rambutans (cv. No. 167), and oranges (cv. Kau Gold) grown on the Island of Hawaii were harvested (papayas at approximately 1/8 to 1/4 ripe) and air-shipped to Chicago/Des Moines, then land transported to Iowa State University, Ames, IA. Papayas and rambutans were evaluated in November 1999 (replication 1) and May 2000 (replication 2). Both replications of oranges were evaluated in May 2000. The fruit were irradiated at the Iowa State University Linear Accelerator Facility (Ames, IA) and evaluated at the Department of Food Science and Human Nutrition. The fruit were irradiated at 0 (control) and 0.75 kGy (irradiated) in the X-ray mode. The absorbed doses for the runs ranged from 0.75 to 0.80 kGy, with the max/min dose rate ratio for irradiation approximately 1.2. The 0.75 kGy dose was selected as three times the minimum quarantine dose of 0.25 kGy to represent the highest possible absorbed dose in a commercial irradiator due to dose rate variations and package configuration. Control and irradiated fruits were stored at room temperature (20C) prior to evaluation. Sensory evaluation and instrumental and chemical analyses of the fruit were conducted at 2 and 9 days following irradiation treatment.

Objective Analyses

Objective analyses of ascorbic acid and total carotenoids contents, pH, percentage titratable acidity, and total soluble solids (TSS), and firmness were completed in triplicate for all treatments and replications.

1-Ascorbic acid (reduced form) contents of the fruits were determined using the 2,6-dichlorindophenol titrimetric method (AOAC Method 967.21; AOAC 1995).

Total carotenoids were extracted from the fruit tissue with acetone and methanol and separated from the acetone with hexane, as described in AOAC Method 941.15 (AOAC 1995). The hexane extract was evaporated to dryness using a rotary evaporator, resolubilized in hexane and applied to a Sep-Pak Plus silica cartridge (Waters Associates, Milford, MA). The carotenoids were eluted from the cartridge with chloroform, while the xanthophylls were retained. The extracted carotenoids were evaporated to dryness, resolubilized in acetone and absorbance at 450 nm was determined.

For acidity and TSS, each fruit sample was blended for 30 s in a blender. The pH of the puree was measured with a pH meter (Model 420A, Orion Research, Beverly, MA). Puree (5 g) was diluted to 100 mL with deionized water, titrated to pH 7.0 with 0.1 N NaOH, and reported as percentage of citric acid. Soluble solids concentration was determined using a refractometer (Bausch & Lomb).

Firmness was measured using an Instron Universal Testing Machine (Model 4500 Series, Instron Corp., Canton, MA) with a Kramer shear cell attachment. Crosshead speed was 200 mm/min, with firmness measured in Newtons (N) of force. Each fruit sample was a 50-g portion of the flesh with skin removed. Papaya, slices (ca. 5.5 × 5 × 1.2 cm) from one-half of three papayas were prepared. Rambutans were cut in half longitudinally and 6 halves were placed concave side down in the cell. Oranges were cut from the center into 2-cm slices. For each treatment, six measurements were determined for the papayas and oranges and three measurements were determined for the rambutans.

Sensory Evaluation

A 15-member panel evaluated the sensory characteristics of the tropical fruits. Panelists were selected from staff and students at Iowa State University and participated in a one-hour training session for each replication to become familiar with the characteristics of the fruits. Panelists evaluated samples under white light in individual booths. Distilled water was provided for oral rinsing between samples. Order of sample presentation to the panelists was balanced and randomized.

Color, texture, aroma, and flavor were evaluated using an anchored 150-mm line with anchor points of 'less intense than reference' (for color, aroma, and flavor) or 'softer than reference' (for texture) at 10 mm, 'reference' at 75 mm, and 'more intense than reference' (for color, aroma, and flavor) or 'firmer than reference' (for texture) at 140 mm. The anchored descriptive analysis method (Larson-Powers and Pangborn 1978) was selected to improve precision and accuracy of panelists' responses in light of the panelists' unfamiliarity with the tropical fruits evaluated. Each panelist was presented with a reference and two samples (control and irradiated) identified with random 3-digit codes. The reference sample was the control fruit and was stored at 20C, as was the control and irradiated fruit. The reference and the control sample were not from the same individual fruit. Off-flavor was evaluated using an unstructured 150-mm line with anchor points of 'none' at 10 mm and 'intense' at 140 mm. Panelists received one set of samples to evaluate color and texture and a second set of samples to evaluate aroma, flavor, and off-flavor.

Statistical Analysis

Analysis of variance was used to analyze the effects of irradiation treatment (control and irradiated) and storage time (2 and 9 days) and interaction of irradiation treatment and storage time in a randomized complete block design. Least square differences (LSD) were determined if analysis of variance indicated a significant ($P<0.05$) main effect or interaction (SYSTAT 1999).

RESULTS

The composition of the objective and sensory attributes of papayas, rambutans, and Kau oranges varied considerably. The effects of irradiation and storage treatments on the attributes of these three fruit were dependent on the specific attribute and the fruit. For a majority of the objective and sensory attributes, the interaction between irradiation treatment and storage time was not significant. Therefore, the results will discuss the effects of irradiation treatment and storage time on the objective and sensory attributes. Data will be presented for the individual irradiation treatment and storage time effects when the interactions were significant.

Effect of Irradiation

Comparison of the effects of irradiation at 0 and 0.75 kGy on the objective attributes of papayas, rambutans, and Kau oranges are presented in Table 1.

TABLE 1.
EFFECT OF X-IRRADIATION ON OBJECTIVE ATTRIBUTES OF TROPICAL FRUIT[1]

	Papaya		Rambutan		Kau Orange	
	0 kGy	0.75 kGy	0 kGy	0.75 kGy	0 kGy	0.75 kGy
Ascorbic Acid (mg/100 g pulp)	69.3[a]	65.1[a]	22.2[a]	22.6[a]	47.4[a]	43.7[a]
Carotenoids (mg/100 g pulp)	3.18[a]	3.34[a]	ND[2]	ND		
Day 2					1.78[a]	1.79[a]
Day 9					1.90[b]	2.52[a]
Titratable Acidity (%)	0.11[a]	0.11[a]	0.45[a]	0.36[a]	0.84[a]	0.60[b]
pH	5.54[a]	5.52[a]	4.55[a]	4.65[a]	4.09[a]	4.29[a]
Soluble Solids (%)	11.8[a]	12.4[a]	17.2[a]	16.0[a]	16.9[a]	15.2[a]
Firmness (N)	308.5[a]	274.0[a]	879.3[a]	619.0[b]	947.5[a]	876.8[a]

[1]Means are triplicate analyses of two replications, with storage time (2 and 9 days) pooled, unless interactions were significant. For each fruit, means with the same superscript designation (a-b) are not significant ($P>0.05$).
[2]Not determined.

Ascorbic acid contents of the three fruits and the carotenoid content of papaya were not affected by the irradiation treatment. However, the carotenoid content of the Kau orange irradiated at 0.75 kGy was significantly higher than the control sample after 9 days of storage, but not after 2 days of storage. Irradiation had a significant effect on the titratable acidity of only the Kau orange, the most acidic of the three fruits. Total soluble solids contents were not significantly affected by the irradiation treatment, although the trends indicate a decrease in soluble solids with irradiation for the rambutans and Kau oranges. Irradiation decreased the firmness of the tissue of all three fruits, however, these differences were significant only for rambutan.

The effects of irradiation treatment on the sensory attributes of papayas, rambutans, and Kau oranges are presented in Table 2. For color, texture, aroma, and flavor, a control sample served as the reference and was given a value of 75. Panelists noted a significant difference in the color of each fruit as attributed to the irradiation treatment. The color of the irradiated oranges was more intense than the control fruit. For the papayas and rambutans, the interaction between irradiation treatment and storage time was significant, with the color intensity of the control fruit greater than the irradiated fruit only after 9 days of storage. The irradiated rambutans and oranges were softer than the control fruit, while the irradiated papayas were firmer than the control fruit. The sensory data for the texture of the rambutans and oranges concur with the results from the objective firmness analyses. The effects of irradiation on the aroma and flavor of the fruit were dependent on the specific fruit. The aroma and flavor of the irradiated papayas was less intense than the control papayas, while the aroma and flavor of the irradiated rambutans was more intense than the control rambutans, with the differences in flavor significant only after storage for 9 days. No significant differences in aroma and flavor, as influenced by irradiation, were noted for the Kau oranges. Contents of off-flavors were higher for each of the irradiated fruit, although these differences were not statistically significant.

Effects of Storage

The changes in the objective attributes of the papayas, rambutans, and Kau oranges that occurred as a result of storage and subsequent ripening are shown in Table 3. The effect of storage on the ascorbic acid and carotenoid contents may reflect differences in the maturity of the individual fruits. The ascorbic acid content of the papayas increased during storage, while the ascorbic acid content of rambutans decreased during storage. Decreases in the ascorbic acid content of the rambutan may be attributed to senescence and ascorbic acid degradation. Carotenoid contents of the papaya and irradiated Kau orange also increased during storage. With the exception of the papaya, titratable acidity, pH and total

TABLE 2.
EFFECT OF X-IRRADIATION ON SENSORY ATTRIBUTES OF TROPICAL FRUIT[1]

	Papaya		Rambutan		Kau Orange	
	0 kGy	0.75 kGy	0 kGy	0.75 kGy	0 kGy	0.75 kGy
Color[2]					72.2^{b}	78.6^{a}
Day 2	68.1^{a}	72.9^{a}	71.6^{a}	66.7^{a}		
Day 9	87.3^{a}	79.8^{b}	87.3^{a}	69.8^{b}		
Texture[3]	66.0^{b}	75.4^{a}	76.0^{a}	52.2^{b}	76.3^{a}	54.3^{b}
Aroma[2]	80.3^{a}	72.8^{b}	77.5^{b}	84.3^{a}	74.4^{a}	71.6^{a}
Flavor[2]	80.4^{a}	74.5^{a}			75.0^{a}	71.4^{a}
Day 2			76.9^{a}	82.0^{a}		
Day 9			73.2^{b}	93.8^{a}		
Off-flavor[4]	20.4^{a}	23.0^{a}	26.4^{a}	39.3^{a}	24.2^{a}	30.1^{a}

[1]Means are from 15 panelists and two replications, with storage time (2 and 9 days) pooled, unless interactions were significant. Reference was fruit receiving 0 kGy irradiation. For each fruit, means with the same superscript designation (a-b) are not significant ($P>0.05$).
[2]0=less intense than reference, 75=equal to reference, 150=more intense than reference.
[3]0=softer than reference, 75=equal to reference, 150=firmer than reference.
[4]0=none, 150=intense.

TABLE 3.
EFFECT OF STORAGE ON OBJECTIVE ATTRIBUTES OF TROPICAL FRUIT[1]

	Papaya		Rambutan		Kau Orange	
	Day 2	Day 9	Day 2	Day 9	Day 2	Day 9
Ascorbic Acid (mg/100 g pulp)	63.5^{b}	71.0^{a}	24.7^{a}	20.1^{b}	46.1^{a}	44.9^{a}
Carotenoids (mg/100 g pulp)	3.07^{b}	3.45^{a}	ND[2]	ND		
0 kGy					1.78^{a}	1.90^{a}
0.75 kGy					1.79^{b}	2.52^{a}
Titratable Acidity (%)	0.11^{a}	0.10^{a}	0.36^{a}	0.45^{a}	0.72^{a}	0.72^{a}
pH	5.42^{b}	5.64^{a}	4.66^{a}	4.54^{a}	4.13^{a}	4.24^{a}
Soluble Solids (%)	12.3^{a}	12.0^{a}	17.8^{a}	15.4^{a}	17.2^{a}	14.9^{a}
Firmness (N)	361.6^{a}	221.0^{a}	976.2^{a}	635.7^{b}	1015.0^{a}	809.3^{a}

[1]Means are triplicate analyses of two replications, with irradiation treatment (0 and 0.75 kGy) pooled,unless interactions were significant. For each fruit, means with the same superscript designation (a-b) are not significant ($P>0.05$).
[2]Not determined.

soluble solids contents of the fruits did not change during storage. Softening of all three fruits occurred with storage with significant differences observed for the rambutan.

The effects of storage on the sensory attributes of the tropical fruit are shown in Table 4. Because the reference fruit were stored under the same conditions as the control and irradiated samples, the effect of storage on the sensory attributes may be diminished. Panelists observed no significant differences in color of the oranges and the irradiated papayas and rambutans. The color of the control papayas and rambutans was more intense after storage for 9 days than after storage for 2 days. The flavor intensity of the irradiated rambutans was higher after storage for 9 days, and the overall intensity of off-flavor increased with storage time.

DISCUSSION

Storage, rather than irradiation, had a greater impact on the ascorbic acid and carotenoid contents of the three tropical fruit evaluated. Effects of storage were dependent on the fruit and reflected the stage of ripeness at the time of irradiation and changes in ascorbic acid content with additional storage and ripening. Irradiation delays ripening and senescence of several climacteric tropical fruits, such as papayas and mangoes, through the reduced capacity of the irradiated fruit to produce ethylene (Khan *et al.* 1974; Akamine and Moy 1983). Definitive effects of inhibition of ripening was not observed in this study. Kilcast (1994) has observed that storage effects and metabolic changes in plant tissue have a greater effect on vitamin contents of fruit than irradiation-induced chemical changes.

The increased content of ascorbic acid in the papaya during storage suggested additional maturation and ripening occurred during storage, resulting in a net synthesis of ascorbic acid. Decreases in the content of ascorbic acid in the rambutan during ripening would be attributed to the decomposition of ascorbic acid as the fruit underwent senescence. Although, not statistically significant, the ascorbic acid contents of irradiated papaya and orange were lower than control fruit, while the ascorbic acid contents of the irradiated rambutan were higher than the control fruit. Irradiation of grapefruit (Moshonas and Shaw 1984), melons (Lalaguna 1998), lemons and Ellendale Mandarins (Mitchell *et al.* 1992), and apples (Bhushan and Thomas 1998) have resulted in no significant changes in ascorbic acid content. Varietal differences, metabolic changes in plant tissue, and storage effects are reported to have a greater impact on ascorbic acid content of fruits than irradiation treatment (Thomas and Janave 1975; Kilcast 1994; Graham and Stevenson 1997).

TABLE 4.
EFFECT OF STORAGE ON SENSORY ATTRIBUTES OF TROPICAL FRUIT[1]

	Papaya		Rambutan		Kau Orange	
	Day 2	Day 9	Day 2	Day 9	Day 2	Day 9
Color[2]					76.4^{a}	74.1^{a}
0 kGy	68.1^{b}	87.3^{a}	71.6^{b}	87.3^{a}		
0.75 kGy	72.9^{a}	79.8^{a}	66.7^{a}	69.8^{a}		
Texture[3]	73.8^{a}	67.6^{a}	65.0^{a}	63.2^{a}	60.4^{b}	70.0^{a}
Aroma[2]	79.3^{a}	73.8^{b}	80.4^{a}	81.4^{a}	75.3^{a}	70.8^{a}
Flavor[2]	73.7^{b}	81.2^{a}			72.6^{a}	73.7^{a}
0 kGy			76.9^{a}	73.2^{a}		
0.75 kGy			82.0^{b}	93.8^{a}		
Off-flavor[4]	19.7^{a}	23.7^{a}	18.5^{b}	49.1^{a}	27.0^{a}	27.3^{a}

[1]Means are from 15 panelists and two replications, with irradiation treatment (0 and 0.75 kGy) pooled, unless interactions were significant. Reference was fruit receiving 0 kGy irradiation. For each fruit, means with the same superscript designation (a-b) are not significant ($P>0.05$).
[2]0=less intense than reference, 75=equal to reference, 150=more intense than reference.
[3]0=softer than reference, 75=equal to reference, 150=firmer than reference.
[4]0=none, 150=intense.

Storage had a significant effect on the carotenoid content of control and irradiated papayas and irradiated Kau oranges. During storage and subsequent ripening, the biosynthesis and accumulation of carotenoids contribute to the development of the yellow-orange color of many fruits (Khan *et al.* 1974; Thomas and Janave 1975). Gamma irradiation of red capsicums and mangoes at up to 0.75 kGy resulted in no significant effect on carotene content (Khan *et al.* 1974; Mitchell *et al.* 1990). On the contrary, Thomas and Janave (1975) showed that irradiated mangoes had slightly higher carotenoid contents than control fruit, regardless of storage temperature and ripening conditions. The higher contents of carotenoids in irradiated fruit have been attributed to an increase in permeability of the irradiated tissue, which enhances pigment extractability, rather than increased synthesis (Khan *et al.* 1974).

Irradiation did not have a significant effect on the total soluble solids and titratable acidity of papayas, rambutans, or Kau oranges, and thus no differences in the perceived sweetness and tartness of the fruits would be expected. Irradiation of numerous fruits, including grapefruit (Moshonas and Shaw 1982), lemons and mandarins (Mitchell *et al.* 1992), mangoes (Khan *et al.* 1974; Mitchell *et al.* 1992), melons (Lalaguna 1998), strawberries (Yu *et al.* 1995) and apples (Bhushan and Thomas 1998) have shown that the acid and sugar levels were not affected by irradiation.

The irradiated fruit were softer than the control fruit throughout the storage period, as determined by instrumental and sensory analyses. Softening of fruit tissue following irradiation has also been observed in strawberries (Yu *et al.* 1995). Irradiation has been shown to delay the ripening and senescence process of climacteric fruits and delay pectin degradation (Khan *et al.* 1974; Akamine and Moy 1983; Zhao *et al.* 1996), it would be expected that the irradiated fruit would be firmer than the control fruit following storage. The softening of irradiated fruits has been attributed to enhanced degradation of high molecular weight carbohydrates (Kilcast 1994) and decreases in the oxalate-soluble pectin fraction (Yu *et al.* 1996). Based on the effect of irradiation on the texture of the irradiated fruit, irradiation does not appear to inhibit the ripening.

The sensory evaluation panel detected differences in the color, texture, and aroma and flavor of the control and irradiated tropical fruit. The effect of irradiation on color of the tropical fruit in this study depended on the individual fruit. Irradiated oranges were more intense in color than the control, while irradiated papayas and rambutans stored for 9 days had greater color intensity than the control. Irradiation of strawberries resulted in a decrease in color intensity, while storage contributed to an increase in browning (Yu *et al.* 1995). The color of orange slices was not significantly affected by irradiation, although the irradiated oranges did demonstrate a greater tendency to develop brown blemishes during storage (O'Mahony *et al.* 1985). In the current study, overall changes in color intensity rather than changes in specific colors were evaluated, thus contributing to the conflicting results.

The effects of irradiation and storage on the aroma, flavor, and off-flavor of the tropical fruit, as perceived by the sensory evaluation panel, depended on the specific fruit. Rambutans appeared to be more sensitive to irradiation treatment than papayas and oranges. For the rambutan, aroma, flavor, and off-flavor were more intense in the irradiated fruit than in control fruit after storage for 9 days. The effects of irradiation on the flavor and aroma of other fruits were also quite variable. Strawberries irradiated at 0 to 2 kGy resulted in no significant differences in flavor and off-flavor (Yu *et al.* 1995), while differences in the flavor and aroma characteristics of control and irradiated oranges were detectable by panelists (O'Mahony *et al.* 1985).

Research in the literature about the impact of irradiation on sensory attributes of tropical fruits is limited. Because of the variability in the composition and flavor profiles of different fruit, each fruit must be evaluated individually to determine whether the fruit can withstand irradiation treatment without adverse effects on quality. Further research is necessary to determine if the observed changes in the intensity of the sensory attributes will affect the consumer acceptability of irradiated tropical fruits.

CONCLUSIONS

Tropical fruits must be disinfested by some type of approved quarantine treatment prior to shipping to the mainland United States. Acceptability of irradiation of tropical fruit relies on demonstration of improvement in the quality, shelf-life, and product availability in comparison to alternative quarantine treatments. This study demonstrated that X-irradiation of papayas, rambutans, and Kau oranges showed no significant changes in nutrient and chemical quality and minor changes in sensory quality in comparison to control, untreated fruit. As converted X-ray is becoming commercially available in the U.S., adaptation of this technology as a quarantine treatment will provide tropical fruits to consumers in the U.S. Mainland and greatly enhance the marketability of these fruits.

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REFERENCES

AKAMINE, E.K. and MOY, J.H. 1983. Delay in post-harvest ripening and senescence of fruits. In *Preservation of Food by Ionizing Radiation*, Vol. III, (E.S. Josephson and M.S. Peterson, eds.) pp. 129–158, CRC Press, Boca Raton, FL.

AOAC International. 1995. *Official Methods of Analysis*, 16th Ed., AOAC International, Gaithersburg, MD.

BHUSHAN, B. and THOMAS, P. 1998. Quality of apples following gamma irradiation and cold storage. Intern. J. Food Sci. Nutr. *49*, 485–492.

CAVALETTO, C.G. 1989. Quality of high-temperature forced-air treated papayas. In *Proceedings — 25th Annual Hawaii Papaya Industry Association Conference*, pp. 10–15, Sept. 29-30, Hilo, HI.

FDA. 1986. Irradiation in the production, processing, and handling of food; final rule (April 18). Fed. Reg. *51*(75), 13375–13399.

GRAHAM, W.D. and STEVENSON, M.H. 1997. Effect of irradiation on vitamin C content of strawberries and potatoes in combination with storage and with further cooking in potatoes. J. Sci. Food Agric. *75*, 371–377.

KHAN, I., SATTAR, A., ALI, M. and MUHAMMED, A. 1974. Some physiological and biochemical changes in irradiated mangoes. Lebensm. Wiss. u.- Technol. *7*, 25–28.

KILCAST, D. 1994. Effect of irradiation on vitamins. Food Chem. *49*, 157–164.

LALAGUNA, F. 1998. Response of 'Galia' muskmelons to irradiation as a quarantine treatment. HortScience *33*, 118–120.

LARSON-POWERS, N. and PANGBORN, R.M. 1978. Descriptive analysis of sensory properties of beverages and gelatins containing sucrose or synthetic sweeteners. J. Food Sci. *43*, 47–51.

MCLAUGHLIN, W.L. 1999. Gamma-ray source vs. X-ray or electron beams for quarantine treatment. In *The Use of Irradiation as a Quarantine Treatment of Food and Agricultural Commodities*, (J.H. Moy and L. Wong, eds.) pp. 78–89, Proceedings of Workshop, November 10–12, 1997, Honolulu, HI.

MERMELSTEIN, N.H. 2000. E-beam-irradiated beef reaches the market, papaya and gamma-irradiated beef to follow. Food Technol. *54*(7), 88–91.

MITCHELL, G.E., MCLAUCHLAN, R.L., BEATTIE, T.R., BANOS, C. and GILLEN, A.A. 1990. Effect of gamma irradiation on the carotene content of mangos and red capsicums. J. Food Sci. *55*, 1185–1186.

MITCHELL, G.E., MCLAUCHLAN, R.L., ISAACS, A.R., WILLIAMS, D.J. and NOTTINGHAM, S.M. 1992. Effect of low dose irradiation on composition of tropical fruits and vegetables. J. Food Comp. Anal. *5*, 291–311.

MOSHONAS, M.G. and SHAW, P.E. 1982. Irradiation and fumigation effects on flavor, aroma and composition of grapefruit products. J. Food Sci. *47*, 958-964.

MOSHONAS, M.G. and SHAW, P.E. 1984. Effects of low-dose γ-irradiation on grapefruit products. J. Agric. Food Chem. *32*, 1098–1101.

MOY, J.H. 1983. Radurization and radicidation — fruits and vegetables. In *Preservation of Food by Ionizing Radiation*, Vol. III, (E.S. Josephson and M.S. Peterson, eds.) pp. 83–108, CRC Press, Boca Raton, FL.

MOY, J.H. 1985. *Radiation Disinfestation of Food and Agricultural Products*. pp. 424, Haw. Inst. Trop. Agri. & Hum. Resources. U. of Hawaii, Honolulu.

MOY, J.H., KANESHIRO, K.Y., OHTA, A.T. and NAGAI, N. 1983. Radiation disinfestation of California stone fruit infested by Medfly — Effectiveness and fruit quality. J. Food Sci. *48*, 928–931, 934.

MOY, J.H. and WONG, L. (eds.). 1999. *The Use of Irradiation as a Quarantine Treatment of Food and Agricultural Commodities*, pp. 116, Proceedings of a Workshop, November 10–12, 1997, Honolulu, HI.

NAGAI, N.Y. and MOY, J.H. 1985. Quality of gamma irradiated California Valencia oranges. J. Food Sci. *50*, 215–219.

O'MAHONY, M., WONG, S.-Y. and ODBERT, N. 1985. Sensory evaluation of navel oranges treated with low doses of gamma-radiation. J. Food Sci. *50*, 639-646.

SYSTAT, 1999. Ver. 9.01, SPSS, Inc., Chicago, IL.

THOMAS, P. and JANAVE, M.T. 1975. Effects of gamma irradiation and storage temperature on carotenoids and ascorbic acid content of mangoes on ripening. J. Sci. Food Agric. *26*, 1503–1512.

URBAIN, W.M. 1989. Food irradiation: The past fifty years as prologue to tomorrow. Food Technol. *43*(7), 76, 92.

USDA. 1997. Papaya, carambola, and litchi from Hawaii: final rule. 7 CFR Parts 300 and 318, (July 10) Fed. Reg. *62*(132), 36967–36976.

YU, L., REITMEIER, C.A., GLEASON, M.L., NONNECKE, G.R., OLSON, D.G. and GLADON, R.J. 1995. Quality of electron beam irradiated strawberries. J. Food Sci. *60*, 1084–1087.

YU, L., REITMEIER, C.A. and LOVE, M.H. 1996. Strawberry texture and pectin content as affected by electron beam irradiation. J. Food Sci. *61*, 844–846.

ZHAO, M., MOY, J.H. and PAULL, R.E. 1996. Effect of gamma irradiation on ripening papaya pectin. Postharv. Biol. Technol. *8*, 209–222.