Market Quality of Sweetpotatoes after Gamma-irradiation for Weevil Control

Raymond G. McGuire and Jennifer L. Sharp

U.S. Department of Agriculture, Agricultural Research Service, Subtropical Horticulture Research Station, 13601 Old Cutler Road, Miami, FL 33158

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Abstract. Roots of sweetpotatoes [*Ipomoea batatas* (L.) Lam.] were treated with 200 to 1000 Gy of ionizing radiation from a ^{60}Co source. Within this range, radiation dosage had no effect on surface injury and decay when roots were evaluated after 1 month of storage at 13C and 90% relative humidity. During storage, weight loss by irradiated roots was 0.5% to 3.3% over that of nontreated roots, which, in some instances, affected root firmness. Changes in peel color were visually imperceptible, but raw medullar tissue of the staple-type, white-fleshed cultivar Picadito had a more intense yellow hue with increasing irradiation. The greatest differences were evident after roots had been baked. The hue of the cooked medullar tissue of the sweet, orange-fleshed cultivar Jewel was not changed by increasing irradiation, although roots were darker and had a lower color intensity. With baking, the medullar tissue of irradiated roots of 'Picadito' lost some of its yellow tinge, but it also became darker with increased irradiation. Taste panelists reported that irradiated roots were sweeter, but these were not preferred to nonirradiated roots, due, in part, to the darkened appearance of treated samples.

Sweetpotato, both the traditional orange-fleshed and the staple-type, white-fleshed cultivars, is an important crop in the southeastern United States, and the roots are a major source of nutrition throughout the world. The importation into the United States of sweetpotatoes that may be infested with the sweetpotato weevil [*Cylas formicarius* (F.)] is prohibited by quarantine regulations. Similar laws restrict movement of roots from states where the weevil has been reported: Kentucky, North and South Carolina, Georgia, Florida, Alabama, Mississippi, Arkansas, Louisiana, and Texas (Nilakhe, 1991).

Before sweetpotato roots can be shipped from proscribed areas to markets in environments where the weevil can become established, they must first be disinfested. Fumigation with methyl bromide is the postharvest quarantine treatment approved to kill sweetpotato weevils in sweetpotatoes (U.S. Dept. of Agriculture, 1992); the treatment, however, causes severe tissue necrosis followed by fungal decay (Brown, 1985). Methyl bromide also has been classified as an ozone depleter and is scheduled to be banned from production and use, pursuant to section 602 of the Clean Air Act. An irradiation dosage of 300 Gy applied to infested sweetpotato roots will produce sterility in adult weevils and kill

eggs and larvae (Dawes et al., 1987). Doses up to 1000 Gy have been approved by the U.S. Food and Drug Administration to preserve and disinfest fruits and vegetables (Federal Register, 1986). Commercial application of irradiation technology to disinfest fruits and vegetables is expected to increase. The purpose of this study was to determine the effect of gamma irradiation on the quality of sweetpotato roots.

Materials and Methods

Orange-fleshed 'Jewel' sweetpotatoes, cured and ranging in weight from 139 to 524 g (median = 250 g), were obtained from a local market in May 1994. 'Picadito' boniatoes, red-skinned and white-fleshed sweetpotatoes grown in Dade County, Fla., and ranging in weight from 120 to 750 g (median = 290 g), were obtained uncured from a local packing-house. In each of four replications per cultivar, 240 roots were randomly sorted into groups of 40 that were, with the exception of the nontreated control, irradiated with a ^{60}Co source of gamma radiation at a rate of 1.35 Gy·sec⁻¹ to yield dosages of 200, 400, 600, 800, and 1000 Gy. The Gammacell model 220 irradiator (Atomic Energy of Canada, Ottawa), its calibration, and principle of operation have been described by von Windeguth (1986). Roots were individually numbered and weighed, then placed into storage at 13C and 90% relative humidity; these then were reweighed weekly and returned to cold storage. At the time of treatment, firmness and the interior and exterior color of 10 roots from each replication were measured as described below for comparison with those completing storage.

Root quality was evaluated after 1 month of storage. Roots were weighed then rated for the percentage of surface decay and surface injury with a 12-point visual acuity scale (Horsfall and Barratt, 1945). Firmness of each

root was measured with an Instron model 1011 Universal Testing Instrument (Instron Corp., Canton, Mass.) fitted with a compression anvil of 12 mm diameter; resistance was recorded after a compression of 3 mm at a crosshead speed of 0.25 mm·sec⁻¹. Surface color measurements were made on each root with a Minolta CR-200 chromameter (Minolta Corp., Ramsey, N.J.) calibrated to a standard white reflective plate and recording in the L* C* h° color system (lightness, chroma, and hue angle, respectively); measurements were taken across an area ≈50 mm² with diffuse illumination at a viewing angle of 0° under CIE (Commission Internationale de l'Eclairage) illuminant C conditions.

Ten roots from each treatment were sliced transversely 1 cm thick, and color measurements were performed, as above, on three internal slices from each root. For 'Jewel', the slices were then baked at 175C for 25 to 30 min, after which a second series of color measurements was performed. Four grams of medullar tissue from each baked root were blended with 1 ml of distilled water; this paste was then transferred to a tube and centrifuged at 5000× g for 15 min. The supernatant was decanted, and its refractive index was determined for calculation of the percentage of total soluble solids (Walter, 1992). Because slices of 'Picadito' roots quickly turned dark after cutting, 10 whole roots were baked at 175C for 45 min, after which color was determined on four slices from each root.

Sensory qualities of baked sweetpotatoes were rated informally by 13 to 15 coworkers; however, the two cultivars were evaluated separately in different manners. In each replication of each cultivar, three roots that had received 0, 400, or 800 Gy were selected. For 'Jewel', these were peeled individually and cut into 1-cm³ cubes, which were then baked at 175C for 15 min. Cubes of individual roots of the three treatments were compared side-by-side at three stations (three subsamplings) and rated from most to least preferred; this evaluation combined flavor and visual characteristics. Whole roots of 'Picadito' were baked at 175C for 45 min, then cut individually into 1-cm³ cubes. Cubes of individual roots of the three treatments were compared side-by-side at three stations. Tasters, however, were asked first to sample a nonirradiated "standard," noting its appearance, texture, and flavor. Tasters then compared individual samples to the standard, separately noting appearance, texture, and flavor, by placing a slash in the appropriate location on a 63.5-mm line. Lines were bounded by 1 on the left end and 10 on the right end, where 1 = an extremely substandard characteristic, and 10 = a characteristic substantially above the standard.

Preference tests of 'Jewel' roots were statistically evaluated according to Fisher and Yates (1949) using scores for ranked data: a sample rated as most preferred received a score of 0.85, a sample rated least preferred received -0.85, and an intermediate preference received a score of 0. Scores were subjected to regression analysis using the SAS statistical software package (SAS Institute,

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Table 1. Color characteristics of peel and medullar tissue of 'Picadito' boniatos following gamma irradiation and 1 month of storage at 13C.

Irradiation dosage (Gy)	Peel			Medulla					
	Raw ^z			Raw ^z			Cooked ^z		
	Lightness	Intensity	Hue	Lightness	Intensity	Hue	Lightness	Intensity	Hue
0	39.3	25.2	29.5	90.0	11.8	98.5	74.4	11.0	103.0
200	40.2	24.8	32.6	88.0	14.0	97.5	68.3	11.6	103.1
400	39.2	24.1	33.6	85.8	15.3	96.0	63.4	15.2	100.6
600	39.7	23.5	34.1	83.8	16.5	94.5	62.6	17.0	98.4
800	39.2	22.9	33.4	82.3	17.0	93.1	63.4	17.5	96.5
1000	39.2	22.3	34.2	81.0	18.4	92.9	62.5	18.9	94.5
Significance ^y (P)	NS	0.0001	0.0325	0.0001	0.0013	0.0021	0.0070	0.0087	0.0030

^zMeans of four replications, each of 10 roots per treatment. Relative values: L* = lightness, where 100 is white and 0 is black; C* (chroma) = intensity, where 100 is most intense and 0 is least intense; h° = hue angle, where 0° is red-purple, 90° is yellow, and 180° is bluish-green.

^yRegression equations (NS = not significant): raw peel: intensity = $25.288 - 0.295(\text{dosage}/100)$ ($r^2 = 0.9947$); hue = $29.920 + 1.181(\text{dosage}/100) - 0.0807(\text{dosage}/100)^2$ ($r^2 = 0.8302$). Raw medulla: lightness = $90.120 - 1.207(\text{dosage}/100) + 0.029(\text{dosage}/100)^2$ ($r^2 = 0.9985$); intensity = $11.983 + 0.932(\text{dosage}/100) - 0.0311(\text{dosage}/100)^2$ ($r^2 = 0.9803$); hue = $98.701 - 0.811(\text{dosage}/100) + 0.0208(\text{dosage}/100)^2$ ($r^2 = 0.9729$). Cooked medulla: lightness = $74.029 - 3.25(\text{dosage}/100) + 0.218(\text{dosage}/100)^2$ ($r^2 = 0.9388$); intensity = $10.458 + 1.214(\text{dosage}/100) - 0.037(\text{dosage}/100)^2$ ($r^2 = 0.9296$); hue = $103.455 - 0.551(\text{dosage}/100) - 0.0373(\text{dosage}/100)^2$ ($r^2 = 0.9654$).

1985). Sensory evaluations of 'Picadito' roots were measured as distances on the lines from the left (1), and the measurements of individual attributes were analyzed similarly. Other data also were tested by regression analysis in SAS. After analysis, Horsfall/Barratt rating values were converted to mean percentages for estimating percent surface area decayed or percent surface area injured.

Results

Regardless of the amount of gamma radiation received by the sweetpotatoes in this study, surface appearances were indistinguishable from those of roots that were not irradiated. After 1 month at 13C, decay on 'Jewel' ranged from 0.04% to 0.75% of the surface area, and surface area with symptoms of injury varied between 2.2% and 4.4%; differences were not significant. The pale orange color of the root peel was also uniform across all treatments and indistinguishable from that of nonirradiated roots (data not shown). Decay on 'Picadito' following cold storage, primarily from species of *Penicillium* and *Rhizopus*, was not statistically affected by irradiation, but averaged 2.7% of the surface area at the lowest dosage to 14.5% at the highest. Injury affected <1% of the surface in all treatments. 'Picadito' roots were initially a dull purplish-red [L^* , C^* , $h^\circ = 42.3, 24.1, 26.6$, respectively (L^* = lightness, where 100 is white and 0 is black; C^* (chroma) = intensity, where 100 is most intense and 0 is least intense; h° = hue angle, where 0° is red-purple, 90° is yellow, 180° is bluish-green, and 270° is blue)]. After 1 month of cold storage, roots were significantly darker and redder, although color intensity was not affected by cold storage (L^* , C^* , $h^\circ = 39.3, 25.2, 29.5$, respectively). Relative to these nonirradiated controls, gamma irradiation significantly reddened the peel but reduced color intensity (Table 1). These color differences, however, were barely perceptible to the eye.

Weight loss during storage of 'Jewel' and 'Picadito' roots was significantly affected by the dosage of gamma radiation. There was no significant weight loss during the first 2 weeks of storage of 'Jewel' sweetpotatoes, but by the end of the third week, a significant effect was

apparent. By the end of the fourth week, weight loss ranged from 3.8% in the controls to 5.1% at 1000 Gy; the changes are described by the equation: percent weight loss = $3.77 + 0.42(\text{dosage}/100) - 0.0695(\text{dosage}/100)^2 + 0.00403(\text{dosage}/100)^3$ ($P = 0.0123$; $r^2 = 0.9794$). For 'Picadito', weight loss in storage was influenced by irradiation as early as the first week. By the end of the fourth week, weight loss ranged from 8.2% in the 'Picadito' controls to 11.4% at 1000 Gy; differences are described by the equation: percent weight loss = $8.086 + 0.44(\text{dosage}/100) - 0.0103(\text{dosage}/100)^2$ ($P = 0.0014$; $r^2 = 0.9794$).

Firmness of 'Jewel' roots after 1 month of storage increased from 82.0 N at 0 Gy to 97.3 N at 600 Gy. This trend reversed above 600 Gy, and at 1000 Gy, firmness of 84.8 N approximated that of control roots, as described by the equation: firmness = $82.024 + 1.758(\text{dosage}/100) + 0.422(\text{dosage}/100)^2 - 0.0572(\text{dosage}/100)^3$ ($P = 0.0697$; $r^2 = 0.8824$). Although control 'Picadito' roots were less rigid after 1 month's storage (118.1 N before vs. 98.1 N after), irradiation created no additional significant effect on firmness; treated roots ranged from 85.1 N to 87.6 N.

The color of raw 'Jewel' root slices was not significantly affected by irradiation, but baking the sweetpotatoes revealed an effect (Table 2). The orange hue of the cooked medullar tissue was not changed by the treatments, but irradiation darkened the color and reduced its intensity (Fig. 1). Medullar tissue of 'Picadito', originally a pale greenish-yellow (L^* , C^* , $h^\circ =$

90.6, 11.9, 100.1, respectively), became significantly (though nearly imperceptibly) more yellow after storage (L^* , C^* , $h^\circ = 90.0, 11.8, 98.5$, respectively). Irradiation made raw medullar tissue darker, more yellow, and more intense (Table 1 and Fig. 1). Baking the root caused the medulla to become darker and slightly greener. Changes in lightness, intensity, and hue that were induced by irradiation in raw roots were still apparent after cooking (Table 1).

Several evaluators reported that the baked irradiated roots of both cultivars tasted sweeter than those that had not been irradiated before baking. However, the percentage of total soluble solids (TSS) in cooked root medulla of the traditional, sweet cultivar Jewel ranged from 16.4% to 16.8% and was not affected by radiation dosage. Overall, reflecting a combined assessment of appearance and flavor, 'Jewel' roots that were not irradiated were preferred substantially over those treated at 400 and 800 Gy; the respective mean scores were 0.331, -0.126, and -0.205 ($LS_{D_{P=0.05}} = 0.143$). The reduced preference for treated roots resulted primarily from the darkening of the samples. Sensory evaluations of 'Picadito' compared appearance, texture, and flavor of baked medullar tissue separately. Appearance was significantly ($P \leq 0.05$) affected by irradiation, with the controls being preferred to treated samples, which were grayer with increasing dosage. Where the maximum score for appearance was 63.5, nonirradiated samples were scored 42.4, whereas samples treated at

Table 2. Color characteristics of raw and cooked medullar tissue of 'Jewel' sweetpotatoes following gamma irradiation and 1 month of storage at 13C.

Irradiation dosage (Gy)	Raw ^z			Cooked ^z		
	Lightness	Intensity	Hue	Lightness	Intensity	Hue
0	70.3	52.7	60.1	55.5	50.2	71.6
200	70.4	50.9	60.1	51.0	44.1	72.7
400	68.7	52.4	59.9	48.2	39.2	71.2
600	69.6	50.3	60.5	46.9	38.1	72.1
800	68.7	52.1	60.1	46.4	37.5	71.6
1000	69.2	50.7	60.4	44.6	35.1	72.8
Significance ^y (P)	NS	NS	NS	0.0036	0.0047	NS

^zMeans of four replications, each of 10 roots per treatment. Relative values: L* = lightness, where 100 is white and 0 is black; C* (chroma) = intensity, where 100 is most intense and 0 is least intense; h° = hue angle, where 0° is red-purple, 90° is yellow, and 180° is bluish-green.

^yRegression equations (NS = not significant): cooked medulla: lightness = $55.066 - 2.007(\text{dosage}/100) + 0.102(\text{dosage}/100)^2$ ($r^2 = 0.9605$); intensity = $49.740 - 2.980(\text{dosage}/100) + 0.160(\text{dosage}/100)^2$ ($r^2 = 0.9531$).

Fig. 1. Relative changes with baking in the color of medullar tissue of 'Picadito' and 'Jewel' sweetpotatoes previously irradiated with a ^{60}Co source (arrow indicates increasing dosage from 0 to 1000 Gy) and stored 1 month at 13C. The angle between the origin and the green/red axis corresponds to hue angle (h°), where 0° is red, 90° is yellow, and 180° is green. The distance from the origin corresponds to intensity (C°), where 100 units would be most intense and 0 least intense.

400 and 800 Gy were scored 31.5 and 25.4, respectively. Texture and flavor were not significantly affected by irradiation.

Discussion

Irradiation has increased respiration of sweetpotatoes, induced the conversion of starch to sucrose, and resulted in accelerated weight loss in storage (Ajlouni and Hamdy, 1988; Hayashi, 1985; Lu et al., 1986). Treatment at 300 Gy, in combination with postirradiation storage at 24C for 8 days, is recommended as a means of increasing the sweetness of these roots (Ajlouni and Hamdy, 1988). Any increase in palatability that derives from the sterilization of the sweetpotato weevil before transport of this product from quarantined areas would be an advantage.

Previous work on irradiated sweetpotatoes seldom compared cooked roots, however. Although irradiation at levels anticipated to sterilize insects does not cause distinguishable surface anomalies or greatly affect the color of raw roots, cooked roots are noticeably altered. Cooking alters the composition of sweetpotatoes, and maltose, not detected in raw roots, can replace sucrose as the predominant sugar in some traditional sweet cultivars, though not necessarily in staple-types (Morrison et al., 1993). When added to sweetpotato puree in sensory evaluations, maltose consistently out-ranked sucrose in preference (Koehler and Kays, 1991). Baking irradiated 'Jewel' sweetpotatoes significantly increased the darkness of medullar tissue and reduced color intensity, which adversely affected preference by the taste panel. Whether this color change resulted from irradiation-induced altered terpene chemistry or degradation of sugars to carbonylic compounds that reacted with amino

acids [as suggested by Zegota and Bachman (1984)] or from a heat-induced caramelization of sugars is unknown.

The white-fleshed, boniato-type of sweetpotato, as exemplified by 'Picadito', differs from the orange in having more starch and less sugar (Picha, 1985). Sweetness of the boniato does increase with cooking (Picha, 1985); nevertheless, similar staple-type, baked roots have only 22% to 35% of the amount of total sugars in 'Jewel' (Morrison et al., 1993). Darkening of the cooked medulla of the boniato, although apparent, was less noticeable than that of the orange-fleshed 'Jewel'; the darkening of 'Picadito' seemed to result from a waterlogging of the cooked tissue. Concomitant changes in hue and color intensity were slight compared with 'Jewel'. Following treatment at 400 Gy, flavor was satisfactory and perhaps improved, but the darkening of both cultivars may be unacceptable to some consumers. A posttreatment reconditioning period of 6 to 12 days at 34 to 35C before cold storage may prevent or reduce this discoloration (Lu et al., 1986).

With the anticipated loss of the fumigant methyl bromide, new methods of quarantine control must be developed. Heat treatments are being investigated (Hansen and Sharp, 1992), but can reduce storage life. Controlled atmospheres with 2% to 4% O_2 and 40% to 60% CO_2 have proven effective within 7 days (Delate et al., 1990). Irradiation is an immediately effective alternative (Dawes et al., 1987), but the sweetpotato weevils, although sterilized, survive and are found by inspectors who may be uncertain that treatment has been successful. Treatment at 400 Gy is minimally injurious to sweetpotato roots. If inspectors' uncertainties could be alleviated and a method, such as reconditioning, could be employed to

maintain desirable root color, irradiation may prove to be an acceptable method of quarantine control in sweetpotatoes.

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