Reducing Irradiation Damage to 'Arkin' Carambola by Plastic Packaging or Storage Temperature

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Additional index words. *Anastrepha suspensa*, *Averrhoa carambola*, quarantine treatment, shelf-life, market quality

Abstract. Carambolas (*Averrhoa carambola* L.) require quarantine treatment for control of the Caribbean fruit fly (*Anastrepha suspensa* Loew) (CFF) prior to shipment to certain domestic and export markets. Low-dose irradiation, ≤ 1.0 kGy, is effective for sterilizing CFF and other fruit flies; however, carambolas are susceptible to irradiation-induced peel injury. Low-dose gamma irradiation treatment generally reduced fruit quality, but the effects were mitigated by packaging carambola fruit in "clamshell" polystyrene containers, rather than conventional fiberboard boxes, prior to treatment. Use of clamshell containers reduced peel pitting, stem-end breakdown, shriveling, and loss of mass after storage for 14 days at 5 or 7 °C. In addition, fruit held in clamshell containers were firmer, with slightly less green peel, and had lower total soluble solids, but the flavor was not quite as good as that of fruit stored in fiberboard boxes. There was no difference in the mastication texture or acidity of fruit by package type at final storage. Packing carambolas in clamshell containers increased their tolerance to irradiation-induced peel disorders and improved the potential for usage of low-dose irradiation for quarantine treatment.

Irradiation in the range of 0.15 to 0.3 kGy is generally required to sterilize most insect pests of fresh fruits and vegetables entering markets with quarantine restrictions (Burditt, 1994). Blueberries (Eaton et al., 1970; Miller and McDonald, 1995; Miller et al., 1994) and cherries (Drake et al., 1994; Jessup, 1990) tolerate low-dose irradiation at levels higher than that required to control quarantine pests. However, the required minimum dosage may reduce fruit quality and shelf-life of fruits such as grapefruit (Hatton et al., 1984) and carambola (Gould and Windeguth, 1990). To achieve the minimum absorbed dose required for disinfestation, some fruit will necessarily absorb higher (maximum) dosage during the treatment process. In commercial applications, commodities will be subjected to less precise and, possibly, higher doses than the minimum required for quarantine purposes. We observed that the minimum : maximum ratio for absorbed dosage for papaya (*Carica papaya* L.)

in a preliminary test was 1:2.7. The actual range in dosage, however, depends on factors such as product density, density of packaged product, the stacking arrangement, and composition of containers.

The generic irradiation dose for quarantine security against Caribbean fruit flies is expected to be ≈ 0.15 kGy when approved by the Animal and Plant Health Inspection Service (APHIS), the regulatory agency of the U.S. Dept. of Agriculture (Federal Register, 1996), for use on fresh fruits and vegetables. Carambolas may be injured at 0.25 kGy, especially when harvested at the green-yellow peel stage (Paull, 1992). We observed the development of peel pitting of carambola after irradiation at 0.25 and 0.5 kGy in preliminary experiments. Gould and von Windeguth (1990) reported no injury to irradiated carambolas at doses < 0.05 kGy, but indicated that some surface disorders developed at higher doses. Forney and Lipton (1990) reported that wrapping in plastic film mitigated or eliminated peel pitting induced by cold treatment of some fresh fruits and vegetables. Miller et al. (1991) found that film wrapping improved postharvest fruit quality of carambola after cold treatment and subsequent storage, but pitting was not a problem in the experiment. Plastic "clamshell" packing containers may provide some protection against peel injury to carambolas caused by irradiation stress, even though this container is more permeable to water vapor, oxygen, and CO₂ than most film wrapping materials. The purpose of this study was to determine: 1) the response of carambola to low-dose irradiation; and 2) if packaging carambolas in clamshell containers alleviated peel damage caused by irradiation stress.

Mature 'Arkin' carambolas ranging in size from 20 to 25 count (100–200 g), with 3% to 25% yellow peel color, were obtained directly from a Dade County packinghouse on 7, 14, and 21 Jan. 1997. The fruit were taken by air-conditioned automobile (5-h trip) to the Horticultural Research Laboratory, Orlando, Fla., for treatment and storage. Fruit were randomized and repackaged in either: 1) the traditional pack, consisting of a commercial fiberboard (FB) carambola box (20 fruit each with fiberboard honeycomb and bottom foam pad); or 2) two-cell preformed clamshell (CS) clear-polystyrene containers (package #45-220-20V; Ultra Packaging, Minneapolis). The CS packages measured 12.4 × 12.4 × 5.4 cm (length × width × height), with four ventilation holes (0.6 cm in diameter) on the top and eight on the bottom surface. The two halves of the CS container were hinged on one side, and the top and bottom 'snapped' together with preformed interlocks. Ten CS containers were placed on edge, with fruit stem-end down toward the hinged side of the CS, into fiberboard boxes. Fruit were not washed or treated with chemicals or coatings.

Each harvest (replication) consisted of 480 fruit packed in 24 boxes. After preparation, fruit were held overnight at 15 °C and taken the following morning by air-conditioned automobile to FOODTECHnology Service irradiation facility in Mulberry, Fla. Four boxes from each of the two types of packs were irradiated at 0.0, 0.15, or 0.5 kGy with a ⁶⁰Co source at a rate of 0.17 kGy·min⁻¹.

After irradiation, two boxes of each treatment combination were placed in storage at 5 or 7 °C for 14 d plus 3 d at 15 °C. All fruit were evaluated for quality attributes 1) following harvest and 2) after 14-d storage, plus 3 additional d at 15 °C.

The severity index and the incidence of peel pitting, bronzing (discoloration), stem-end breakdown (SEB), and surface shriveling were determined, and loss of fresh mass was calculated. Peel pitting and surface bronzing were scored as follows: 1 = 0%, 2 ≤ 10%, 3 = 11% to 25%, 4 = 26% to 50%, and 5 ≥ 51% of surface area affected. Stem-end-breakdown was scored on the percentage of the fruit stem-end area that developed necrotic tissue. Each fruit was rated for shriveling: 1 = not shriveled, or 2 = shriveled. Mass loss was determined by weighing each fruit after harvest and after final storage, and calculating the incremental change.

Fruit firmness (destructive test) was determined on 15 fruit immediately after harvest, and on five fruit per box at the end of storage, with an Instron Food Texture machine (model 4410; Instron Corp., Canton, Mass.). This recorded the amount of force required to extend an 11-mm-diameter cylinder with a rounded face 3 mm into the fruit rib at 25 mm·min⁻¹ without puncturing the peel surface. Objective peel color was measured on two ribs of each of five fruit per box at each inspection with a Minolta Chromameter (model CR 200; Minolta Camera Co., Osaka, Japan)

Received for publication 2 Sept. 1997. Accepted for publication 31 Mar. 1998. Mention of a trademark, warranty, proprietary product, or vendor does not constitute a guarantee by the U.S. Dept. of Agriculture and does not imply its approval to the exclusion of other products or vendors that may be suitable. We acknowledge statistical assistance provided by V. Chew, statistician, USDA/ARS, Gainesville, Fla., and technical expertise by C.C. Carroll, biological scientist, Univ. of Florida, Gainesville. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

calibrated with a white standard tile in the International Commission on Illumination [CIE (1976)] L*, a*, b* color mode. Hue (h°) and chroma (C*) color values were calculated. Total soluble solids (TSS) in the juice was determined with a refractometer (model AO MK11AO; Scientific Instruments, Keene, N.Y.) and pH was also determined. Acidity was determined by titrating to pH 8.2 with 0.01 N NaOH and expressed as percentage of anhydrous oxalic acid on a fresh-mass basis. Relative sensory evaluations of flavor and mastication texture were determined by seven untrained panelists. Ratings were made on sliced fruit samples from each treatment using a modified hedonic scale from 1 (extremely unacceptable) to 100 (extremely acceptable).

The experimental design was a 2 (package types) × 3 (doses = 0.0, 0.15, 0.5 kGy) × 2 (storage temperatures = 5, 7 °C) factorial. Fruit were replicated on the three separate harvests. Means were calculated of 30-fruit (two 15-fruit samples) for each treatment combination of each of the three harvests. Differences among main factors and their interactions were determined by PROC ANOVA procedures using SAS (SAS Institute, Gary, N.C.). Least significant difference (LSD) ($P \leq 0.05$) values were calculated to detect treatment differences. Only terminal storage data are presented.

Results

Peel pitting. The effect of package type on the severity of pitting was dependent on the interaction of the storage temperature × dose (Table 1). There was a trend for reduced severity of pitting when fruit were packaged in CS containers regardless of dose; however, at 7 °C there was no difference in severity between "clamshell" fruit treated at 0.15 kGy and control fruit. Control fruit had less pitting or were devoid of pitting compared with fruit treated with irradiation. The incidence of pitting was not affected by storage temperature, but was reduced 45% or 23% when fruit were packaged in CS containers and treated at 0.15 or 0.5 kGy, respectively, compared with similarly treated, conventionally packaged fruit.

Bronzing (peel discoloration). Conventionally packed fruit that were irradiated had more severe bronzing (3.9 vs. 3.0) and increased incidence of bronzing than did those that were not irradiated (83.1% vs. 68.9%), but irradiation had no significant effect on bronzing of fruit packaged in CS containers (Table 1). Fruit stored at 5 °C had a higher severity index (3.6) and higher incidence (81%) of bronzing than did those held at 7 °C (3.3 and 75%, respectively).

Stem-end-breakdown (SEB). Conventionally packed fruit stored at 5 °C had more severe SEB (2.0) than did similar fruit held at 7 °C (1.6), but storage temperature had no significant effect on SEB in fruit packaged in CS containers (Table 1). The severity of SEB also increased as dose increased for fruit conventionally packaged, but not for those packaged in CS containers. The incidence of SEB was

49.5% and 35% for fruit held at 5 and 7 °C, respectively. The effect of package type on SEB was influenced by irradiation dose. The incidence of SEB increased with dose for fruit packed in either FB or CS containers, but the rate of increase was greater for fruit in FB than for those packed in CS containers.

Shriveling. There was a significant interaction among all main factors (package, dose, and storage temperature) for shriveling (Table 1). Incidence of shriveling was less in CS than in FB containers regardless of storage temperature, except for fruit irradiated at 0.15 kGy. Incidence of shriveling at 7 °C was less than at 5 °C, except for control fruit packaged in CS containers; and FB fruit shriveled more when treated with 0.5 kGy than did those treated with 0.15 kGy or not treated. The incidence of shriveling changed little in fruit packaged in CS containers; regardless of treatment, CS fruit had the lower incidence of shriveling than did FB fruit.

Loss of mass. Fruit packaged in CS lost 60% less mass than did those packaged in FB (Table 1); the loss was not affected by irradiation dose or storage temperature.

Fruit firmness. Fruit packaged in FB were less firm ($N = 24.3$) than those packaged in CS ($N = 26.2$) after final storage (Table 2). Firmness of fruit held at 5 °C was greater ($N = 26.1$) than that of those held at 7 °C ($N = 24.4$), irradiated fruit were firmer than control fruit,

and the fruit packed in CS containers and irradiated were the most firm.

Peel color. Package type affected the L* value, but the difference of 1.1 units was small; therefore, the difference indicates that the peel of fruit packed in FB ($L^* = 43.4$) was only slightly darker than that of fruit held in CS containers ($L^* = 44.5$) (Table 2). Small differences in the L* value are probably not observable to the consumer. The effect of storage temperature on the L* value was dependent on irradiation dose, but, again, the effect, although significant, was very small. Mean chroma values for fruit packaged in FB and CS packages were 20.4 and 21.9, respectively, indicating that the color of fruit held in FB packages was less vivid. The color of fruit held at 5 °C ($C^* = 20.8$) was also less vivid than of that fruit held at 7 °C ($C^* = 21.4$). Irradiation dose affected chroma, and mean C* values for 0.0, 0.15, or 0.5 kGy were 21.6, 20.9, or 21.0, respectively. In addition, fruit packed in FB ($h^\circ = 97.6$) were more greenish/yellow than fruit held in CS containers ($h^\circ = 96.3$). The hue value decreased as irradiation dose increased; thus, nonirradiated fruit were less yellow ($h^\circ = 99.8$) than fruit irradiated at 0.15 ($h^\circ = 96.0$) or 0.5 kGy ($h^\circ = 95.2$).

Flavor and mastication texture. Fruit flavor ratings were lower for fruit in CS containers (index value = 67.9) than for those in FB boxes (index value = 74.4), but were not af-

Table 1. Severity and incidence of peel pitting, bronzing, and stem-end-breakdown (SEB), incidence of fruit shrivel and mass loss (%) of carambola as influenced by package type (fiberboard, "clamshell"), storage temperature (5 or 7 °C), and irradiation dose (0.0, 0.15, or 0.5 kGy).

Package type	Temp (°C)	Dose (kGy)	Pitting		Bronzing		SEB		Shrivel	Mass loss
			(Index)	(%)	(Index)	(%)	(Index)	(%)	(%)	(%)
Fiberboard	5	0.00	1.2 ^a	13.3	3.2	72.2	1.6	42.2	46.7	5.3
		0.15	2.4	63.3	4.0	86.7	2.1	68.9	37.8	5.1
		0.50	3.3	81.8	4.2	87.8	2.4	80.0	55.6	4.7
		Mean	2.3	52.8	3.8	82.2	2.0	63.7	46.7	5.0
	7	0.00	1.0	0.0	2.8	65.6	1.2	16.7	28.9	5.2
		0.15	2.6	57.8	3.8	82.2	1.6	55.6	32.2	5.1
		0.50	3.6	86.7	3.6	76.7	1.9	68.9	44.4	5.3
		Mean	2.4	48.2	3.4	74.8	1.6	47.1	35.2	5.2
	Mean		2.4	50.5	3.6	78.5	1.8	55.4	41.0	5.1
Clamshell	5	0.00	1.0	1.1	3.1	74.4	1.3	25.6	8.9	1.9
		0.15	1.9	41.1	3.4	81.1	1.3	28.9	24.4	2.3
		0.50	2.5	62.2	3.6	84.4	1.6	51.1	23.3	1.9
		Mean	1.8	34.8	3.4	80.0	1.4	35.2	18.9	2.0
	7	0.00	1.0	0.0	2.8	73.3	1.1	10.0	18.9	2.0
		0.15	1.4	25.6	3.2	66.7	1.3	24.4	12.2	2.0
		0.50	2.4	67.8	3.6	82.2	1.4	33.3	7.8	2.1
		Mean	1.6	31.1	3.2	74.0	1.3	22.6	13.0	2.0
	Mean		1.7	33.0	3.3	77.0	1.4	28.9	16.0	2.0
LSD ^b			0.5	19.5	0.6	12.3	0.3	18.2	19.2	0.8
Main effects and interactions ^c										
Pack (P)			*	*	*	NS	*	*	*	*
Temperature (T)			NS	NS	*	*	*	*	*	NS
Irradiation (D)			*	*	*	*	*	*	*	NS
P × T			*	NS	NS	NS	*	NS	NS	NS
P × D			*	*	*	*	*	*	*	NS
P × T × D			*	NS	NS	NS	NS	NS	*	NS

^aAll values are means of three replicates; 30 observations per replicate.

^bLSD values for significance at $P \leq 0.05$ among values for all treatments within a column.

^c(T × D) Nonsignificant interaction is not shown.

^{ns}Nonsignificant or significant at $P \leq 0.05$ by PROC ANOVA.

Table 2. Firmness, peel color, flavor, and total soluble solids (TSS) of carambola as influenced by package type (fiberboard, "clamshell"), storage temperature (5 or 7 °C), and irradiation dose (0.0, 0.15, or 0.5 kGy).

Package type	Temp (°C)	Dose (kGy)	Firmness (N)	Peel Color			Flavor (Index)	TSS (%)
				L*	C*	h°		
Fiberboard	5	0.00	22.8	43.7	20.5	100.0	75.5	7.8
		0.15	25.9	42.5	19.7	95.6	76.8	8.1
		0.50	26.6	43.0	20.1	95.8	73.3	8.0
	Mean		25.1	43.1	20.1	97.1	75.2	8.0
	7	0.00	20.8	43.9	20.9	100.3	73.3	8.2
0.15		24.4	43.4	20.2	97.3	73.8	7.8	
0.50		25.5	43.7	21.0	96.2	73.8	7.8	
Mean	Mean		23.6	43.7	20.7	97.9	73.6	7.9
			24.4	43.4	20.4	97.5	74.4	8.0
Clamshell	5	0.00	23.7	45.0	22.5	99.3	73.6	7.7
		0.15	28.0	43.7	21.4	95.3	90.9	7.6
		0.50	29.7	43.2	20.8	93.9	66.3	7.8
	Mean		27.1	44.0	21.6	96.2	76.9	7.7
	7	0.00	21.9	45.2	22.3	99.2	64.4	7.5
0.15		26.0	44.9	22.1	95.5	71.9	7.5	
0.50		27.7	44.9	22.1	94.4	60.4	7.6	
Mean	Mean		25.2	45.0	22.2	96.4	65.6	7.5
			26.2	44.5	21.9	96.3	71.3	7.6
	LSD ^y		4.0	1.2	1.3	3.5	9.2	0.3
Main effects and interactions ^x								
Pack (P)			*	*	*	*	*	*
Temperature (T)			*	*	*	NS	NS	NS
Irradiation (D)			*	*	*	*	NS	NS
P × D			NS	NS	NS	NS	NS	NS
T × D			NS	*	NS	NS	NS	NS

^aAll values are means of three replicates; 30 observations per replicate.

^bNonsignificant interactions (P × T, P × D, P × T × D) are not shown.

^cLSD values for significance at $P \leq 0.05$ among values for all treatments within a column.

^{ns} Nonsignificant or significant at $P \leq 0.05$ by PROC ANOVA.

ected by storage temperature or irradiation (Table 2). Mastication texture (overall mean value 74.7) was not affected by main factors or their interactions (data not shown).

Total soluble solids (TSS) and acidity. Fruit packaged in FB had higher TSS (8.0 %) than those packaged in CS (7.6%); however, TSS was not affected by storage temperature or irradiation (Table 2). Mean titratable acidity over all treatment combinations was 0.15% (oxalic acid) and no main factor had a significant effect (data not shown). Mean TSS : TA ratio and pH were 52.8 and 4.2, respectively, and neither was affected by any main factor or interaction (data not shown).

Discussion

Our findings indicate that 'Arkin' carambolas are injured by an irradiation dose as low as 0.15 kGy, a dose that probably will be recommended for quarantine treatment against the Caribbean fruit fly if irradiation is approved by regulatory agencies. The main symptoms of injury expressed after 17 d of storage were increases in severity and incidence of peel pitting, surface bronzing, and SEB. Gould and von Windeguth (1990) reported no damage to carambola at dosages <0.05 kGy, whereas we observed considerable injury at 0.15 kGy. Gould and von Windeguth held fruit at 25 °C for 9 d and did not indicate stage of fruit ripening, i.e., fruit color; we held fruit at

5 or 7 °C following irradiation and fruit were 3% to 25% yellowish. Paull (1992) found that green-yellow carambola fruit treated with 0.25 kGy were pitted after storage, but yellow-orange fruit were not injured. He also stored fruit at 22 °C after irradiation, whereas our fruit were stored at 5 or 7 °C. Morris and Jessup (1989) reported that irradiation could delay or slow ripening at low doses, especially in nonripe fruit; however, irradiation may accelerate fruit ripening at higher doses, which can result in rapid softening of fruit.

Miller and McDonald (1996) reported that carambola with slightly yellow peels had less peel damage after cold treatment and 5 °C storage than did mature green fruit. Although this study concerned cold stress, the findings are consistent with those reported for irradiation by Paull (1992).

We held our fruit in storage for 2 weeks at low temperatures to simulate commercial storage, distribution, and merchandising. We observed irradiation effects on both severity and incidence of pitting, although fruit packed in CS containers suffered less injury. The incidence of peel bronzing was relatively high, ranging from 69% to 84% over the combinations of package type by dose. Control fruit tended to have a slightly lower incidence of bronzing in FB than in CS containers. Causes for the high incidence of bronzing remain unknown. Fruit packed in CS containers had both a lower severity and incidence of SEB;

however, the response to package type was dependent on dose. Although SEB increased with dosage, packaging in CS containers greatly reduced this unsightly disorder. Shriveling was also reduced in fruit packed in CS containers, even though the interaction of all main factors was significant. Loss of mass was also much less in CS than in FB and probably reflects less shriveling. Irradiated fruit packed in CS containers and held at 7 °C had the lowest incidences of shriveling. In addition, fruit packed in CS containers were firmer, and were slightly less greenish/yellow and slightly more vivid in color than fruit held in FB boxes. Again the reduced loss of mass limited fruit softening in CS containers. Finally, flavor of fruit held in CS containers was poorer than that of fruits in FB boxes, probably because of a lower percentage of TSS in the former. In this study, lack of softening, coupled with lower TSS of fruit packed in CS, implies a slight retardation in fruit ripening, and these characteristics are of greater influence than the slight decrease of peel greenness packed in CS packages.

Coatings of various waxes or plastic films have reduced or eliminated peel injury of many fruits and vegetables caused by exposure to lower than optimal storage temperatures (Forney and Lipton, 1990). Plastic film reduced peel injury in carambola caused by low temperature of (Miller et al., 1993), but has not been tested for reducing injury from irradiation.

Carambolas should be harvested at a color break stage of ripeness (≈25% yellow), irradiated in CS containers, and held at 7 °C to maintain quality after irradiation treatment. Further experimentation is warranted to determine if carambola fruit with >25% yellow color may be less susceptible to irradiation-induced peel injury.

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