Proc. Fla. State Hort. Soc. 110:215-218. 1997.

QUALITY OF IRRADIATED AND NONIRRADIATED BLACK SAPOTE (*DIOSPYROS DIGYNA* JACQ.) AFTER STORAGE AND RIPENING

W. R. MILLER[1], J. L. SHARP[2] AND E. BALDWIN[3]
[1]*United States Department of Agriculture*
Agricultural Research Service
2120 Camden Road
Orlando, FL 32803

[2]*United States Department of Agriculture*
Agricultural Research Service
13601 Old Cutler Road
Miami, FL 33158

[3]*United States Department of Agriculture*
Agricultural Research Service
600 Avenue S. NW
Winter Haven, FL 33881

Additional index words. Quarantine treatment, postharvest quality.

Abstract. **Black sapote (*Diospyros digyna* Jacq.) were irradiated at 0.15 or 0.3 kGy and held at 25°C until ripe. Nonirradiated fruit were placed in storage at 1, 5, 10, 15, 20, or 25°C for up to 7, 10, or 15d and fruit that remained unripe were then held at 25°C until ripe. Nonirradiated fruit held at 15, 20, or 25°C for 7, 10, or 15 d ripened normally when transferred to 25°C. Fruit stored at 10°C for 7 d then transferred to 25°C ripened normally, but some fruit held at 10°C for 10 or 15 d had abnormal ripening. Most fruit stored at 1 or 5°C did not ripen normally or failed to ripen regardless of storage duration. Fruit exposed to 0.15 kGy ripened normally, but some fruit treated at 0.3 kGy had random areas of pulp that failed to fully soften and ripen. Ripening of irradiated fruit was delayed about 4 d compared with controls. Based on this preliminary study, ripening may be satisfactorily delayed by storage at 15 or 20°C prior to ripening at 25°C. Additionally, black sapote will tolerate irradiation at 0.15 kGy, but abnormal ripening will likely occur with some fruit treated at 0.3 kGy.**

Black sapote (*Diospyros digyna* Jacq.:syn. *D. obtusifolia* Humb. & Bonpl. ex Willd.) is native to Mexico (Campbell et al., 1988; Popenoe, 1924; Ruehle, 1953; Sturrock, 1959), however, this minor tropical fruit is also grown in Dade County, Fla., mostly as a backyard crop. Most sales of black sapote are through roadside stands with minor quantities marketed through commercial wholesalers. In the future, fruit most likely will be shipped to markets that require extended storage or that have quarantine restrictions for pests such as the Caribbean fruit fly (CFF) (*Anastrepha suspensa* Loew.). Black sapote is considered a minor commercial crop in Dade County and production is expected to slowly increase (personal communications, R. Knight). This fruit is climacteric and is usually harvested at full maturity (fully shapened, green/slight yellowish peel) and is very soft when ripened (edible stage) at ambient conditions. Mature fruit will usually ripen within 10 d (Morton, 1987) after harvest. Black sapote will ripen very rapidly at maturity and within 1 to 2 d of reaching full ripe and will disintegrate rapidly. Delaying the ripening of mature fruit may be useful to growers in their attempt to gain some control over the duration and timing of the ripening process so that more orderly marketing can occur. However, no information is available on postharvest storage temperature/duration and subsequent ripening information for the emerging black sapote industry.

Delaying postharvest ripening of certain climacteric fruits is achievable by methods such as storage at temperatures lower than optimum for ripening (Hardenburg, et al., 1986), prestorage heat treatments (Paull, 1990), or irradiation (Akamine and Moy, 1983; Moy, 1977). Low-dose irradiation also has potential for quarantine treatment purposes (Nation and Burditt, 1994). Fresh fruits and vegetables can be treated with irradiation at doses to 1.0 kGy (Anonymous, 1986) and recommended doses for sterility of fruit flies is about 0.3 kGy (Burditt, 1994). Therefore, the purpose of this investigation was to determine the postharvest physiological response of black sapote to low-dose irradiation, storage and ripening, and to determine ripening response of fruit after storage, at various temperatures.

Materials and Methods

Source of fruit. Black sapote were harvested from a planting of seedlings that are part of the USDA national germplasm repository at the USDA Subtropical Horticultural Research Laboratory, Miami, Fla. Harvests were on two different dates for the two separate experiments of tolerance to irradiation, and storage potential prior to ripening. At harvest, fruit were determined mature as indicated by size, color and being well shapened.

Fruit preparation. For the irradiation experiment fruit were harvested on 24 February, wiped clean of surface residue and irradiated at doses of 0.15 or 0.3 kGy applied at the rate of 0.0933 kGy·min^{-1} with a Gammacell (Co^{60}) irradiator located at the U.S. Subtropical Horticultural Research Station. Control (nonirradiated) and irradiated fruit were carefully packed 23 fruit each into six 4/5 bu. commercial fiberboard citrus boxes. The boxes of fruit were shipped overnight, arriving the next morning at the USDA U.S. Horticultural Research Laboratory (USHRL) in Orlando. On arrival, fruit were immediately unpacked and immature and bruised fruit were removed. The sound fruit were randomized into three 10 fruit samples for each of the three dosages (0, 0.15, 0.3 kGy). Fruit were inspected initially before storage at 25°C (RH 90% ± 5%) and on reaching the soft ripe stage.

To determine storage potential, fruit were harvested on 6 March, boxed and shipped to the Orlando USHRL as stated above. On arrival, fruit (all nonirradiated) were unpacked and immature, ripe, or bruised fruit were culled and remaining fruit were randomized into 18, 5-fruit samples. Three, 5-fruit samples were placed in each of six storage temperatures,

Mention of a trademark, warranty, proprietary product, or vendor does not constitute a guarantee by the U.S. Department of Agriculture and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

1, 5, 10, 15, 20, or 25°C. Fruit placed at 25°C were control fruit since 25°C is considered the best temperature for ripening. One 5-fruit sample was removed from each storage temperature at the end of 7, 10, and 15 d. After 15 d any unripe fruit were placed at 25°C to ripen. Fruit were inspected initially before storage, at the end of 7, 10, or 15 d storage, and on reaching soft ripe.

Quality and condition evaluations. Before storage, fruit weights were measured using a Mettler balance. Fruit firmness was initially determined objectively on a 5-fruit sample with an Instron Food Firmness Texture Machine (model 1142, Canton, Mass.). The Instron was calibrated to record the force (N) for an 11 mm diam. round faced cylinder to penetrate 3 mm into the fruit cheek at 25 cm·min^{-1} travel speed. Since black sapote are extremely soft when ripe only subjective firmness ratings were used to determine fruit firmness at the soft ripe stage (terminal inspection). Subjective firmness ratings were; 1 = firm (no yield to moderately applied finger pressure (MAFP)), 2 = fairly firm, (slight yield to MAFP), 3 = fairly soft, (moderate yield to MAFP), 4 = soft (ripe stage, little resistance to MAFP), and 5 = very soft (over ripe, 'slip skin' with watery mushy pulp). Peel color was subjectively rated; 1 = 100% green (mature), 2 = mostly green/slight yellow, 3 = moderately yellow/green, 4 = olive green/brown (ripe), and 5 = mostly brown 'slip skin' (over ripe). Calyx color was rated 1 = green, 2 = green/yellow, 3 = green/brown, 4 = yellow/brown, and 5 = brown/black. Pitting was rated 1 = no disorder, 2 = <10%, 3 = 10% to <25%, 4 = 25% to 50%, and 5 = >50% of surface area affected. When ripe, pulp color was rated 1 = dark brown, 2 = light brown, or 3 = mixed color (dark/light brown). Pulp consistency at the soft ripe stage was rated 1 = mostly very moist and viscous, 2 = viscous with some dry fibrous tissue, and 3 = mostly fibrous and dry. Initially, surface scarring and blossom end cracking were noted and percentage of fruit affected was calculated.

Percentage of decayed fruit (not specifically identified) or fruit with superficial mold growth on lesions or scarred tissue was also calculated. Informal flavor and mastication texture sensory evaluations were made as each fruit reached the soft ripe stage, and ratings were indicated as acceptable or unacceptable.

Fruits from the irradiation experiment were analyzed for soluble solids concentration (SSC) by refractometer (Jones and Scott, 1984), titratable acidity (TA) with NaOH (Jones and Scott, 1984), and individual sugars by HPLC (Baldwin et al., 1991). Fruit homogenate (40g) was extracted in 70 mL of 80% ethanol. The filtered extract was injected onto a 20 μL sample loop and on a Perkin Elmer 410 HPLC system equipped with a Waters sugar pak column at 90°C with a mobile phase of 100 μm ethylenediaminetetraacetic acid disodium-calcium salt (CaEDTA) and a flow rate of 0.5 mL·min^{-1}. A Waters 410 Differential Refractometer was used to measure sugars and filtered analytical grade reagents were used for standard preparation to establish HPLC retention times and calibration.

Experimental design. The irradiation experiment was a completely randomized design consisting of three replicated 15-fruit samples for each of three treatments. Mean separations among treatment combinations for each attribute were conducted using ANOVA procedures or General Linear Model procedures for the chemical assays (SAS, Cary, N.C.) at $P \leq 0.05$. For the storage experiment, the design was completely randomized with a single 5-fruit sample for each storage temperature/time combination, hence replications were on fruit for mean separations. Treatment means were analyzed for separations among storage temperatures at each storage duration (i.e., 7, 10, or 15 d) separately.

Results

Fruit ripening was delayed by approximately 4 d by exposure to irradiation (Table 1). The number of days to ripen was variable and ranged from 2 to 8 for nonirradiated fruit and from 3 to 14 for irradiated fruit (data not shown). There was no difference in peel color among treatments, however calyx tissue was more necrotic (darker) in irradiated fruit compared with control fruit. Pulp tissue among treatments were similar in color and consistency when fruit reached the full ripe stage. The observations indicated a tendency for pulp of fruit irradiated at 0.3 kGy to be slightly more fibrous compared with fruit irradiated at 0.15 kGy or nonirradiated control.

There was a nonlinear change in SSC and TA by irradiation dose (Table 2), resulting in a relatively high mean SSC/TA ratio, 189, due to a very low percentage of TA. There was no difference in the means for fruit pH by treatment dose. Sucrose decreased with increasing irradiation dose, but no change was observed with glucose and fructose. Flavor and mastication texture were acceptable on all fruit that ripened normally at the soft-ripe stage (data not shown).

There was considerable variation in the mean number of days for fruit to ripen following 7 d storage at various temperatures, ranging from 3 to 7 d for fruit held at 15 and 5°C, respectively, compared with only 3 d into the 7 d storage time for control fruit. There were no statistical differences for number of days to ripen among storage temperatures (Table 3). Fruit held at 10, 15, or 20°C and control fruit held at 25°C ripened normally and had the characteristic brown/olive peel at the soft-ripe (eating) stage. Fruit held at 1 or 5°C ripened abnormally, the pulp contained areas of tissue that were very dry and fibrous without the 'chocolate pudding' consistency associated with the soft-ripe stage. Fruit held at 1°C developed large random shapened black lesions on the peel, and this disorder is likely an external symptom of chilling injury.

Fruit held 10 d at various temperatures and then at 25°C ripened on average in 2 d. Days for fruit to ripen after place-

Table 1. Condition of black sapote after irradiation at 0, 0.15 or 0.3 kGy and storage at 25°C until ripe.

Treatment (kGy)	Ripeness[z] (d)	Peel color[y]	Calyx color[x]	Pulp color[w]	Pulp cons[v]
0.0	3.5	3.9	3.8	1.0	1.0
0.15	6.1	4.6	4.4	1.4	1.2
0.3	6.4	4.4	4.8	1.7	1.5
Means	5.3	4.3	4.3	1.6	1.4
Significance	*	ns[u]	*	ns	ns

[z]Days to eating-ripe stage.
[y]Peel color index. 1 = green, 2 = mostly green/slight yellow, 3 = moderately green/brown, 4 = brown/olive green, and 5 = dark olive green ("slip skin").
[x]Calyx color index. 1 = green, 2 = green/yellow, 3 = green/brown, 4 = yellow/black, and 5 = brown/black.
[w]Pulp color index. 1 = dark brown, 2 = light brown, and 3 = dark/light brown.
[v]Pulp (con)sistency index. 1 = mostly moist (pudding like), 2 = moist/dry (fibrous), and 3 = mostly dry (abnormal).
[u]ns, * = nonsignificant or significant, respectively, at $P \leq 0.05$.

Table 2. Percentage of soluble solids (SSC), titratable acidity (TA), pH, sucrose, glucose, and fructose of black sapote exposed to 0.0, 0.15 or 0.3 kGy of irradiation and stored at 25°C until soft ripe.

Dose (kGy)	SCC	TA[z]	pH	Sucrose	Glucose	Fructose
0.00	17.1	0.09	5.94	1.98	2.25	2.94
0.15	12.1	0.07	5.97	1.85	1.95	2.57
0.30	16.1	0.09	5.83	1.07	2.03	2.57
mean	15.1	0.08	5.91	1.62	2.08	2.69
Significance						
Linear	ns[x]	ns	ns	*	ns	ns
Quadratic	*	*	ns	ns	ns	ns

[z]Expressed as anhydrous citric acid.
[y]Means of eight individual fruit assays for each treatment.
[x]ns, * = nonsignificant or significant, respectively, at $P \leq 0.05$.

ment at 25°C was variable and ranged from 2 d before the end of the 10 d storage to 8 d following for fruit held at 15 and 20°C respectively, compared with control fruit which ripen in 2 d after storage at 25°C. Fruit held at 15, 20, or 25°C ripened normally whereas fruit held in storage at 10, 5, or 1°C had increased areas of unripened tissue as storage temperatures decreased. Fruit held at 1 or 5°C did not develop the characteristic brown/olive green peel color when they ripened and had brown or black calyxes indicating increased senescence. The pulp color of fruit held at 1 or 5°C did not develop the characteristic dark chocolate color, and the pulp had a more dry/fibrous consistency and was firmer at the soft ripe stage when held at 1 or 5°C compared with fruit stored at higher temperatures. Again, the peel of fruit held at 1°C developed black lesions on the peel.

Fruit stored for 15 d at various temperatures were ripe on average in about 1 d after placement at 25°C. Days to ripen ranged from 6 d before the end of 15 d storage to 5 d after for fruit held at 20 or 5°C, respectively, compared with 7 d after placement at 25°C for control fruit. Fruit held at 15, 20, or 25°C ripened normally, and they developed normal peel color, and had comparable pulp consistency at the soft-ripe stage. Fruit held at 10°C or less had extremely senescent calyx tissue compared with other fruit held at higher temperatures. At the soft-ripe stage, fruit held at 1 or 5°C did not have the very soft pulp that is characteristic of full ripeness, and those fruit held at 1°C developed black lesions on the peel surface.

Discussion

Irradiation delayed ripening and caused no abnormal changes in pulp color, consistency, or peel color. The delay in ripening could benefit marketing due to the short time re-

Table 3. Quality attributes of black sapote after storage for 7, 10, and 15 d, at 1, 5, 10 15, 20, or 25°C (control fruit) plus ripening at 25°C.

Storage temperature	Ripe[z] (d)	Ripe index[y]	Peel color[x]	Calyx color[w]	Pulp color[v]	Pulp cons[u]	Firm index[t]	Injury (CI)[s]
				7 d storage plus ripening at 25°C				
1	13	2.0	3.8	5.0	2.2	1.6	3.5	2.0
5	14	1.6	3.8	4.6	2.6	1.6	4.0	1.0
10	11	1.0	4.1	4.0	2.6	1.2	4.1	1.0
15	10	1.0	4.1	3.4	2.2	1.6	4.1	1.0
20	11	1.0	4.1	4.2	1.6	1.0	4.1	1.0
25 (control)	3	1.0	4.0	3.8	1.0	1.0	4.0	1.0
Mean	10	1.3	4.0	4.2	2.0	1.3	4.0	1.2
signif.	ns[r]	*	ns	ns	*	ns	*	*
				10 d storage plus ripening at 25°C				
1	16	2.0	3.1	5.0	2.8	2.4	3.3	2.0
5	14	1.8	3.0	5.0	3.0	1.8	3.0	1.0
10	14	1.2	3.9	4.8	2.0	1.4	3.9	1.0
15	8	1.0	4.1	3.4	1.4	1.4	4.2	1.0
20	18	1.0	4.2	4.6	1.6	1.4	4.2	1.0
25 (control)	2	1.0	4.0	3.6	1.8	1.2	4.1	1.0
Mean	12	1.3	3.7	4.4	2.1	1.6	3.8	1.2
signif.	*	*	*	*	*	*	*	*
				15 d storage plus ripening at 25°C				
1	19	3.0	3.0	5.0	2.0	2.0	3.0	2.0
5	20	1.8	3.4	5.0	1.6	1.8	3.5	1.0
10	19	1.2	4.0	5.0	1.6	1.2	4.0	1.0
15	15	1.0	4.0	3.8	1.6	1.6	4.0	1.0
20	6	1.0	4.0	3.8	1.8	1.4	4.0	1.0
25 (control)	7	1.0	4.1	3.2	1.4	1.6	4.1	1.0
Mean	14	1.5	3.8	4.3	1.7	1.6	3.8	1.2
signif.	*	*	*	*	ns	ns	*	*

[z]Days to ripen. Includes storage time at temperatures indicated.
[y]Ripe index value. 1 = normal, 2 = uneven, and 3 = will not ripen.
[x]Peel color index. 1 = green, 2 = mostly green/slight yellow, 3 = moderately green/brown, 4 = brown/olive green, and 5 = dark olive green ('slip skin').
[w]Calyx color index. 1 = green, 2 = green/yellow, 3 = green/brown, 4 = yellow/black, and 5 = brown/black.
[v]Pulp color index. 1 = dark brown, 2 = light brown, and 3 = dark/light brown.
[u]Pulp (cons)istency. 1 = mostly moist (pudding like), 2 = moist/dry (fibrous), and 3 = mostly dry (abnormal).
[t]Firmness index. 1 = firm/hard, 2 = fairly firm, 3 = fairly soft, 4 = very soft (ripe), and 5 = mushy.
[s]Peel chilling injury (CI). 1 = no injury, 2 = injury.
[r]ns, * = nonsignificant or significant, respectively, at $P \leq 0.05$.

quired for mature fruit to ripen under ambient temperatures. However, the increased variability of ripening among irradiated fruit will not generally benefit marketing. Moy (1977) found that irradiation delayed ripening of papaya for 3 to 4 d, and that ripening of fruit at ambient temperature was normal compared with controls. The nonlinear change in SSC and TA as dose increased from 0, 0.15, to 0.3 kGy is largely unexplained, however due to the relatively small sample of fruit assayed, the likely presence of some immature fruit included in samples assayed could have unduly influenced results. Working with papaya, mango and litchis, Beyers and Thomas (1979) found no significant differences in compositional changes in total sugar of irradiated (from 0.75 to 3.0 kGy) fruit compared with nonirradiated controls. Mango and papaya (Salunkhe and Desai, 1984) are similar to black sapote in that they have relatively high total sugars and low acidity. We conclude that low-dose irradiation is not detrimental to the ripening of mature black sapote when ripened at about 25°C following irradiation treatment.

Black lesions on peel tissue that developed during storage at 1°C have not been previously described. These lesions are likely external symptoms of chilling injury. Lesions of lesser severity did not develop at 5°C or higher. Fruit held at 10 or 15°C after harvest and then ripened had some areas of slightly dry/fibrous pulp at the soft-ripe stage, otherwise these fruit had similar attributes as fruit held at 20 or 25°C. Slight dry/fibrous areas of pulp were observed in most fruit held at 15°C or less although no difference in the pulp consistency index value by storage temperature was indicated statistically. We conclude that mature black sapote fruit may be stored for 7 d at temperatures of 15 or 20°C, and then ripened at 25°C. After removal of fruit from storage they will ripen within 3 to 4 d, whereas fruit placed at 25°C after harvest ripened in 3 d. This investigation indicates that 15°C is likely near the threshold temperature in which increased sensitivity to low temperature will cause uneven ripening of pulp tissue.

This investigation indicates new findings on the understanding of the physiological and physical response of black sapote to exposure to irradiation and to various storage temperatures of varying duration. Additionally, this study provides information to growers and shippers on 1) the potential of using irradiation as a quarantine method when required, and 2) the feasibility of storing fruit as low as 15°C prior to ripening. Further, this information will assist users in improving the maintenance of postharvest quality of black sapote as increased production moves through the distribution and marketing processes. The authors recognize that future postharvest investigations with black sapote are warranted to 1) better characterize physical features and physiological characteristics to more precisely identify green-mature fruit at harvest, 2) improve the uniform ripening among fruit from the same harvest lot, and 3) determine if irradiation increases (or changes) the chilling sensitivity of fruit pulp or peel tissue to either storage or ripening temperatures compared with nonirradiated control fruit.

Literature Cited

Akamine, E. K. and J. H. Moy. 1983. Delay in postharvest ripening and senescence of fruit. p. 129-158. In: E. S. Josephson, and M. S. Peterson (eds.). Preservation of food by ionizing radiation. CRC Press, Inc. Boca Raton, Fla.

Anonymous. 1986. U.S. Food and Drug Administration. Irradiation in the production, processing, and handling of foods. Final rules: Fed. Register 51:13375-13399.

Baldwin, E. A., M. O. Nisperos-Carriedo and M. G. Moshonas. 1991. Quantitative analysis of flavor and other volatiles and for certain constituents of two tomato cultivars during ripening. J. Amer. Soc. Hort. Sci. 116:265-269.

Beyers, M. and Thomas, A. C. 1979. Gamma irradiation of subtropical fruits. 4. Changes in certain nutrients present in mangoes, papayas, and litchis during canning, freezing, and gamma irradiation. J. Agric. Food Chem. 27:48.

Blakesley, C. N., J. G. Loots, L. M. duPlessis and G. deBruyn. 1979. Gamma irradiation of subtropical fruits. 2. Volatile components, lipids, and amino acids of mango, papaya, and strawberry pulp. J. Agric. Food Chem. 27:42.

Burditt, Jr., A. D. 1994. Irradiation. pp. 101-117, In: J. L. Sharp and G. J. Hailman (eds.), Quarantine Treatments for Pests of Food Plants. Westview Press, Inc., Boulder, Colo.

Campbell, C. W., J. Popenoe and S. E. Malo. 1988. 'Merida', An early-maturing black sapote cultivar. Proc. Fla. State Hort. Soc. 101:245-246.

Hardenburg, R. E., A. E. Watada and C. Y. Wang. 1986. The commercial storage of fruits, vegetables, and florist and nursery stocks. U.S. Department of Agric., Agric. Res. Ser., Agric. Handb. No 66 (revised).

Jones, R. A. and S. J. Scott. 1984. Genetic potential to improve tomato flavor in commercial F_1 hybrids. J. Amer. Soc. Hort. Sci. 109:318-321.

Morton, J. F. 1987. Fruits of warm climates, p. 416-418. In: C. F. Dowling, Jr. (ed.). Fruits of warm climates. Creative Resource Sys., Inc. Winterville, NC.

Moy, J. H. 1977. Potential of gamma irradiation of fruits. A review. J. Food Technol. 12:449-457.

Nation, J. L. and A. K. Burditt, Jr. 1994. Irradiation, p. 85-102. In: R. E. Paull and J. W. Armstrong (eds.). Insect pests and fresh horticultural products: treatments and responses. CAB International, Wallingford, U.K.

Paull, R. E. 1990. Postharvest heat treatments and fruit ripening. Postharvest News and Info. 1:355-363.

Popenoe, W. 1924. Manual of Tropical and Subtropical Fruits. Macmillan, New York.

Ruehle, G. D. 1953. Miscellaneous tropical and sub-tropical Florida fruit. Fla. Agric. Ext. Ser. Bull. 156A:48-49. Revised.

Salunkhe, D. K. and B. B. Desai. 1984. Papaya. p. 13-26. In: D. I. Salunkhe and B. B. Desai (eds.). Postharvest biotechnology of fruits. CRC Press, Inc., Boca Raton, Fla.

Sturrock, D. 1959. Fruits of Southern Florida. Southeastern Printing, Inc., Stuart, Fla.