Ripening Behavior of Papaya Genotypes

Li-Xin Zhang¹ and Robert E. Pau^{1,2}

Department of Plant Molecular Physiology-HITAHR, University of Hawaii at Manoa, 3190 Maile Way, Honolulu, HI 96822

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Abstract. Four papaya (*Carica papaya* L.) lines that may have commercial value were surveyed for variability in ripening characteristics. Skin and flesh yellowing, fruit softening, respiration rate, and ethylene production were compared. Skin yellowing and flesh softening followed a similar sigmoid pattern for all lines. However, the temporal relationship between skin yellowing and flesh softening differed among the lines. Fruit from lines RL-1-3 and RL-1-12 did not begin to soften until the skin was 80% yellow, compared to 40% yellow for the commercial cultivars Kapoho and Sunrise. Fruit from RL-1-3 and RL-1-12 took 12 and 16 days, respectively, to reach 100% yellow from color break, which was two to three times as long as that of 'Kapoho' and 'Sunrise' at 22°C. All lines showed typical climacteric respiration and ethylene patterns. The time between the start of skin yellowing and the rise in respiration varied from ≈2 days in 'Kapoho' and 'Sunrise' to ≈4 days in line RL-1-3 and 8 days in line RL-1-12. The respiratory peak was greatly reduced in RL-1-12. The patterns of softening in lines RL-1-3 and RL-1-12 differed from 'Kapoho' and 'Sunrise': RL-1-3 softened slowly, but reached similar firmness values to other lines 4 days after 100% yellow skin color; RL-1-12 had a much slower rate of softening and the fruit were still firm 4 days after the fruit reached 100% yellow. The ripening patterns of line RL-1-3 and RL-1-12 could be useful in postharvest handling and provide material for studying the genetic control of fruit softening.

Papaya is a major economic crop in Hawaii. There is variation in the rates of fruit ripening, skin degreening, and softening in various commercial cultivars. Papaya trees having fruit with slower or altered ripening patterns have been detected by plant breeders but apparently never used in a breeding program (Higgins, 1916). Therefore, the objectives of this research were to characterize the ripening behavior of two lines reported to have differing ripening characteristics and to compare these with the two major current commercial cultivars.

Fruit from the commercial cultivars Kapoho and Sunrise and two slower-ripening lines of papayas, RL-1-3, RL-1-12, were picked from 17 to 21 trees of each grown at the Poamoho Experimental Station in central Oahu, Hawaii. Line RL-1 shows considerable tree-to-tree variation and the behavior of fruit from trees 3 and 12, i.e., RL-1-3 and RL-1-12, had shown apparently atypical ripening in an earlier brief report (Zhang and Pau, 1989). Mature fruit, at least 15 from

each line, with the first sign of color break were used. Fruits were returned to the laboratory within 4 hr. All fruit were treated for 20 min with hot water at 49°C, cooled for 30 min in tap water, and dipped in 1% (w/v) thiabendazole (TBZ) for 1 min to control decay (Couey and Farias, 1979).

Fruit were allowed to ripen at room temperature, 22 ± 1°C, and evaluated daily until they were overripe and soft. External visual color (percent yellow) was subjectively estimated. Firmness (N) was determined as deformation force necessary to depress a 1.5-cm disk 1 mm into the fruit (Pau et al., 1988). Individual fruits were placed into sealed (2400 ml) jars for 1 hr at 22 ± 1°C and 1-ml and 5- or 10-ml gas samples were taken from the jar for ethylene and CO₂ determination, respectively. Ethylene was determined on a gas chromatography (Varian Aerograph Model 1440; Varian, Palo Alto, Calif.) fitted with an alumina column (2 m × 3 mm) and photoionization detector (HNU PI-52, HNU Systems, Newton, Mass.). Carbon dioxide was determined by using an infrared gas analyzer (IR503; Infrared

Industries, Santa Barbara, Calif.). The data for single fruit were used in the figures of respiration rate and ethylene production to illustrate typical patterns selected from fruits.

Full skin degreening and flesh color development took 7 to 12 days for 'Sunrise' and 'Kapoho' from color break stage (Fig. 1A, Table 1). Changes in internal flesh color paralleled skin degreening (Table 1) in the commercial lines; changes in RL-1-3 and RL-1-12 were slightly delayed. Skin (Fig. 1A, Table 1) and flesh color changes occurred in 'Kapoho' and 'Sunrise' at the same time as the rise in respiration rate (Fig. 1C) and C₂H₄ production (Fig. 1D). A noticeable rise in respiration and C₂H₄ occurred when the commercial fruit were 20% to 30% yellow, with a peak when the fruit were ≈85% yellow. Fruit from lines RL-1-3 and RL-1-12 did not have an increased respiration rate or ethylene production until the skin was at least 80% yellow (Fig. 1A).

The rate of fruit softening of 'Kapoho' and 'Sunrise' accelerated when the fruit were ≈40% yellow (Fig. 1B) and their rates of softening were similar. Commercial observations have shown that 'Sunrise' softens faster than 'Kapoho'. 'Kapoho' is grown principally on the island of Hawaii, with 'Sunrise' being grown on Kauai. The more-rapid rate of softening found for 'Kapoho' in these experiments, compared to commercial experience, may be due to the environmental conditions experienced in this Oahu planting. The RL-1-3 and RL-1-12 fruit did not begin to soften significantly until the skin was 80% yellow. The softening of RL-1 genotypes differed, with RL-1-3 softening more rapidly than RL-1-12. Fruit of RL-1-3 and RL-1-12 had deformation forces of >107 N at the 100% yellow stage. Four days after the 100% yellow stage, fruit of RL-1-12 had a deformation force of ≈78 N, while RL-1-3 had a deformation force of ≈40 N, similar to the commercial lines at the 100% yellow stage.

The time courses of the changes in the climacteric patterns of respiration rate and ethylene production varied with the lines (Fig. 1 C and D). The respiration and ethylene production began to increase on the 2nd or 3rd day after color break in the commercial lines. The respiration and ethylene peaks occurred very late (on 11th day) in RL-1-3 and RL-1-12, with respiration peak being lower than those of the commercial cultivars, however, ethylene peak height in RL-1-3 and RL-1-12 was similar to 'Sunrise' and 'Ka-

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¹Graduate Student.

²Plant Physiologist.

Table 1. Ripening characteristics of two papaya cultivars and two lines during storage at 22°C.^a

Cultivar or line	Days to 100% yellow from color break	Internal color at 100% yellow skin (%)	Force	
			At 100% yellow skin (N)	4 days after 100% yellow skin (N)
Sunrise	7 c	100 a	54.9 c	33.3 b
Kapoho	8 c	100 a	58.8 c	35.2 b
RL-1-3	12 b	90 c	144 a	40.1 b
RL-1-12	16 a	95 bc	107 b	78.3 a

^aMean separation within columns for each cultivar by Duncan-Waller multiple range test, *P* = 0.05, *n* = 6.

Fig. 1. Changes during ripening at 22°C in (A) skin color, (B) penetration force, (C) respiration rate, and (D) ethylene production of papaya cultivars, Sunrise (x), and Kapoho (○) and lines RL-1-3 (□) and RL-1-12 (△). Typical patterns for individual fruits are shown for respiration rate and ethylene production. Skin color and penetration force points are means of at least 3 fruits $\pm$ SD.

poho'. These results for commercial cultivars are consistent with earlier studies on 'Kapoho' (Akamine and Goo, 1976, 1979), 'Sunrise' (Paull and Chen, 1983), and 'Taiping' and 'Bentong' (Nazeeb and Broughton, 1978). The reduced respiration peaks and apparently normal ethylene production of RL-1-3 and RL-1-12 contrast with the lack of capacity to produce ethylene shown by the slow-ripening genotypes of nectarines (Brecht et al., 1984; Brecht and Kader, 1984). Ethylene and propylene stimulated ripening when applied to these slow-ripening nectarine genotypes (Brecht and Kader, 1984). A limited supply of fruit has prevented us from testing whether ripening in RL-1-3 and RL-1-12 papaya genotypes is enhanced by ethylene.

The temporal displacement of softening, respiration climacteric, and ethylene production with respect to skin degreening and flesh

color development appears to be unique when compared with tomatoes (Grumet et al., 1981; Tigchelaar et al., 1978) and nectarines (Brecht and Kader, 1984; Brecht et al., 1984). The displacement in sequence, coupled to the small respiration rise and normal ethylene production in the RL-1-3 and RL-1-12 lines, provides a possible useful system to study the control of fruit ripening.

Color development in the commercial cultivars paralleled changes in respiration and ethylene production, while in RL-1-3 and RL-1-12 the color developed much earlier than the rise in ethylene production. This difference suggests that endogenous ethylene may not be the initiator of yellowing in RL-1-3 and RL-1-12, or that ethylene sensitivity had increased and was saturated by the low basal levels of ethylene produced by the fruit.

Papaya are harvested after the first sign of yellow, with mature-green papaya not rip-

ening satisfactorily (Akamine and Goo, 1976). Because papaya fruit have no starch reserves for production of soluble sugars after harvest (Chan et al., 1979), a fruit remaining on the tree accumulates more sugar and develops a higher quality. Fruit with >50% yellow skin are difficult to handle commercially because of their susceptibility to mechanical injury. A slower softening rate would allow greater flexibility in harvesting and handling papaya fruit. The fruit from RL-1-3 and RL-1-12 would have more yellow skin and be firmer, and therefore could be harvested at a later stage when more sugar has accumulated. The mode of action of the slow ripening in RL-1 papaya is not known, but RL-1 may be useful material for developing commercial lines with longer shelf life and for research on the genetic regulation of ripening of papaya.

Literature Cited

- Akamine, E.K. and T. Goo. 1976. Respiration, ethylene production, and shelf-life extension in irradiated papaya fruit after storage under simulated shipping conditions. *Hawaii Agr. Expt. Sta. Tech. Bul.* 93.
- Akamine, E.K. and T. Goo. 1979. Concentrations of carbon dioxide and ethylene in the cavity of attached papaya fruit. *HortScience* 14:138-139.
- Brecht, J.K. and A.A. Kader. 1984. Ethylene production by fruit of some slow-ripening nectarine genotypes. *J. Amer. Soc. Hort. Sci.* 109:763-767.
- Brecht, J.K., A.A. Kader, and D.W. Ramming. 1984. Description and postharvest physiology of some slow-ripening nectarine genotypes. *J. Amer. Soc. Hort. Sci.* 109:596-600.
- Chan, H.T., K.L. Hibbard, T. Goo, and E.K. Akamine. 1979. Sugar composition of papayas during fruit development. *HortScience* 14:140-141.
- Couey, H.M. and G. Farias. 1979. Control of postharvest decay of papaya. *HortScience* 14:719-721.
- Grumet, R., J.F. Fobes, and R.C. Herner. 1981. Ripening behavior of wild tomato species. *Plant Physiol.* 68:1428-1432.
- Higgins, J.E. 1916. Growing melons on trees. *J. Hered.* 7:208-220.
- Nazeeb, M. and W.J. Broughton. 1978. Storage conditions and ripening of papaya 'Bentong' and 'Taiping'. *Scientia Hort.* 9:265-277.
- Paull, R.E. and N.J. Chen. 1983. Postharvest variation in cell wall-degrading enzymes of papaya (*Carica papaya* L.) during fruit-ripening. *Plant Physiol.* 72:382-385.
- Paull, R.E., N.J. Chen, and T.T.C. Goo. 1989. Waxing and plastic wraps influence water loss from papaya fruit during storage and ripening. *J. Amer. Soc. Hort. Sci.* 114:937-942.
- Tigchelaar, E.C., W.B. McGlasson, and M.J. Franklin. 1978. Natural and ethephon-stimulated ripening of F₁ hybrids of the ripening inhibitor (rin) and non-ripening (nor) mutants of tomato (*Lycopersicon esculentum* Mill.). *Austral. J. Plant Physiol.* 5:449-456.
- Zhang, L.X. and R.E. Paull. 1990. Variation in the ripening characteristics of papaya. *Acta Hort.* (In press.)