Fruit Development and Ripening in Yellow Pitaya

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ABSTRACT. Changes occurring during fruit ripening and duration of fruit development were studied in *Selenicereus megalanthus* (Scum. ex Vaupel) Moran (yellow pitaya), a climbing cactus grown in protected structures at three sites in the Israeli Negev desert. During ripening, peel color turned from green to yellow, fruit dimensions slightly changed, and pulp content markedly increased. Total soluble solids and soluble sugars in the pulp increased, while starch content decreased. Acidity decreased at the last stage of ripening. Fruit in which most of the peel area had turned yellow (stage 4) were given the highest taste grade by a panel of tasters. Measurements of ethylene and CO₂ evolution indicated that fruit was nonclimacteric. The mean number of days from anthesis to fruit of stage 4 was negatively correlated with the mean of the maximum and the minimum temperatures during the growth period. Daily accumulation of heat units (HUs) was calculated as the difference between daily mean temperature and a base temperature of 7 °C. Sum of HUs for the period from anthesis to ripening was 1558 ± 12 HUs.

Yellow pitaya is a shade-tolerant climbing cactus of tropical origin, which has recently been developed as a fruit crop (Cacioppo, 1990; Mizrahi et al., 1997). The fruit is a medium-sized oblong berry, with a yellow thorny peel and a sweet white pulp containing numerous small soft seeds (Nerd and Mizrahi, 1997). The crop is grown extensively in Colombia (>4000 ha) and on a small scale in Israel. In Colombia, the orchards are cultivated successfully in the open, but in Israel the plants must be protected from high solar radiation as well as from subfreezing temperatures (Mizrahi et al., 1997; Weiss et al., 1994). In Colombia where the flowering period is long, the fruit is harvested practically all year round (Cacioppo, 1990), whereas in Israel, where flowering lasts only a few weeks at the end of the summer and in the autumn, the harvest period is restricted to winter and spring (Nerd and Mizrahi, 1997).

Very little experimentation has been carried out on fruit development in yellow pitaya. Weiss (1995) showed that fruit growth, expressed as an increase in length or diameter, has a curvilinear pattern and that when dimensional growth stops, peel color turns from green to yellow. Similarly, little is known about the timing of development of the different fruit tissues, the physicochemical changes during maturation, and the effect of environmental variables on fruit development. Weiss (1995) proposed that temperature may be the dominant factor in fruit development, since the length of time from anthesis to ripening depended on the season, e.g., 13 weeks were recorded for the autumn flowering and 22 weeks for the winter flowering.

In the present study, we determined a number of physicochemical and organoleptic parameters of fruit harvested during the time of color change with the objective to determine the criteria for ripening. Assuming that temperature is indeed a major factor in fruit development, we examined whether the accumulation of heat units (HUs) determines the developmental time from anthesis to ripening.

In the common method of calculating daily accumulation of HUs (growing degree days) each degree above a base temperature has a linear effect on plant development and on the accumulation of HUs (Abeles and Lightner, 1984; Arnold, 1959; Dufault, 1997; Ritchie and Nesmith, 1991; Smith, 1985). Daily accumulation of HUs is calculated by the following equation: $HU = [(T_{max} + T_{min})/2] - T_{base}$, where T_{max} = daily maximum temperature, T_{min} = daily minimum temperature, and T_{base} = base temperature.

The operative base temperature (or threshold temperature) can be assessed by summation of the HUs for several environments using different arbitrary base temperatures. The base temperature that gives the smallest coefficient of variation will be chosen as the operative base temperature (Arnold, 1959).

Materials and Methods

A commercial clone of yellow pitaya introduced from Colombia (clone A, Weiss et al., 1994) was studied in the fruiting season of 1996–97 in three orchards planted in 1992 at sites located in the Negev desert of Israel: Beer-Sheva, Besor and Qetura (northern, western, and southeast Negev, respectively). The climates of Besor and Beer-Sheva are colder than that of Qetura (Nerd et al., 1990). The orchard in Beer-Sheva was established in a ventilated greenhouse, whereas those at the other sites grew in shaded structures. Plants at all sites received ≈50% full sun light. Noon photosynthetic photon flux at the canopy level ranged between 1100 mmol·m⁻²·s⁻¹ (summer) and 500 mmol·m⁻²·s⁻¹ (winter). Cultural practices were similar at the three sites. The plants were spaced at 1.5-m intervals in rows 2.5 m apart and trained on 1.5-m high trellis systems for support. The plants were drip irrigated once a week with 5 L of water per plant in the summer and 2.5 L in the winter. The electrical conductivity of water was 1 dS·m⁻¹ at Beer-Sheva and Besor and 3.7 dS·m⁻¹ at Qetura. Fertilizer (23N–3P–20K) at a concentration of 70 mg·L⁻¹ was applied with the irrigation water at all irrigations. At each site, 15 randomly selected plants were sampled. The nocturnal flowers were tagged and hand-pollinated with the goal of obtaining high fruit set and large fruit (Weiss et al., 1994).

The changes occurring during ripening were studied in fruit that set in mid-September in Beer-Sheva. Length and midlength diameter of fruit attached to the plant were measured with a caliper weekly during the period of peel color change. The ripening stage of fruit harvested during color change was defined by the peel color (on a scale of 1 to 5): 1 = bright green, 2 = only the proximal side of the fruit (base) yellow, 3 = yellow area extending to the middle of the fruit, 4 = most of the fruit is yellow (tips of the tubercles remaining green), 5 = fully yellow.

At the beginning of January 1997, six fruit of each category were picked in the morning for the determination of fruit properties. Color values of the peel at the midlength of the fruit were determined with a Minolta Chroma Meter CR-200 (Ramsey, N.J.) calibrated against a white tile ($L = 65$, $a = 34$, $b = 43$) and values of the hue angle were calculated for these data (McGuire, 1992).

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Fig. 1. Relative dimensional changes during color change of the peel in attached yellow pitaya fruit ($n = 6$) of the early crop (developed from September flowers) in Beer-Sheva. Length and diameter at the beginning of color change were 10.8 ± 0.6 and 5.7 ± 0.3 cm, respectively.

Peel and pulp were separated, and a sample of each was oven dried at 70°C for determination of water content. Total soluble solids (TSS) were measured with a refractometer (PR-100, Atago, Japan) in sap pressed from the pulp.

Total soluble sugars and starch concentrations were determined in 50-mg samples of dry pulp. Soluble sugars were separated from the starch by extraction with 12 methanol : 5 chloroform : 3 water (by volume) (Haissig and Dickson, 1979) and measured by the phenol-sulfuric acid method (Dubois et al., 1956). Starch concentration was determined by measuring glucose concentration after enzymatic digestion (Haissig and Dickson, 1979). To determine acid concentration, 10 g of fresh pulp tissue was macerated in distilled water and titrated with 0.025 M NaOH to pH 7. The taste of fruit of various ripening stages was assessed simultaneously according to a hedonic scale (1 = least acceptable to 5 = most acceptable).

Ethylene and CO_2 evolution were measured in fruit harvested at ripening stages 2, 3, and 4, held at 20°C at a light regime of 12 h dark/12 h fluorescent light ($42 \text{ mmol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$). The fruit, four for each stage, were weighed and placed individually in closed 500-mL jars with a continuous flow of moistened air ($5 \text{ mL}\cdot\text{min}^{-1}$) through the jar. Ethylene and CO_2 concentrations in the effluent air stream were analyzed with a gas chromatograph (Varian 3300, Sugarland, Tex.) at noon once a day during 6 d from the time the fruit were placed in the jars.

The number of days from anthesis to ripening stage 4 were determined in the Beer-Sheva orchard for fruit of the entire flowering period (from mid-September 1996 to the end of November 1996). In the Besor and Qetura orchards, which were less accessible, only fruit that developed from the main flush of flowering (third week of November 1996) were recorded. Means of days to ripening stage 4 were calculated for fruit (15 to 20) ripened during a week period.

Cumulative HUs for fruit development from anthesis to ripening stage 4 was determined in ripe fruit weighing $>130 \text{ g}$ (commercially acceptable). Daily minimum and maximum temperatures were measured in Beer-Sheva by means of a thermograph placed at a height of 1 m in the middle of the greenhouse. For the other sites, data obtained from the local meteorological stations were used. Temperatures 4 to 9°C were used for the determination of the appropriate base temperature, i.e., that giving the lowest coefficient of variation (4°C was the lowest temperature recorded during fruit development).

Results and Discussion

FLOWERING PERIOD. The flowering period in Beer-Sheva and Besor extended from the end of September to the beginning of December, with a major flowering flush ($\approx 70\%$ of the flowers) in

November, while at Qetura it was confined to the second half of November. The number of flowers per plant ranged from 25 to 30 at Beer-Sheva and Besor and 3 to 7 at Qetura. The lower flower production at Qetura may be attributed to the heat stress imposed on the plants due to the high summer temperatures, which rose up to 47°C , or to the salt stress resulting from the saline irrigation water used at that site.

FRUIT RIPENING. The dimensions of tagged fruit on the plant showed small changes during ripening; the diameter increased 8.5% and the length decreased 2.5% from the beginning of color change ($\approx 80 \text{ d}$ from anthesis) to full color (Fig. 1). Characteristics of fruit harvested at various ripening stages are given in Fig. 2. The decreasing values of peel hue angle express the development of the yellow color during ripening (Fig. 2A). Pulp content (percent of fruit fresh mass) increased significantly from stage 1 (bright green) to stage 3 (yellow area extending to the middle of the fruit), with only a slight increase toward stage 4 (most of the fruit was yellow), reaching at this stage $\approx 48\%$ of fruit fresh mass (Fig. 2B). Water percentage in the pulp increased in parallel to the increase in pulp content, while peel water percentage decreased slightly (Fig. 2C). When water content was calculated as percentage of whole fruit fresh mass the values in pulp and peel were 11.7% and 76.4%, respectively, at stage 1 and 45.4% and 47.4%, respectively, at stage 4.

The concentration of TSS and soluble sugars measured in the pulp increased markedly from stage 1 to stage 3 and remained unchanged. The increase in soluble sugars being accompanied by

Fig. 2. Properties of yellow pitaya fruit sampled at different stages of ripening determined according to color grade. Peel color (A), peel and pulp content, fresh mass basis (B), percent water in peel and pulp, fresh mass basis (C), total soluble solids in pulp, fresh mass basis (D), soluble sugars and starch in pulp, fresh mass basis (E), acidity in pulp, H^+ , fresh mass basis (F). Color scale ranged from 1 = bright green to 5 = fully yellow. Values are means $\pm$ SE ($n = 6$).

Table 1. Days from anthesis to stage 4 fruit and growing period mean temperatures for orchards growing in Beer-Sheva, Besor and Qetura. Data are given for Beer Sheva for the entire flowering period and the other sites for the main flowering period.

Site	Flowering time		Days to ripening	Temp (°C)
	Month	Week		
Beer-Sheva	September	3	120 e ²	20.1
	October	4	152 cd	17.5
	November	1	156 bc	17.4
	November	2	157 bc	17.3
	November	3	157 bc	17.6
	November	4	150 cd	17.7
Besor	November	3	181 a	15.4
Qetura	November	3	162 b	16.9

²Means for 15 to 20 fruit. Mean separation within columns by Duncan's test at $P \leq 0.05$.

a decrease in starch concentration (Fig. 2 D and E). Although soluble sugars are the main component of the TSS, their concentration (fresh mass basis) was about half of that of the TSS. This can be explained by the high content of seeds in the dry pulp which was used for sugars extraction (TSS was measured in pulp sap). Titratable acidity, measured in the pulp, was unchanged between stages 2 and 4 then decreased at stage 5 (fully yellow) (Fig. 2F). Organoleptic tests showed that fruit at stage 4 were most acceptable followed by fruit of stage 5, while fruit at stages 1 and 2 were least acceptable. In this respect, yellow pitaya differs from the widely cultivated cactus pear *Opuntia ficus-indica* (L.) Miller, the fruit of which reach their maximum consumption quality at the beginning of peel color change (Barbera et al., 1992; Nerd and Mizrahi, 1997). Rates of ethylene and CO₂ production remained low and did not peak during ripening. In fruit harvested at the beginning as well as at advanced stage of color change, rates of ethylene and CO₂ production ranged from 0.01 to 0.03 mL·kg⁻¹·h⁻¹ and from 0.6 to 1.2 mL·kg⁻¹·h⁻¹, respectively. This finding indicates that fruit of yellow pitaya are not climacteric.

Yellow pitaya fruit can persist on the plant for several months after reaching full color, but the taste deteriorates with time. Visual assessment of the stage of ripening will aid in avoiding harvest of overripe fruit. Yellow pitaya fruit accumulate starch, which is degraded to soluble sugars during ripening. Since final size is reached at the beginning of ripening (stage 1) it seems that it may be possible to harvest fruit for marketing before the optimal taste stage (stage 4). However, studies of the effects of postharvest handling on fruit quality are required for ascertaining that ripening will proceed normally in fruit harvested at an early stage of ripening. Although hue angle is an objective measure of color, by which peel yellowing can be determined, we recommend that maturity be assessed visually (color score), because it is more convenient and takes into account the whole peel color, which changes gradually during ripening.

HEAT UNIT MODEL. The results of temperature analysis indicates that the number of days from anthesis to ripening in yellow pitaya depends strongly on temperature (Table 1). Fewer days to ripening were required in Beer-Sheva for fruit set in the third week of

September than for fruit set later when temperature decreased. Among the fruit set in the third week of November at the various sites, the longest time to ripening was in Besor. For Beer-Sheva, the average temperature was 20.1 °C in September and 17.5 °C in October and November, while Besor and Qetura had lower temperatures, 15.4 and 16.9 °C, respectively. The mean number of days to ripening was negatively correlated with mean temperature. Regression analysis gave $Y = 380 - 13X$, $r = -0.983$ ($P = 0.01$), where Y is days to ripening and X is mean temperature.

The coefficient of variation calculated for cumulative daily HUs was the lowest (2.13), when 7 °C was chosen as the base temperature, the coefficient increasing as higher or lower base temperatures were chosen (4.58 at 9 °C and 3.56 at 4 °C). An overall mean of 1558 ± 12 HUs was calculated when 7 °C was used as the base temperature. Although the operative base temperature was determined arbitrarily, it may represent a level below which fruit development may be slowed down or even inhibited. The heat unit model has the potential to predict the ripening time of yellow pitaya fruit.

Literature Cited

- Abeles, F.B. and G.W. Lightner. 1984. Optimal harvest data equation for West Virginia apples. *HortScience* 19:431-432.
- Arnold C.Y. 1959. The determination and significance of the base temperature in a linear heat unit system. *Proc. Amer. Soc. Hort. Sci.* 74:430-445.
- Barbera, G., F. Carimi, and M. Panno. 1992. Physical, morphological and chemical changes during fruit development and ripening in three cultivars of prickly pear *Opuntia ficus indica* (L.) Miller. *J. Hort. Sci.* 67:307-312.
- Cacioppo, O. 1990. Pitaya: Una de las mejores frutas producida por Colombia. *Informativo Agroecologico* (Febrero):15-19.
- Dubois, M., K.A. Gilles, J.K. Hamilton, P.A. Rebers, and F. Smith. 1956. Calorimetric method for determination of sugars and related substances. *Anal. Chem.* 28:350-356.
- Dufault, R.G. 1997. Determining heat unit requirements for broccoli harvest in coastal South Carolina. *J. Amer. Soc. Hort. Sci.* 122:169-174.
- Haissig, B.E. and R.E. Dickson. 1979. Starch measurement in plant tissue using enzymatic hydrolysis. *Physiol. Plant.* 47:151-157.
- McGuire, R.G. 1992. Reporting the objective color measurements. *HortScience* 27:1254-1255.
- Mizrahi, Y., A. Nerd, and P.S. Nobel. 1997. Cacti as crops. *Hort. Rev.* 18:292-320.
- Nerd, A. and Y. Mizrahi. 1997. Reproductive biology of cactus fruit crops. *Hort. Rev.* 18:322-346.
- Nerd, A., A. Aronson, and Y. Mizrahi. 1990. Introduction and domestication of and wild fruit and nut trees for desert areas, p. 353-365. In: J. Janick and J.E. Simon (eds.). *Advances in new crops*. Timber Press, Portland, Ore.
- Ritchie, J.T. and D.S. Nesmith. 1991. Temperature and crop development, p. 5-29. In: R.J. Hanks and J.T. Ritchie (eds.). *Modeling plant and soil systems*. Amer. Soc. Agron. Monogr. 31.
- Smith, R.B. 1985. Predicting the data of first commercial harvest of selected Ontario peach cultivars. *J. Amer. Soc. Hort. Sci.* 110:650-654.
- Weiss, J. 1995. The biology of flowering, pollination and fruit development in night-blooming and day-blooming cacti. PhD Thesis, Ben-Gurion Univ. of the Negev, Beer-Sheva, Israel.
- Weiss, J., A. Nerd, and Y. Mizrahi. 1994. Flowering behavior and pollination requirements in climbing cacti with fruit crop potential. *HortScience* 29:1487-1492.