Description and Postharvest Physiology of Some Slow-ripening Nectarine Genotypes

Jeffrey K. Brecht and Adel A. Kader
Department of Pomology, University of California, Davis, CA 95616

David W. Ramming
Agricultural Research Service, U.S. Department of Agriculture, P.O. Box 8143, Fresno, CA 93747

Additional index words. Prunus persica, respiration, ethylene production, color, firmness, composition, internal breakdown

Abstract. The postharvest behavior of several slow-ripening nectarine genotypes that originated from 'Fantasia' was investigated. These fruit were firmer and greener than 'Fantasia', had higher phenolic compounds and soluble solids contents, a higher pH, lower titratable acidity, and equal or greater levels of total and reducing sugars. Changes in flesh color and firmness during storage were much slower than in 'Fantasia', but the rate of softening varied among the genotypes. Although all of the genotypes tested seemed to be climacteric-type fruit, the preclimacteric period at 20°C could exceed 1 month, and C2H4 production was much lower than in 'Fantasia'. Application of C2H4 during the preclimacteric period stimulated respiration rates, with the maximum response occurring at 10 ppm. A 2nd application of C2H4 resulted in a 2nd increase in respiration, as with nonclimacteric fruit. Incidence of internal breakdown generally was worse compared to 'Fantasia' following 4 weeks of storage at 5°C, although the genotype P19-11 appeared to be somewhat resistant to chilling injury.

Ripening of normal nectarine fruit involves dramatic changes in color, firmness, and aroma. Rapid increases in the rates of CO2 and C2H4 production accompany these changes (2). Generally, harvested mature fruit are eating-ripe after 5 or 6 days at 20°C. Recently, we reported (3) that some nectarine selections developed at the USDA Horticultural Crops Research Laboratory in Fresno, Calif., do not show this characteristic pattern of ripening changes. Mature fruits remained firm and green and exhibited no rise in CO2 or C2H4 production rates during one month or more at 20°C. As has been shown with the ripening mutants of tomatoes (10), these nectarine genotypes may be useful experimental subjects for studying the relationships among the various ripening parameters, as well as the differences between climacteric and nonclimacteric fruits.

From a total of 12 lines evaluated in preliminary studies (3), 4 (P19-63, P19-70, P65-17, P66-18) were chosen for further work on the basis of their slow ripening behavior and 1 (P19-11) due to its moderate resistance to low temperature breakdown. We now report on their postharvest behavior in terms of the changes in CO2 and C2H4 production, composition, and their responses to C2H4 treatments.

Materials and Methods

Plant material. The nectarines used in this study were picked from trees grown at the USDA Research Laboratory or, in the case of 'Fantasia', obtained from a commercial packinghouse in Fresno, Calif., during the 1979 through 1983 seasons. All of the slow-ripening genotypes were harvested on the same day of each season. In all cases, the fruit were transported to Davis, sorted for defects, and dipped for 30 sec in an aqueous suspension of Benomyl (0.3 g/liter) and Botran (0.8 g/liter) for decay control. Three to 5 single-fruit replicates were used for most treatments, except for internal breakdown (IB) evaluations where 10 fruit per replicate were used. All experiments were carried out at 20°C, except those for IB susceptibility evaluations which were conducted at 5°C.

Gas mixing and analysis methods. Constant flow rates of air or air plus various C2H4 concentrations were established using a barometric tower and needle valve flowmeters. The gas was bubbled through water (to maintain 95% to 100% relative humidity) and the flow rate adjusted so that CO2 accumulation remained below 0.25%. Chambers containing C2H4-treated fruit were subjected to low pressure (125 mm Hg) for 2 min to remove residual C2H4 following treatment. Ethylene levels were determined by gas chromatography, while CO2 was measured by either a colorimetric method (5) or an infrared gas analyzer.

Measurement of color and firmness. Flesh color was measured with a Gardner Color Difference Meter using the 'Rd', 'a', and 'b' modes. The instrument was calibrated with a standard
white reference plate ($X = 81.7$, $Y = 84.1$, $Z = 97.9$). A portion of skin was removed from the 2 cheeks, and using the large aperture, one measurement was taken on each cheek. The increase in ‘a’ value reflects loss of green color, and this value showed the greatest variability during storage. Therefore, color changes are presented in terms of changes in the ‘a’ value. Following the color determinations, flesh firmness was measured on each of the peeled areas by means of a UC Firmness Tester (4) with a 0.79 cm diameter tip.

**Chemical analysis.** Fruit samples were homogenized in a blender and centrifuged 20 min at 13,000 × g to obtain a transparent juice which was used for analysis. Soluble solids content (SSC), pH, titratable acidity (TA) expressed as the percentage of malic acid, total sugars (6), reducing sugars (9), and total phenolic compounds (8) were measured.

**Internal breakdown.** Fruit were evaluated after 2 or 4 weeks of storage at 5°C plus 3 days at 20°C and scored for IB using the following scoring system: 0, red pit cavity, no browning; 1 brown strands in red pit cavity; 2, brown or black pit cavity (red beginning to turn pale); 3, slight discoloration of the flesh; 4, discoloration extending well into the flesh; 5, dark brown discoloration throughout most of the flesh.

**Results**

**Origin and description.** The selections used, all derived from ‘Fantasia’ (Fig. 1), are late-season fruit that reach physiological maturity about the 1st week of October in Fresno as judged by size and color, but they do not normally abscise unless damaged by birds or fungal growth. We have observed fruit on the trees as late as the latter part of December. ‘Fantasia’ fruit reach physiological maturity about the 3rd week of July in Fresno.

The fruit size of the genotypes is small to average: P66-18 and P19-63 average about 5.7 cm in diameter and weigh 110–115 g; P65-17, P19-70, and P19-11 are larger, averaging 7.0 cm and weighing 130–140 g, respectively, the same as ‘Fantasia’. The fruit also tend to be somewhat oblong, similar to ‘Fantasia’. The skin is greenish-yellow with little or no red blush, but the red blush increases after the leaves have abscised. The flesh is greenish-white, with a small amount of red at the pit cavity. The fruit are sweet and subacidic at harvest with a slight grassy flavor and a crisp texture. The color changes from greenish to pale yellow during storage, and the flesh becomes mealy (reminiscent of an overripe apple). The flavor becomes bland and the characteristic aroma does not develop. The fruit tend to develop flesh browning, which begins at the pit cavity and extends out to the surface of the fruit during storage at 20°C. This browning is very similar to that which is seen following chilling.

Expression of the late maturation and slow ripening characteristics of these genotypes seems to be controlled by a single recessive gene. When ‘Fantasia’ is self-fertilized, the fruit appears in 25% of the F1 generation; when these genotypes are selfed it is present in 100% of the offspring.

**Comparison of the slow-ripening genotypes with ‘Fantasia’.** At harvest, the fruit from the slow-ripening genotypes seemed to be less mature than the normal ‘Fantasia’ fruit in some respects, and more mature in others (Table 1). The genotypes were about 60% firmer and their flesh was greener than that of ‘Fantasia’. They were higher in pH and lower in TA, and had a higher SSC than ‘Fantasia’. There was little difference in total reducing sugars contents between ‘Fantasia’ and the slow-ripening genotypes. Only P65-17 had a significantly different total sugars content than ‘Fantasia’, while P66-18 and P65-17 had higher reducing sugars contents than ‘Fantasia’. The phenolic content tended to be higher in these genotypes than in ‘Fantasia’.

During the 6 days of storage at 20°C there were dramatic changes in ‘Fantasia’ fruit (Table 1). Firmness, TA, and SSC declined greatly, while the flesh color (‘a’ value) and pH increased. In contrast, there were virtually no changes in the compositions of the slow-ripening genotypes during 28 days, and only relatively small (though statistically significant) changes in firmness and color. The various genotypes behaved quite similarly during holding at 20°C, except that losses of firmness ranged from less than 10% for P65-17 to about 65% in P19-70 over the 28-day storage period.

**CO₂ and C₃H₄ production.** The rate of CO₂ production by ‘Fantasia’ fruit began to increase immediately after harvest, while the various genotypes maintained low rates of CO₂ production during at least 4 weeks at 20°C (Fig. 2A). The rate of CO₂ production by P19-11 increased on the 28th day with the increase occurring about 5 days later in P65-17 and P19-63. The rate for fruit of the P66-18 genotype did not increase during holding for 42 days. The rate of CO₂ production reached normal levels during the climacteric rise in P19-70 and P19-63, and about 50% of normal in P65-17 compared to ‘Fantasia’.

Ethylene production by ‘Fantasia’ fruit also rose quickly after harvest, while the slow-ripening genotypes maintained a very low basal rate of C₃H₄ production for almost 4 weeks (Fig. 2B). Ethylene production began to increase several days before the respiratory rise in P19-70, P65-17, and P19-63. Compared to ‘Fantasia’, the peak rate of C₃H₄ production was about 33% of normal for P19-63 and about 15%–20% of normal in P19-70 and P65-17. Ethylene production remained low throughout storage in P66-18.

**Color and firmness changes.** Both flesh color and firmness of ‘Fantasia’ fruit changed rapidly during ripening (Fig. 3A and B), and seemed to correlate closely to the increases in CO₂ and C₃H₄ production (Fig. 2A and 2B). The rapid loss of green color, indicated by the increasing ‘a’ values, was accompanied by a dramatic drop in firmness. Fruit were at about 30% (2 lb) and美术品-ripe in only 3 days. In contrast to ‘Fantasia’, the slow-ripening genotypes showed slow, gradual losses of green color and decreases in flesh firmness with time.

While there were no differences in the pattern of changes in flesh color among the 4 genotypes, the softening pattern showed some genotypic variation. P19-70 fruit softened to normal levels

---

Fig. 1. Origin of selected slow-ripening nectarine genotypes. o.p. = open pollination.
Table 1. Comparison of flesh firmness, color, and composition of 'Fantasia' with P66-18, P65-17, P19-63, and P19-70 nectarines at harvest and after holding at 20°C (1980 data).

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Days at 20°C</th>
<th>Firmness</th>
<th>Flesh color</th>
<th>pH</th>
<th>TA (mg malic acid 100 g)</th>
<th>SSC (%)</th>
<th>Total sugars (%)</th>
<th>Reducing sugars (ºBrix)</th>
<th>Total phenolics (mg 100 ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fantasia</td>
<td>0</td>
<td>52 (1.18) b</td>
<td>3.3 bc</td>
<td>3.59 a</td>
<td>0.93 c</td>
<td>11.9 a</td>
<td>8.7 a</td>
<td>4.3 ab</td>
<td>29 a</td>
</tr>
<tr>
<td>P66-18</td>
<td>6</td>
<td>51 (1.11) a</td>
<td>10.6 d</td>
<td>3.75 b</td>
<td>0.66 a</td>
<td>10.7 a</td>
<td>8.4 a</td>
<td>3.4 a</td>
<td>26 a</td>
</tr>
<tr>
<td>P65-17</td>
<td>28</td>
<td>60 (13.5) d</td>
<td>3.8 bc</td>
<td>3.94 c</td>
<td>0.62 a</td>
<td>14.2 c</td>
<td>8.6 a</td>
<td>5.9 cd</td>
<td>49 b</td>
</tr>
<tr>
<td>P19-63</td>
<td>0</td>
<td>82 (18.5) e</td>
<td>-2.3 a</td>
<td>3.77 b</td>
<td>0.76 b</td>
<td>14.0 c</td>
<td>10.5 b</td>
<td>6.9 d</td>
<td>54 b</td>
</tr>
<tr>
<td>P19-70</td>
<td>28</td>
<td>75 (16.9) c</td>
<td>6.0 c</td>
<td>3.82 b</td>
<td>0.64 a</td>
<td>14.0 c</td>
<td>11.6 cd</td>
<td>6.3 cd</td>
<td>53 b</td>
</tr>
</tbody>
</table>

Mean separation in columns by LSD test at 5% level.

After 10 days at 20°C, while P65-17 fruit remained quite firm (60 N; 13 lbF), and P66-18 and P19-63 were intermediate. Color and firmness changes do not seem to be closely related to endogenous C2H4 production in these fruit. With the possible exception of P19-63, which softened at a faster rate later in storage, the rates of softening and color changes remained constant throughout storage.

Response to exogenous C2H4. The effect of various concentrations of C2H4 on the respiration rate of P66-18 is shown in Fig. 4. The response of the other genotypes was very similar. Ethylene stimulated the respiration rate over the entire 14-day application. There was no difference between 10 ppm and 100 ppm in terms of the respiratory response, and 1 ppm was intermediate in its effect between the control and the higher C2H4 levels. Following the removal of the exogenous C2H4, the respiration rate of the 1 ppm-treated fruit continued to decline over the next 4 days and C2H4 production remained low. Respiration remained high in the fruit treated with 10 or 100 ppm C2H4, and C2H4 production rose to 1.3–1.5 µl/kg hr over the same period, about 10 times higher than the rate of the control.

Exogenous C2H4 treatment caused a stimulation of CO2 production which could be repeated with the same fruit (Fig. 5). Following the removal of the exogenous C2H4, CO2 production rates declined, though not to the level of the untreated controls. Ethylene production by the C2H4-treated fruit began to increase.

![Fig. 2. Production of CO2 (A) and C2H4 (B) by nectarine fruit at 20°C. CO2 production data are means ± se of 5 fruit. Note that C2H4 production is on a logarithmic scale: data shown are means of 5 fruit (1980 data).](image)

![Fig. 3. Changes in flesh color (Gardner 'a' value) (A) and firmness (B) of nectarines held at 20°C. Data shown are means ± se of 5 fruit (1980 data).](image)

598

on day 13. The CO₂ production reversed its downward trend, and began rising slightly beginning on day 16.

Susceptibility to internal breakdown. IB affected fruit of the slow-ripening genotypes more severely than that of 'Fantasia' (Fig. 6). Scores of 3 or above would significantly reduce the marketability of the fruit. The 4 genotypes selected for their very slow ripening characteristics (P66-18, P65-17, P19-63, and P19-70) were all severely injured by 4 weeks of storage at 5°C. Only the genotype P19-11 remained in good condition after exposure to low temperature from among the 12 genotypes originally evaluated.

Discussion

Ripening changes in the slow-ripening nectarine genotypes described in this study were dramatically delayed and/or reduced compared to 'Fantasia'. The slow and gradual loss of firmness and disappearance of green color throughout storage indicates that these ripening changes are not controlled by endogenous C₂H₄ levels in these fruit, or that they were saturated by the low basal levels of C₂H₄ produced by the fruit. The latter is not likely, however, since we observed enhanced yellowing and softening following exogenous C₂H₄ treatments (data not shown).

All of these nectarine selections exhibited a respiratory climacteric and initiation of autocatalytic C₂H₄ production, although P66-18 required a long treatment with exogenous C₂H₄ before a climacteric response was observed. These genotypes differed from 'Fantasia' in both timing and magnitude of the surges in CO₂ and C₂H₄ production. The initiation of the climacteric was delayed by 1 month or longer in all the genotypes, and CO₂ production was reduced in P66-18 and P65-17 compared to 'Fantasia'. Ethylene production was reduced in all 4 slow-ripening genotypes. When exogenous C₂H₄ was applied during the preclimacteric period, the response of these fruit was similar to that of nonclimacteric fruit (1). At low concentrations (1 and 10 ppm), C₂H₄ caused an increase in respiration which was roughly proportional to the C₂H₄ concentration. Furthermore, a short exposure to C₂H₄ elicited a respiratory rise without affecting the endogenous rate of C₂H₄ production. When the exogenous C₂H₄ was subsequently reapplied, a second respiratory rise occurred. The C₂H₄ treatments did, however, decrease the time to the onset of the climacteric compared to air controls.

Thus, these unusual nectarine genotypes seem to possess characteristics of both the climacteric and nonclimacteric classes of fruit. Their ripening behavior indicates that a basic similarity may exist between climacteric and nonclimacteric type fruit. Our observations suggest that in the absence of autocatalytic C₂H₄ production, a mature climacteric fruit may ripen in a manner indistinguishable from a nonclimacteric fruit. This suppression in turn leads to us to suggest that, rather than controlling the onset of ripening in normal fruit, endogenous C₂H₄ may act to accelerate and coordinate various changes associated with ripening while one or more of yet unrecognized factors control the initiation of these processes.

Although the poor sensory qualities and high susceptibility to IB rule out any commercial potential for these genotypes, they may prove useful in breeding for F₁ hybrids with ripening characteristics intermediate to those of slow-ripening and normal nectarines, or early season cultivars with the same slow ripening characteristics. Such a program is presently underway.

Fig. 6. Internal breakdown (IB) scores of nectarines held for 2 or 4 weeks at 5°C plus 3 days at 20°C (1 = none, 5 = severe). Each bar represents the means score ± se of 10 fruit. No IB developed in Fantasia' following 2 weeks of storage (1980 data).

Many nectarine and other stone fruit cultivars are subject to internal breakdown, a low temperature-induced injury (7). Among peaches and nectarines there is a general pattern of increasing susceptibility to IB from early to late season cultivars. The slow-ripening genotypes used in this study seemed likely to have high susceptibility to IB. In addition to being extremely late maturing, they had shown a tendency to develop mealiness during ripening, and the relatively high levels of total phenolics measured suggested high browning potential, as well. P19-11 fruit exhibited a low susceptibility to IB which indicates a possibility for using this selection in crosses aimed at producing late-maturing cultivars with low IB susceptibility.

The mode of action of these slow-ripening nectarine genotypes is not yet clear. If a single gene is responsible for the ripening behavior of these fruit, it is apparently eliciting a large number of secondary effects. These secondary effects must be separated from the primary effect before a mode of action can be determined. Since the exogenous C,H, treatments reported here tend to advance the onset of C,H, production and the climacteric, it is possible that the inhibition of ripening is due to an effect on ethylene synthesis.

Literature Cited


