Physical and Chemical Changes during the Maturation of Peaches (Cv. Majestic)

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Nonvolatile acids, sugars, and aroma volatiles from Majestic peaches were measured during maturation from 54 to 126 days after flowering. The highest levels of sucrose, lowest quinic acid levels, and second maximum malic/citric acid ratio occurred when mesocarp dry matter and seed reached their highest weight. Linalool, benzaldehyde, γ-decalactone, and δ-decalactone increased significantly during the final stages of maturation with γ-decalactone being the principal volatile compound. The increased levels of volatiles also closely paralleled seed and mesocarp growth. Pit lignification was complete about 50 days before the seed and mesocarp fully developed. Sucrose, quinic acid, malic/citric acid ratio, and major volatiles either singly or in combination appear to be useful indices for determining physiological maturity in the mesocarp and seed of Majestic peaches.

INTRODUCTION

Various maturity indices have been used to monitor fruit development so that appropriate harvest dates for a given fruit could be determined (Romani and Jennings, 1971). Many of these indices include the aroma volatiles, although any information on the relationship between volatiles and other chemical components with fruit development is lacking. Several compounds have been identified that could be used as reliable maturity indices in Monroe peaches (Chapman and Horvat, 1990). Physiological maturity in these peaches occurred when sucrose reached its highest level in the mesocarp. Also, other compounds that are indicative of physiological maturity were identified. Low quinic acid levels were found to occur about the same time as sucrose levels were highest and, therefore, could be used as a reliable index of peach maturity. Although the levels of malic and citric acids fluctuated during maturation, the maximum malic/citric acid ratio could also be used as in index of maturity (Chapman and Horvat, 1990). The major changes in all these compounds occurred in the mesocarp during peach development. However, their relationship to pit (endocarp) and seed development is essentially unknown. Seed development has been shown to be critical for proper development of the mesocarp, and when the seed (embryonic axis and cotyledons) is aborted or injured, mesocarp growth is dramatically altered (Tukey, 1938). Therefore, chemical changes in the mesocarp may also be useful indicators that may reflect changes in seed during development.

The volatile compounds, which are important contributors to peach aroma, are biosynthesized during the final stages of peach development (Horvat and Chapman, 1990a,b), but no relationship between these compounds with the changes in sugars and nonvolatile acids has been demonstrated during peach maturation. This study was undertaken to determine the relationship between the changes in sugars and nonvolatile acids relative to the aroma volatile compounds during maturation and to determine if such changes could be useful indices of maturity for Majestic peaches.

MATERIALS AND METHODS

Peach Fruit. About 15 peaches (cv. Majestic) were hand harvested from five trees at the University of Georgia Horticultural Farm, Watkinsville, GA. The trees were about 5–6 years old and properly maintained by the horticultural farm staff. Rainfall was above average for the summer of 1989. About 15 fruits were sampled at weekly intervals from 54 days after flowering (DAF) on May 8 until 126 DAF (July 19). The beginning of fruit drop occurred around 117 DAF (July 10). During the final stages of maturation, samples were taken about every 3 days. To ensure sample uniformity, peaches having about the same maximum diameter were harvested. Immediately after arrival at this laboratory, each fruit was weighed and then delayed light emission (DLE) measurements were made by using equipment and procedures described by Forbus and Chan (1989). Delayed light emission is a low-intensity light that is emitted from a chlorophyll-containing plant material for several seconds after illumination (Strehler and Arnold, 1951). DLE has been shown to be an effective nondestructive technique for predicting peach maturity (Forbus and Dull, 1990). From the fruit harvested, 10–12 fruits having similar weights and DLE values were chosen to be representative of that stage of maturation. Fresh weight was determined from the average of these 10–12 fruit.

Moisture Content. Ten-gram samples of fresh mesocarp tissue from three individual peaches at each maturity stage were freeze-dried to a constant weight (approximately 24 h) by using a Labconco Lyph-lock 6 freeze-dry system (Labconco Corp., Kansas City, MO). Moisture content was based on weight loss. Chemical components were analyzed after isolation from the dried samples.

Chemical Analysis. Approximately 900–1200 mg of freeze-dried mesocarp tissue from the moisture determinations was quantitatively transferred to a mortar and ground to a fine powder. Powdered mesocarp was extracted with 50 mL of 75% ethanol and filtered for chemical analysis. Nonvolatile acids and sugars were quantitated as previously described (Chapman and Horvat, 1989). Results were based on mesocarp dry weight.

Isolation and Determination of Volatile Components. The volatile components were isolated from 250 g of blended fresh fruit by continuous steam distillation–hexane extraction and were identified and quantitated by GLC/MS and GLC as previously described (Horvat et al., 1990).

Determination of Pit and Seed Growth. Pits were removed from three peaches at each maturation stage. Adhering tissue between sutures was removed with a spatula, and the pits were washed with a stiff brush and then patted dry. The pits were allowed to air-dry for about 20 min, and the average fresh weight was determined. Pits were carefully sawed along the major suture and split open with a screwdriver, and the seed (embryonic axis and cotyledons removed) was dried, and weighed.

Total Mesocarp Dry Matter Determination. The total mesocarp dry matter/peach (TMD) at each maturity stage was

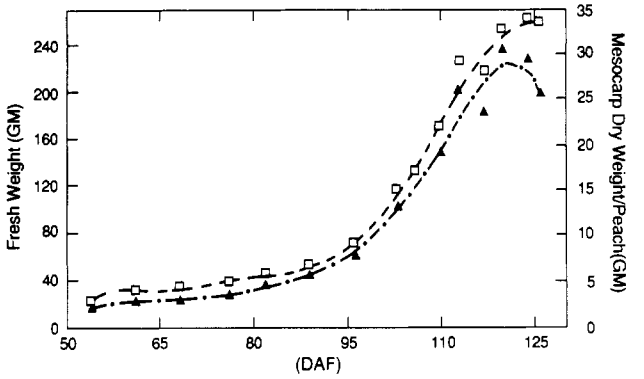

Figure 1. Changes in dry (▲) and fresh (□) weight of Majestic peaches during maturation.

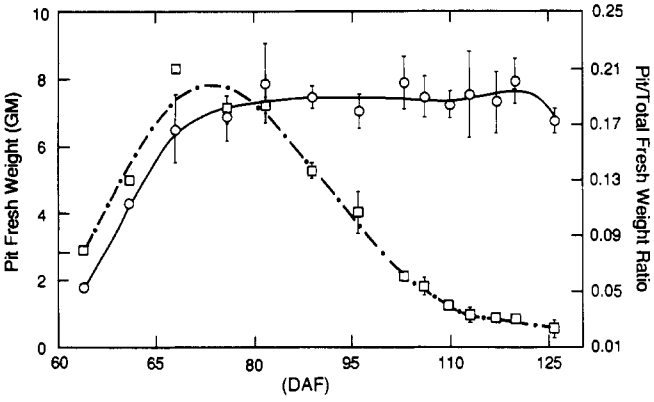

Figure 2. Changes in pit weight (○) and pit/total peach fresh weight ratio (□) during Majestic peach maturation. Ranges among samples are depicted by horizontal bars.

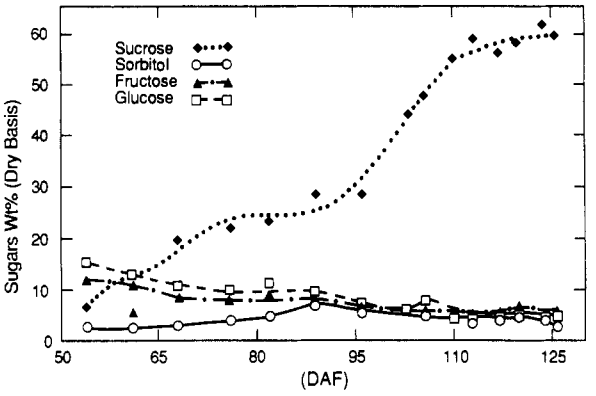

Figure 3. Changes in the major carbohydrates in Majestic peach mesocarp tissue during maturation.

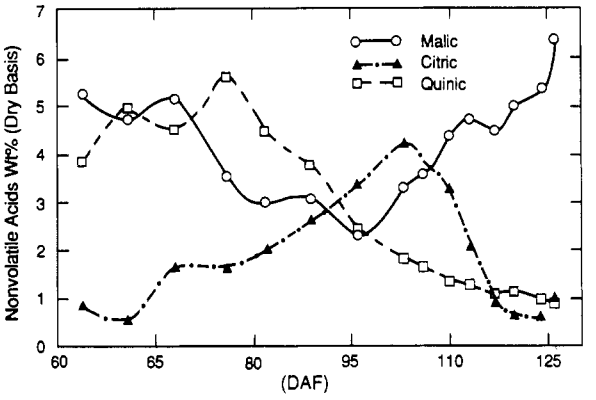

Figure 4. Changes in the major nonvolatile acids in Majestic peach mesocarp tissue during maturation.

determined by: TMD = [FW - PFW][1 - %M/100], where FW is fresh weight, PFW is pit fresh weight, and %M is % moisture.

RESULTS AND DISCUSSION

Simple correlation coefficients between DLE values and fresh weight, total chlorophyll, and DAF for the sample were −0.98, 0.84, and −0.93, respectively. The high correlations between variables confirm that the method used to select samples representing each maturity stage was effective. The fresh weight of Majestic peaches increased about 11-fold from an average of 24 g at 54 DAF to 265 g at 126 DAF, and similar trends in mesocarp dry matter were also observed (Figure 1). Dry matter accumulation is thought to follow a double-sigmoidal curve (Chalmers et al., 1975); however, linear regression analysis on natural log plots of mesocarp dry matter growth between 68 and 113 DAF yielded a linear relationship ($r^2 = 0.97$). From these data, an equation was derived: $y = 0.98e^{0.048x}$, where y is mesocarp dry weight and x is DAF. The results indicate the mesocarp is in an exponential growth phase during this period and probably corresponds to the end of dry weight stage II and all of dry weight stage III described by Chalmers et al. (1975).

The pits developed rapidly between 54 and 82 DAF, and then the average weight leveled off at about 8 g with ranges of about ±2 g for the rest of maturation (Figure 2). Most of the rapid weight gain during this period is due to the lignification of the pit. This process is also indicated by the increase in pit/total fresh weight ratio during the same period (Figure 2). The maximum ratio occurred at 69 DAF, and at this time the pit accounted for about 21% of the total fresh weight. The maximum ratio value is similar to that found at 53 DAF for Flordasun peaches (Sharma, 1982). From visual observations and pit weight, complete lignification occurred by 76 DAF, although the pits continued to invaginate and become more pigmented for the rest of the maturation period. The drop in the pit/total fresh weight ratio from 69 to 110 DAF coincided with a rapid increase in mesocarp dry weight (Figure 1). At the minimum ratio, the pits were about 2–3% of the total peach fresh weight. Although some pit weights ranged more than 2 g on any given maturity date, the variation in pit/total fresh weight among samples was very small.

The trends in nonvolatile acids and sugars during maturation of Majestic peachs were similar to those observed with the cv. Monroe, even though the former results were based on dry matter and the latter on fresh weight (Figures 3 and 4; Chapman and Horvat, 1990). Initially (54 DAF), glucose and fructose were the major sugars, but the levels of sucrose increased rapidly during the first 2 weeks (54–68 DAF, first sigmoidal) and then increased gradually for the next 30 days (97 DAF) (Figure 3). The most rapid increase (second sigmoidal) occurred between 97 and 113 DAF and appeared to level off between 117 and 126 DAF at about 57–60% of total dry weight (Figure 3). Glucose and fructose steadily decreased from 54 to about 95 DAF, while the levels of sorbitol increased during this period. From 95 DAF to the end of the maturation period, the levels of these three components declined slightly (Figure 3). The trends in sugar changes during maturation of Majestic peaches were also similar to those found in cv. Hakuto by Moriguchi et al. (1990). Xylose and inositol were identified in Majestic peaches, but their levels were <1% during maturation and not reported.

The nonvolatile acid composition was similar to the cv. Monroe with malic, citric, and quinic being the major acids isolated (Figure 4). Succinic acid was identified and

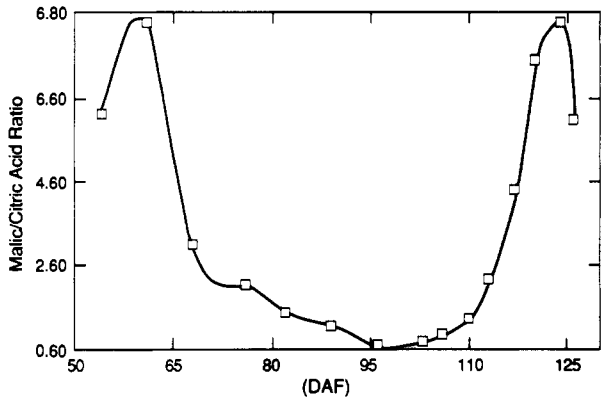

Figure 5. Malic acid/citric acid ratio during Majestic peach maturation.

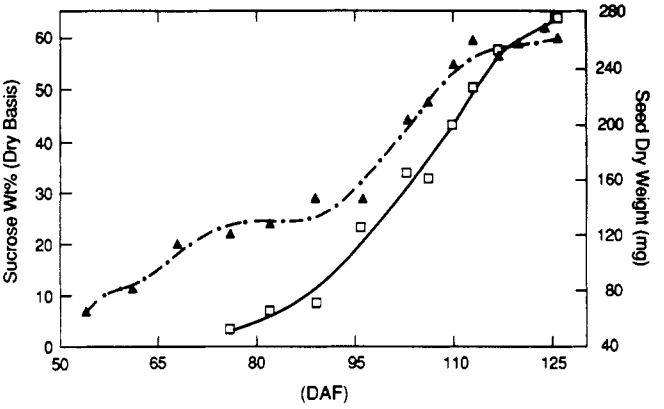

Figure 6. Seed development (□) during Majestic peach maturation in relation to mesocarp sucrose levels (▲).

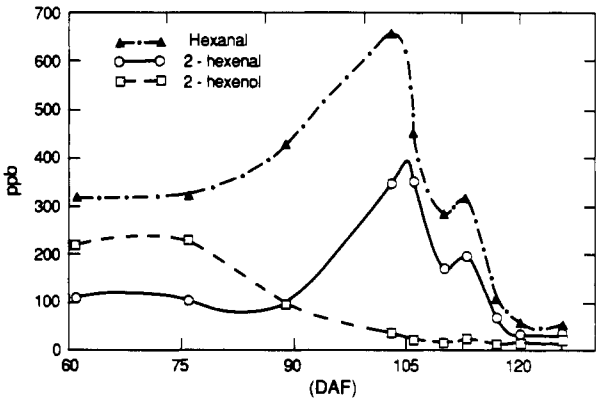

Figure 7. Changes in hexanal, 2-hexenal, and 2-hexenol during Majestic peach maturation.

quantitated from mesocarp extracts, but level were <1% and not reported. Malic and quinic were the major acids at immature growth stages, with quinic being the major acid from about 68 to 89 DAF. Quinic acid continued to decline after reaching its highest level at 75 DAF to the end of the maturation period. The lowest levels occurred between 117 and 126 DAF and could signify physiological maturity of the mesocarp. Similar trends in quinic acid were also observed in developing Monroe peaches (Chapman and Horvat, 1990). Citric was the major acid from 96 to about 106 DAF and then declined rapidly. Citric has been identified as the major acid in cv. Monroe and other peach cultivars for short periods during maturation (Chapman and Horvat, 1990; Li and Woodruff, 1968). In the final growth stages (109–126 DAF), malic became the principal acid and continued to increase for the rest of the maturation period (Figure 4). We have previously reported that one indicator of mesocarp physiological maturity could be the time when the malic/citric acid ratio reached a maximum (Chapman and Horvat, 1990). However, the acid ratio was observed for longer growth periods in this study, and consequently two maxima were observed (Figure 5). The first maximum occurred at very immature stages (61 DAF), and the second occurred at more mature stages (123 DAF). The second maxima occurred about the same time fresh weight, dry weight, and sucrose reached their highest levels and when quinic acid levels were lowest (Figures 1 and 3). Thus, the second maximum malic/citric acid ratio may be a useful indicator of physiological maturity.

Mesocarp moisture averaged 88.11 ± 0.81% and changed very little during the 72 days of maturation. The percent moisture values were slightly lower than those found for other peach cultivars (Lee et al., 1984).

Majestic peaches probably reached physiological maturity about 120 DAF on the basis of the changes in fresh and dry weight, nonvolatile acids, and sugars. These events occured about 50 days after complete lignification of the pit (Figure 2). Physiological maturity of Majestic peaches occurred about 1 month before that of cv. Monroe (viz. Jul 17 vs Aug 10; Chapman and Horvat, 1990). Both cultivars are freestone, but Monroe is a cold-hardy, late-maturing variety (G. A. Couvillon, 1989, personal communication). However, the changes in nonvolatile acids and sugars in the two cultivars during maturation were very similar. Therefore, the same compounds can be used as maturity indices for both cultivars and would suggest they probably would be useful indicators for most peach cultivars.

The low seed weight at 76 DAF is the beginning stage of rapid seed growth which occurred about the time pit lignification was complete (Figures 2 and 6). Seed weight increased rapidly from 76 DAF and reached its highest weight at 126 DAF (Figure 6). Peach seeds have previously been shown to reach full development near the end of the final pericarp swell (Chalmers and van den Ende, 1977). The highest seed weight occurred only 3 days after sucrose reached its highest levels in the mesocarp and would suggest the mesocarp and seed probably reached physiological maturity at the same time.

High levels of hexanal, (*E*)-2-hexenal, and (*E*)-2-hexenol from volatile fractions of peaches, other fruits, and oilseeds have been associated with lipoxygenase and alcohol dehydrogenase activities (Tressl et al., 1980; Eriksson, 1975). Precursors for these compounds are thought to be linoleic acid (Tressl et al., 1981; Engel et al., 1988), which has been found as one of the major fatty acids in peach seed and endocarp (Takenaga et al., 1984). The levels of the two C_6 aldehydes were highest between 90 and 106 DAF (Figure 7) and may indicate the time during maturation when lipoxygenases were the most active. The maximum level of the volatile C_6 aldehydes also coincided with highest levels of citric acid at 103 DAF (Figures 4 and 7). The levels of C_6 aldehydes and alcohol dropped sharply for the rest of the maturation period. These events also correspond to the time when the seed and mesocarp begin their final growth phases (Figures 1 and 6). As the C_6 compounds decreased during the final growth phase (106–126 DAF), γ- and δ-decalactones, linalool, and benzaldehyde increased between 117 and 126 DAF (Figure 8). The levels of γ-decalactone increased 24-fold, while δ-decalactone and benzaldehyde levels increased about 2-fold during this period. Linalool also increased about 3-fold between 113 and 117 DAF but then declined slightly by 126 DAF. These results are consistent with a previous study of the volatiles of Monroe peaches (Horvat and Chapman, 1990a,b). Both linalool and γ-decalactone were

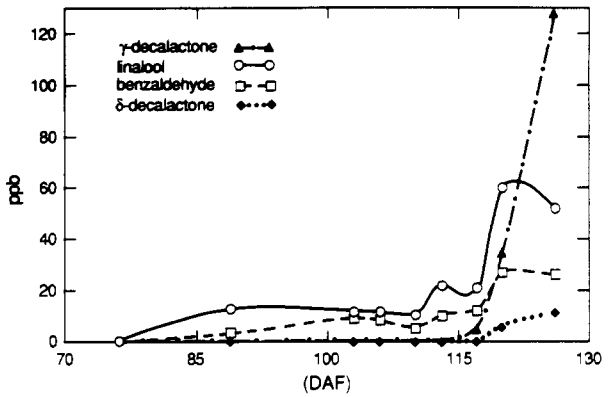

Figure 8. Changes in the principal aroma components during Majestic peach maturation.

present above their threshold levels (6 and 11 ppb; Buttery et al., 1971; Engel et al., 1988) in Majestic peaches and should contribute to peach aroma. Benzaldehyde levels were found much below its threshold value (350 ppb; Buttery et al., 1971) and therefore would contribute very little to peach aroma. Around 117 DAF, a fragrant "peach aroma" became detectable, and by 126 DAF this fragrant aroma was much stronger, suggesting that maximum aroma occurred simultaneously as the seed and mesocarp reached full development. The principal contributor to this aroma is probably γ-decalactone on the basis of its 24-fold increase by 126 DAF (Figure 8). This lactone has also been shown to increase about 16-fold immediately after ripe peach fruit was picked from the tree (Mookherjee et al., 1986).

The compositional changes in sugars, nonvolatile acids, and aroma volatiles reported in this study were very similar to those found during the maturation of Monroe peaches (Chapman and Horvat, 1990; Horvat and Chapman, 1990a,b). These findings add support to previous results that sucrose, quinic acid, and the malic/citric acid ratio can be used as reliable indices to establish the time of physiological maturity in peaches. The major volatile components play an important role in the development of peach aroma, and on the basis of the results of this study could also serve as indicators of peach maturity.

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Registry No. Sucrose, 57-50-1; sorbitol, 50-70-4; fructose, 57-48-7; glucose, 50-99-7; malic acid, 6915-15-7; citric acid, 77-92-9; quinic acid, 77-95-2; hexanal, 66-25-1; (*E*)-2-hexenal, 6728-26-3; (*E*)-2-hexenol, 928-95-0; γ-decalactone, 706-14-9; linalool, 78-70-6; benzaldehyde, 100-52-7; δ-decalactone, 705-86-2.