Effect of Cold Storage and Maturity on the Physical and Chemical Characteristics and Volatile Constituents of Peaches (Cv. Cresthaven)

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The effects of cold storage and maturity on the physical and chemical characteristics and volatile flavor constituents of peaches (cv. Cresthaven) were determined. In general, size, weight, soluble solids (SS), sucrose content, SS/TA ratio, volatiles, and Minolta *a* value increased with increased maturity of unripened fruit. Minolta *L* and *b* values, glucose, fructose, and sorbitol contents, and total phenolics did not vary significantly by maturity. Titratable acidity and hue angle decreased significantly with increased maturity. The weights of the peaches of all maturity grades decreased significantly during storage at 0 °C with an average decrease of about 3.5%/week. During cold storage, Cresthaven peaches also underwent significant decreases in hue angle, sucrose content, and titratable acidity (TA) and significant increases in glucose and fructose contents and SS/TA ratios. The volatiles generally decreased during storage. Data indicate that cv. Cresthaven peaches of the three maturity grades evaluated will hold up under 0 °C storage for about 4 weeks. After 4-week storage, significant deterioration probably will occur.

The decision as to when peaches should be harvested is complicated by market flexibility as opposed to optimum fruit quality. Peaches that are picked immature will not ripen to dessert quality, whereas those left too long on the tree become soft, do not ship well, and have reduced shelf life (Fisher et al., 1943). The effects of storage temperature on different peach cultivars have been reported by a number of investigators (Anderson, 1979; Buescher and Griffith, 1976; Fisher et al., 1943; Haller and Harding, 1939). Cold storage of peaches after harvest will retard ripening and lengthen storage life but only up to a certain point. Peaches held in cold storage too long will not ripen and will suffer internal browning and woolly texture (International Organization for Standardization, 1980). The ISO International Standard for peaches states that the optimum storage temperature for peaches is −1 to +2 °C and a storage life of only 2–4 weeks can be expected for most cultivars.

The aroma and/or volatiles of peaches are an important criteria of quality. The major volatile constituents of peaches have been identified (Horvat et al., 1990; Do et al., 1969; Sevenants and Jennings, 1966; Jennings and Sevenants, 1964). Do et al. (1969) isolated 86 and identified 17 of the volatiles at four different stages of maturity of Gleason Early Elberta peaches. They reported increased concentrations of the volatiles with advancing fruit maturity. Lactones, particularly γ-lactones, have been implicated in peach aroma (Jennings and Sevenants, 1964; Sevenants and Jennings, 1966). Horvat et al. (1990) identified 32 volatile compounds from 13 peach cultivars and breeding lines. However, little if any information is in the literature on the changes in the aroma and/or volatiles during low-temperature storage. The objective of this investigation was to determine the effect of cold storage and ripening on the physical and chemical characteristics and volatile flavor constituents of three maturity grades of Cresthaven peaches.

MATERIALS AND METHODS

Samples. Peaches, cv. Cresthaven, were obtained from a local commercial orchard in July 1987. The fruit were hand-picked on three dates and immediately transported to the laboratory. Fruit were sorted into immature, threshold mature, and mature grades (Delwiche and Baumgardner, 1983) by a combination of standard color chips (Delwiche and Baumgardner, 1985) and Minolta *a* color values.

Samples were evaluated before ripening, after ripening, and after storage at 0 °C and 80–90% RH for 1, 2, 4, 6, and 8 (except as shown) weeks each followed by ripening. Samples were ripened at 20 °C and at least 85% RH 7 days for the immature and threshold mature and 4 days for the mature.

Storage Experiment. One hundred eighty fruit from each maturity grade were dipped in a suspension of benomyl (300 ppm) and botran (900 ppm) for 2 min prior to storage. Fruit were air-dried and then placed in storage at 0 °C (as above). After 0 °C storage, samples were ripened and then analyzed for color, firmness, and chemical constituents as described below.

Physical Measurements. Before and after ripening, 15 peaches of each maturity grade were measured for weight, skin color, and firmness. The size of the fruit of each maturity grade also was determined by measuring the diameter of the fruit with vernier calipers. Ground color was measured on the greenest area of each fruit on opposite cheeks with a tristimulus colorimeter (Minolta CR-100 equipped with a Minolta DP-100 data processor). The colorimeter employed a d/0 geometry illuminating system and an 8-mm viewing aperture. The instrument was calibrated with a white reference plate ($Y = 87.1$, $x = 0.311$, $y = 0.318$), and measurements were recorded using *L*, *a*, and *b* color coordinates. The Minolta *a* and *b* values were used to compute values for hue angle ($\theta = \tan^{-1}(b/a)$), a parameter that is effective for visualizing the color appearance of food products (Little, 1975).

Firmness was determined on opposite pared cheeks of 15 peaches using the Magness-Taylor pressure tester with an 8-mm tip. The mean of the two measurements was expressed in newtons.

Chemical Analyses. Fifteen peaches from each maturity grade were divided into three replications of five fruit each. The five fruit were sliced, pit was removed, and slices were ground to a puree in a Waring blender for 1–3 min. Soluble solids (SS), pH, and titratable acidity (TA) were determined on the ground puree (Robertson and Meredith, 1988). Duplicate analyses were carried out on all the chemical analyses. Individual sugars were determined by HPLC (Meredith et al., 1988). For total phenolics, peach samples were prepared as described by Senter et

Table I. Effect of Maturity and Ripening on the Physical Characteristics[a] of Peaches (cv. Cresthaven)

maturity	size, mm		weight, g		firmness,[d] N		color value L		color value a		color value b	
	ur[b]	r[c]	ur	r	ur	r	ur	r	ur	r	ur	r
immature	67.6 ± 4.7	64.4 ± 4.3	159 ± 28	143 ± 24	65 ± 12	8 ± 4	67.8 ± 2.2	73.0 ± 2.4	-7.8 ± 1.6	-0.6 ± 2.3	39.4 ± 2.5	51.3 ± 2.3
threshold mature	76.3 ± 5.2	67.7 ± 3.7	226 ± 38	163 ± 26	64 ± 12	5 ± 3	71.5 ± 1.8	71.8 ± 2.1	-2.7 ± 2.0	4.6 ± 2.3	44.6 ± 1.9	51.0 ± 3.1
mature	76.4 ± 6.2	76.2 ± 4.9	222 ± 45	218 ± 48	61 ± 16	4 ± 2	71.4 ± 1.9	70.3 ± 2.2	4.5 ± 2.9	7.9 ± 2.4	45.1 ± 2.6	48.9 ± 2.9

[a] Values are the means for 15 fruits ± standard deviations. [b] Unripened peaches. [c] Peaches ripened at 20 °C and 85% RH for 4–7 days. [d] Newtons of force.

Table II. Effect of Maturity and Ripening on the Chemical Characteristics of Peaches[a] (cv. Cresthaven)

maturity	soluble solid, %		titratable acidity, % as malic acid		SS/TA		total phenolics,[b] mg %	
	ur[c]	r[d]	ur	r	ur	r	ur	r
immature	12.9 ± 0.1	13.0 ± 0.2	0.76 ± 0.02	0.80 ± 0.09	17.0	16.3	1.86 ± 0.20	1.40 ± 0.09
threshold mature	13.7 ± 1.0	13.4 ± 1.2	0.72 ± 0.02	0.70 ± 0.03	19.0	19.1	1.37 ± 0.13	1.48 ± 0.20
mature	14.3 ± 0.1	13.9 ± 0.6	0.62 ± 0.07	0.61 ± 0.03	23.1	22.8	1.43 ± 0.09	1.49 ± 0.28

[a] Values are the means for 15 fruits ± standard deviations. [b] Dry weight. [c] Unripened peaches. [d] Peaches ripened at 20 °C and 85% RH for 4–7 days.

Table III. Effect of Maturity and Ripening on the Sugar Content[a] of Peaches (cv. Cresthaven)

maturity	sucrose,[b] %		glucose, %		fructose, %		sorbitol, %	
	ur[c]	r[d]	ur	r	ur	r	ur	r
immature	4.55 ± 0.32	4.79 ± 0.44	1.42 ± 0.06	1.26 ± 0.04	1.58 ± 0.09	1.57 ± 0.06	1.62 ± 0.13	0.43 ± 0.11
threshold mature	5.89 ± 0.07	6.31 ± 0.84	1.29 ± 0.08	1.11 ± 0.12	1.45 ± 0.08	1.46 ± 0.16	1.73 ± 0.19	0.57 ± 0.16
mature	7.14 ± 0.25	7.13 ± 0.43	1.40 ± 0.05	1.28 ± 0.15	1.66 ± 0.06	1.58 ± 0.14	1.42 ± 0.11	0.89 ± 0.35

[a] Values are the means for 15 fruits ± standard deviations. [b] Fresh weight. [c] Unripened peaches. [d] Peaches ripened at 20 °C and 85% RH for 4–7 days.

al. (1989) and analyzed by procedure of Swain and Hillis (1959).

Isolation of Volatiles by Continuous Extraction. Steam distillation–hexane extraction of peach volatiles was performed with a modified Likens–Nickerson extraction apparatus (Schultz et al., 1977). Samples of freshly harvested peaches of the different maturities were analyzed on the day of harvest. However, samples of the 0 °C stored fruit analyzed in this study were stored at −20 °C for up to several months because we were capable of conducting only two extractions per day. Although frozen storage probably has an influence on the concentration of volatiles, frozen storage of fruit samples is used commonly in fruit volatile research (Do et al., 1969; Etievant et al., 1986). In addition, the values found in this study reflect differences among the various samples since they were stored under identical conditions.

On the day of analysis, samples were removed from freezer and partially thawed at room temperature. The fruit were then pitted, halved, diced, and composited. A 250-g aliquot of fruit and 200 mL of distilled water were blended with a Waring blender for 2 min. The resulting slurry was transferred with 500 mL of distilled water into a 3-L round-bottom flask and connected to the Likens–Nickerson distilling head. Hexane (120 mL) was used as the extracting solvent, and the extraction was carried out at a reduced pressure (110 mmHg) for 4 h. The hexane extract was concentrated to 20-μL volume by a gentle stream of nitrogen.

Capillary GC Analysis. Quantitation of the volatiles was made by capillary GC analysis. The column used was a 15 × 0.25 mm (i.d.) fused silica capillary coated (0.25 μM thick) with DB-1 (J & W Alltech. Inc., Deerfield, IL). Injector and detector temperatures were 225 and 280 °C, respectively. Oven temperature was held at 60 °C for 1 min, programmed to 90 °C at 3 °C/min and held for 0.5 min, then programmed to 210 °C at 5 °C/min, and held for 15 min. Injected volume was 1 μL.

GLC/Mass Spectral Analysis. Mass spectral analyses were made with an Extrel Model C50/400 quadrupole mass spectrometer that was interfaced with a Perkin-Elmer Model Sigma 300 GLC equipped with a cold on-column injector. Chromatographic separations were made on a 30 m × 0.32 mm (i.d.) fused silica capillary column coated (0.25 μM thick) with DB-1. The column oven was programmed from 50 to 100 °C at 2 °C/min and held for 0.5 min and then programmed to 220 °C at 3 °C/min and held for 40 min. For estimating levels of hexanal, *trans*-2-hexenal, benzaldehyde, linalool, and γ- and σ-decalactone, standard curves were prepared by plotting amounts of each compound versus GLC peak areas.

Mass spectrometer conditions: ion source temperature, 150 °C; scan rate, 200 amu/s; ionization voltage, 70 eV. Data were acquired with Technivent software and interface and processed on an IBM PC.

Statistical Analysis. The data were analyzed by the General Linear Models (GLM) program of the Statistical Analysis System (SAS) for personal computers (SAS Institute, Inc., 1985).

RESULTS AND DISCUSSION

The effects of maturity and ripening on the physical and chemical characteristics of cv. Cresthaven peaches are shown in Tables I–III. In general, size, weight, soluble solids, sucrose content, SS/TA ratio, and Minolta *a* values increased with increased degree of maturity of the unripened fruit. Minolta *L* and *b* values, glucose, fructose, and sorbitol contents, and total phenolics were not significantly different among maturities. Titratable acidity decreased significantly ($P < 0.01$) with increased maturity, whereas firmness of the three different maturities of unripened fruit was not significantly different. The firmness of peaches is normally highly correlated with maturity (Rood, 1957). The differences found in this study among the maturities were not as great as we expected on the basis of previous studies (Meredith et al., 1989).

It has been suggested that the ratio SS/TA indicates ripeness of fresh fruit (Deshpande and Salunkhe, 1964) and that mature Redhaven peaches had a minimum SS/TA value of 13 (Salunkhe et al., 1968). However, this ratio is quite variable, and our data show that immature Cresthaven peaches had a SS/TA value of 17 (Table II). The sugar content (Table III) agreed generally with that

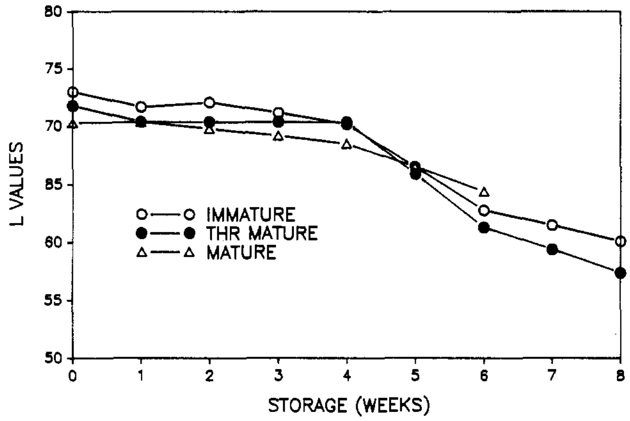

Figure 1. Effect of storage at 0 °C and harvest maturity on the Minolta *L* values of ripened Cresthaven peaches.

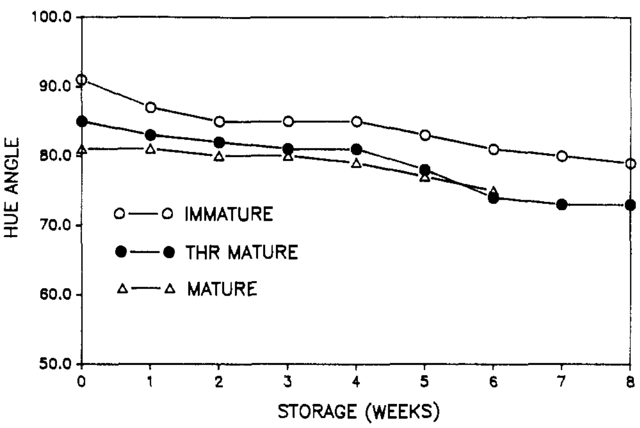

Figure 2. Effect of storage at 0 °C and harvest maturity on the hue angle of ripened Cresthaven peaches.

reported by Haller and Harding (1939) and Souty and Andre (1975), but it was significantly higher than that reported by Salunkhe et al. (1968).

As expected, the most significant changes due to ripening at 20 °C were an increase in ground color *a* value and softening of the fruit (Table I). The *a* value increase was primarily due to the disappearance of chlorophyll (Delwiche and Baumgardner, 1983) and an increase in red blush. Ripening softened the fruit to firmness of 4–8 N. Fruit with a firmness of 13 N or below are eating-ripe or tree-ripe (Deshpande and Salunkhe, 1964). Ripening also resulted in a variable but significant decrease in weight (average 13%) even though the ripening rooms were held at no less than 85% RH.

Storage of cv. Cresthaven preaches at 0 °C had a variable effect on the physical and chemical characteristics of all three maturity grades. The weights of the peaches of all maturity grades decreased significantly during storage with an average decrease of about 3.5%/week and 21% total decrease after 6-week storage.

The effects of storage on the Minolta *L* value and hue angle are shown in Figures 1 and 2. No significant change in *L* values occurred until after 4 weeks of storage where there were sharp decrease. The sharp reductions in *L* values show that the three maturity groups of peaches were becoming darker in color, indicating fruit deterioration. Hue angle data (Figure 2) show that immature peaches are greener and have less yellow and red color than threshold mature and mature peaches. The hue angle of the three maturity categories all decreased significantly ($P < 0.01$) during 6-week storage. These results show that even in very cold storage (0 °C) peaches will degreen and will develop more yellow color.

Table IV. Effect of Storage at 0 °C on the Sugar Contents[a] (%, Fresh Weight) of Ripened Peaches (cv. Cresthaven)[b]

	immature	threshold mature	mature
		Week 0	
sucrose	4.79 ± 0.44	6.31 ± 0.84	7.13 ± 0.43
glucose	1.26 ± 0.04	1.11 ± 0.12	1.28 ± 0.15
fructose	1.57 ± 0.06	1.46 ± 0.16	1.58 ± 0.14
sorbitol	0.43 ± 0.11	0.57 ± 0.16	0.89 ± 0.35
		Week 1	
sucrose	5.74 ± 0.31	6.60 ± 0.49	7.44 ± 0.39
glucose	1.09 ± 0.06	0.94 ± 0.11	1.33 ± 0.09
fructose	1.46 ± 0.07	1.30 ± 0.14	1.75 ± 0.17
sorbitol	0.39 ± 0.01	0.52 ± 0.07	0.83 ± 0.11
		Week 2	
sucrose	5.87 ± 0.86	7.09 ± 0.69	7.24 ± 0.33
glucose	1.13 ± 0.15	1.07 ± 0.20	1.20 ± 0.03
fructose	1.56 ± 0.18	1.51 ± 0.25	1.56 ± 0.05
sorbitol	0.53 ± 0.10	0.58 ± 0.13	0.78 ± 0.04
		Week 4	
sucrose	5.23 ± 0.11	6.10 ± 0.34	6.72 ± 0.14
glucose	1.01 ± 0.03	1.06 ± 0.07	1.44 ± 0.08
fructose	1.71 ± 0.08	1.72 ± 0.09	2.03 ± 0.15
sorbitol	0.98 ± 0.17	0.91 ± 0.10	1.16 ± 0.26
		Week 6	
sucrose	2.58 ± 0.73	3.27 ± 0.16	4.32 ± 0.74
glucose	2.03 ± 0.35	2.00 ± 0.27	2.41 ± 0.27
fructose	3.09 ± 0.36	3.13 ± 0.28	3.06 ± 0.27
sorbitol	1.31 ± 0.11	1.21 ± 0.16	1.25 ± 0.24
		Week 8	
sucrose	1.52	1.80	
glucose	2.47	2.42	
fructose	3.59	3.48	
sorbitol	1.29	1.29	

[a] Values are the means for 15 fruits ± standard deviations. [b] Ripened at 20 °C and 85% RH.

The effect of storage on the sugar content of ripened Cresthaven peaches is shown in Table IV. During the first 2 weeks of storage, sucrose content appeared to slightly increase, but between the fourth and eighth weeks of storage, sucrose significantly ($P < 0.01$) decreased regardless of the maturity grade. By 6 weeks of storage, sucrose content had decreased about 50%. Data show that sucrose content increased significantly with maturity. On the other hand, glucose and fructose contents were not affected by maturity and beginning with the fourth week of storage significantly increased with time. Sorbitol content was low but varied significantly with maturity and also increased significantly with storage time. Since sucrose content decreases and glucose and fructose increased with storage, it is probable that sucrose was hydrolyzed during storage, yielding glucose and fructose.

Soluble solids (SS) content increased significantly with maturity but did not change significantly with storage (Figure 3). Deshpande and Salunkhe (1964) reported that SS of Redhaven peaches increased with maturity. They indicated that Redhaven peaches with more than 9.5% SS could be classified as of optimum maturity. Such is not the case for Cresthaven peaches in which immature fruit have a 13% SS content. In fact, the SS content of peaches varies so widely depending on agronomic conditions, maturity, and cultivar that it would not be feasible to attempt to relate SS to optimum maturity or good flavor quality (Kader et al., 1982; Nightingale et al., 1930). Storage at 0 °C had no significant effect on the total phenolic content of the fruit (data not shown) but resulted in a significant ($P < 0.01$) decrease in titratable acidity with storage time (Figure 4).

Peach volatiles hexanal, *trans*-2-hexenal, benzaldehyde, and linalool decreased in concentration in ripened

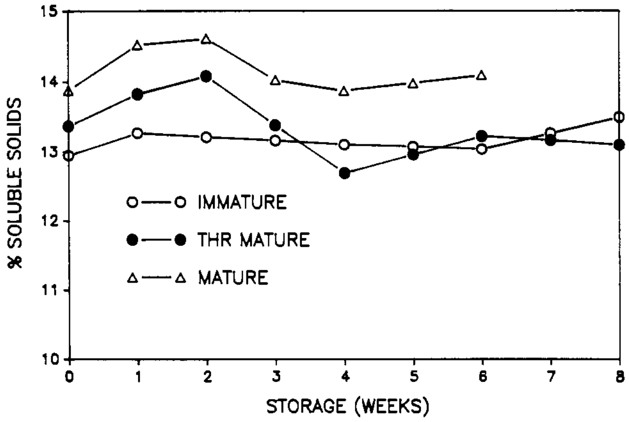

Figure 3. Effect of storage at 0 °C and harvest maturity on the soluble solids content of ripened Cresthaven peaches.

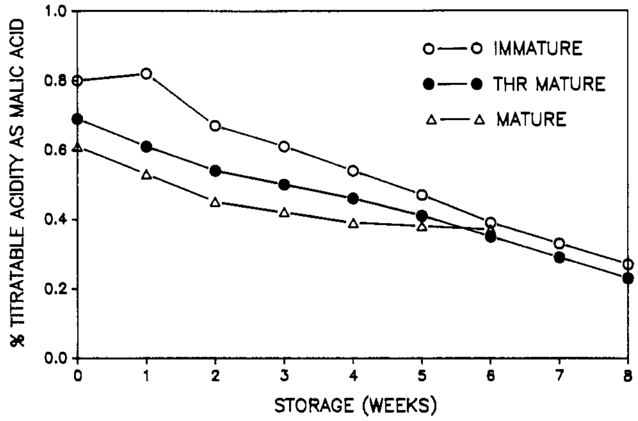

Figure 4. Effect of storage at 0 °C and harvest maturity on the titratable acidity of ripened Cresthaven peaches.

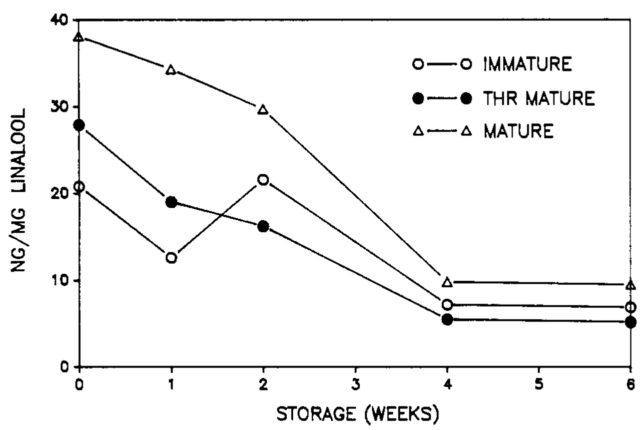

Figure 5. Effect of storage at 0 °C and harvest maturity on the linalool content of ripened Cresthaven peaches.

immature, threshold mature, and mature fruit stored for up to 6 weeks at 0 °C and subsequently ripened at 20 °C. γ-and δ-lactone concentrations in this study were found to be essentially the same as reported in tree-ripened peaches (Horvat et al, 1990). This is contrary to the findings of Do et al. (1969). Figure 5 shows the increase in linalool with maturity and the decrease with week of storage. Horvat et al. (1990) reported that linalool was a constituent of the aroma of ripening peaches. However, γ-decalactone increased significantly during the first 2 weeks of storage and then decreased significantly during 4 weeks of storage (Figure 6). Mookerjee et al. (1988) reported that certain volatile components present in peaches attached to the tree are not found after the peach

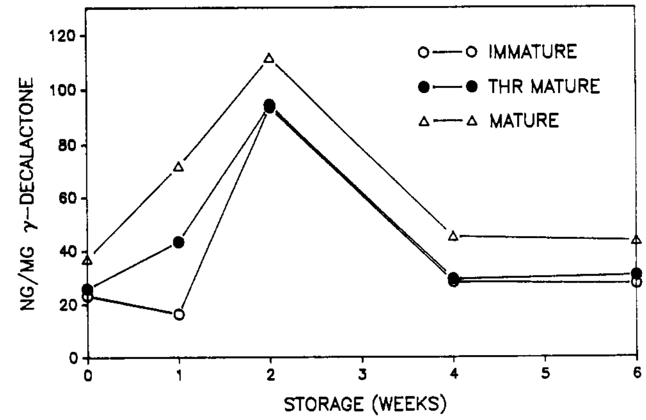

Figure 6. Effect of storage at 0 °C and harvest maturity on the γ-decalactone content of ripened Cresthaven peaches.

has been picked. However, they reported that γ-decalactone and 6-pentyl-α-pyrone increased in the picked fruit as we observed for γ-decalactone. The decreases in levels of certain low molecular weight compounds might be due to the lack of substrates in the picked peaches, which are required for their biosynthesis. It appears that the contents of volatiles from peaches ripened at 20 °C are significantly lower than tree-ripened fruit.

Data on the physical and chemical characteristics and volatile flavor constituents show that cv. Cresthaven peaches at later maturity stages developed dessert-quality fruit characteristics such as softening, high yellow color with a red blush, low acid levels, increased sugar contents, and increased peach volatiles. Results also indicate that peaches of the three maturity grades evaluated will hold up under 0 °C storage for about 4 weeks. After 4 weeks of storage, sharp decreases in Minolta *L* and *b* values and sucrose content indicate that significant deterioration probably will occur.

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Registry No. Glucose, 50-99-7; fructose, 57-48-7; sucrose, 57-50-1; sorbitol, 50-70-4; hexanal, 66-25-1; *trans*-2-hexenal, 6728-26-3; benzaldehyde, 100-52-7; linalool, 78-70-6; γ-decalactone, 706-14-9.

Fatty Acid Hydroperoxide Lyase in Germinating Soybean Seedlings

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A fatty acid hydroperoxide lyase from soybean seeds (*Glycine max* var. Williams) has been partially purified by differential centrifugation, ion-exchange chromatography, and gel filtration. The enzyme preparation, which is free of *cis*-3:*trans*-2-enal isomerase, has an optimun pH in the range 6-7. The lyase cleaves the 13-hydroperoxides of linoleic and linolenic acids to form the volatile aldehydes hexanal and *cis*-3-hexenal, respectively. In both case the ω-oxo carboxylic acid 12-oxo-*cis*-9-dodecenoic acid is also formed. The enzyme does not act on 9-hydroperoxides of these acids. The activity of hydroperoxide lyase was followed for 6 days of germination and found to increase constantly. Lipoxygenase activity (L-2 + L-3) also increased, as did the level of fluorescence in the phospholipids extracted. These facts suggest that lipoxygenase and hydroperoxide lyase may be involved in the formation of fluorescent substances.

Although it is well-established that lipoxygenase are widespread throughout the plant kingdom, their physiological role and the fate of their products, lipid hydroperoxides, are incompletely understood. The hydroperoxides derived from polyunsaturated fatty acids are intrinsically unstable. They undergo both enzymatic and nonenzymatic changes, including carbon chain cleavage. The enzymatic cleavage of the polyunsaturated fatty acid

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