J. Amer. Soc. Hort. Sci. 111(4):549–553. 1986.

Peach Skin Discoloration

E.G. Denny[1], D.C. Coston[1], and R.E. Ballard[2]
Clemson University, Clemson, SC 29631

Additional index words. *Prunus persica*, black streak, anthocyanin, pH effect, metallic complex, chlorination, epidermis, trichome, defuzz

Abstract. **Black, purple, and tan discolorations have been found within red-pigmented areas of the peach fruit skin. Scanning electron and light micrographs show damage caused by defuzzing and roller drying, which could facilitate entry of causal agents associated with peach skin discoloration. Comparisons of reflectance and transmittance spectra (380–700 nm) of discolored (purple) and nondiscolored (red) peaches show the mean reflectance value for discolored peaches is 100% darker than nondiscolored peaches. However, transmittance spectra of acidified extracts of discolored and nondiscolored peach skins are similar throughout these wavelengths. Extracted pigment color was altered by pH changes and metallic ion concentration. At low pH, discoloration may be caused by ion complexing with anthocyanin pigment. At high pH, discoloration may result from alkaline hydrolysis of the pigment molecule.**

In the last 20 years, peach growers in the southeast have reported an increasing incidence of discolored fruit in the fresh peach market. This abnormal coloration has many names, but the most common is "black streak" (10). The term "black streak" refers to the black color that occurs most often as a streaked pattern in the red-pigmented area (or blush) of the peach skin. The discoloration also may cover the entire blush area, may take the form of speckles or spots, and may be purple or tan rather than black (14). In some instances, the black or purple coloration disappears, leaving the affected areas a translucent tan color. Abnormal colors, particularly brown and tan, often occur outside the blush area. These discoloration disorders are restricted to the skin and do not affect the flesh. We will refer to these disorders as peach skin discoloration (PSD).

The increased incidence of PSD has been related to the development of agri-chemicals, bulk handling, hydrocooling, chlorination, and the multi-procedured packing operations that roll or rub fruit (3, 10, 14, 16). Iron salts in hydro-procedures have been implicated in intensifying discoloration (10). PSD often does not appear until several hours after the fruit has been packed (10, 14). Frequently, the fruit is in transit or has arrived at its destination when discoloration occurs.

The only appreciable red pigment reported to be in the peach is cyanidin-3-glucoside (7, 11, 17). This compound is an anthocyanin, and many anthocyanins change color when their environmental pH is altered (1, 6, 9, 18, 20) and/or when they bind with metallic ions (6, 13).

We hypothesized that pigment structure changes result in the change in color associated with peach skin discoloration. These changes may be affected by the handling system that would alter the pigment's environment, particularly pH, metallic ion concentration, or chlorine content. Physical damage to the fruit skin during the packing operations may predispose the fruit to the effects of these causal agents.

Received for publication 28 May 1985. Technical Contribution No. 2359. South Carolina Agricultural Experiment Station, Clemson, SC 29631. Appreciation is expressed to Larry Dyck, Dept. of Biological Sciences, George E. Carter, Jr., Dept. of Plant Pathology and Physiology, and Ed Vaughn, School of Textiles, for their assistance and the use of laboratory equipment. Appreciation is also expressed to Clyde Moore and JoAn Hudson, Electron Microscopists, for their assistance and support. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

[1]Dept. of Horticulture, Institute of Phytopolyology.
[2]Dept. of Biological Sciences.

Materials and Methods

Microscopy. Samples of skin (5 × 5 mm) were taken from 'Redglobe' peaches with pubescence intact and from fruit that had been defuzzed on a commercial washer–waxer. All samples were fixed in 3.5% glutaraldehyde for 24 hr and dehydrated in an ethanol series (50%, 60%, 70%, 80%, 90%, 95%, and 100%) at 30-min intervals. Samples for scanning electron microscopy (SEM) were critical-point dried and sputtered with gold. Samples for light microscopy were embedded in JB-4 plastic embedding medium, and 5 μ cross-sections were prepared on an ultramicrotome.

Purification and spectral analysis. Reflectance measurements (380–700 nm) were taken from a 1-cm-diameter area of the darkest areas on discolored and nondiscolored fruit with a Bausch and Lomb Match-Scan 3000 colorimeter. The sample areas then were removed with a 1-cm-diameter cork borer, the fruit tissue separated from the skin, and the skin extracted in 0.5 N oxalic acid. Transmittance measurements were taken as described.

The blush area of 'Marsun' peach skins was extracted with 1% HCl-methanol. The procedures used for paper chromatography and UV spectral analysis were those outlined by Mabry et al. (15).

For pH and metallic complexing determinations, a 200-μl aliquot of the concentrated extract was added to a series of 5-ml aqueous solutions of 0.5 N oxalic acid that had been adjusted over a pH range of 1–9 with dibasic potassium phosphate. Metallic treatments were prepared similarly with the addition of 100 ppm of metallic ions from commercially prepared solutions of metals commonly used in agri-equipment. After 5 min equilibration time, the samples were examined spectrally in the visible range (400–600 nm) on a Beckman Model 25 Spectrophotometer. Three samples per treatment were used.

To establish minimal metallic concentrations for effects, 200-μl aliquots of the concentrated extract were added to 5-ml aqueous solutions (0, 10, 50, and 100 ppm of each metallic ion) acidified to pH 1.0 with hydrochloric acid to assure complete solubility of the metals. The samples (3 per treatment) were examined visually at 4, 8, 24, and 32 hr.

To establish minimal chlorine concentrations for effects, 200-μl aliquots of the concentrated extract were added to 5 ml of distilled deionized water (acidified with hydrochloric acid to pH 1.8 for stability of the pigment). Sources of chlorine were sodium hypochlorite and calcium hypochlorite at 0, 10, 50, and 100 ppm. The samples (3 per treatment) were examined visually at 4, 8, 24, and 32 hr.

Results

Initial examinations of extracts from discolored (purple) and nondiscolored (red) peach skins suggested that PSD is a pigment response. The acidified methanolic extracts from both discolored and nondiscolored peach skins are red. Co-chromatography (TLC) of these extracts showed that the pigments from each have identical R_f values.

The relationship of pH to skin color was observed by placing a drop of 1.0 N hydrochloric acid (HCl) or 1.0 N potassium hydroxide (KOH) on the blush area of discolored and nondiscolored fruit. The HCl turned the area under the drop on discolored fruit from purple to red; the area on nondiscolored fruit remained red. The HCl was removed and replaced with a drop of KOH, which turned both areas black. When the KOH was removed and replaced with HCl, the black areas again turned red. This reversible effect lasted for several minutes, after which the skin became translucent tan as the pigment leached from the cells.

Light microscopy of skin peeling revealed stoma at the center of each red speckle outside of the red blush area. Likewise, in the blush areas, the darkest concentration of color is around the stomata. After a drop of 0.01 N KOH was placed on the nondefuzzed skin, the area around the stoma was the first to discolor. The discoloration spread slowly from the stomal area throughout the skin. Ten to 20 min following the initial discoloration, the skin became translucent. Under similar conditions with defuzzed skins, discoloration occurred around broken trichomes and stomata. The discoloration spread rapidly (20 to 40 min), and again the skin became translucent.

Microscopy. The effects of defuzzing fruit are shown in Fig. 1. Figure 1 A and C show a high population of trichomes on nondefuzzed fruit, whereas Fig. 1 B and D show population depletion and surface pitting caused by trichome removal. Many of the remaining "short" trichomes (Fig. 1 B and D) are actually broken stumps that appear whole due to the illusory effect of electron "charging" in SEM.

Light microscopy further depicts the damage to the epidermis and trichomes from defuzzing (Fig. 2). The peach skin is made up of an epidermis, consisting of small cells, that is generally 3 to 4 cells deep (Fig. 2A a), and a hypodermis of somewhat larger cells that is usually 2 to 3 cells deep (Fig. 2A b). The mesocarp cells (fruit tissue) are considerably larger than those of the skin (Fig. 2A c). The epidermis surrounds the trichome base, which usually originates in the 2nd or 3rd layer of cells (Fig. 2A d) (4). Typical damage incurred by the epidermis and trichomes includes cleanly severed trichomes (Fig. 2B), lacerated trichomes (Fig. 2C), and lacerated epidermis (Fig. 2D).

Spectral analysis. The reflectance spectra for discolored and nondiscolored fruit are similar from 380 to 600 nm (Fig. 3). From 600 to 700 nm, reflectance from nondiscolored areas is about twice that from discolored areas. Transmittance spectra for pigments extracted from discolored and nondiscolored fruit are similar throughout the 380 to 700 nm range.

For the purified pigment, the band I maxima of 528 nm falls into the spectral range for a cyanidin glycoside (8). Further, the band I shift in aluminum chloride is indicative of the free B-ring hydroxyls present in cyanidin.

Color changed gradually as the pH increased (data not shown). The color from pH 1–4 was generally stable but became lighter. At pH 4 to 5 the pigment was colorless. Color gradually returned between pH 5–7, and was accompanied by a bathochromic shift of wavelength maxima and percentage of absorbance. As pH increased from 7–9, both the wavelength maxima and absorbance increased, and the color darkened from purple to purple-gray. Through the following 24 hr, the appearance of a reddish brown precipitant increased with time and pH.

Response of extracted pigment to metallic ion treatments (data not shown) varied slightly from the control treatments between pH 1–6, with the exception of tin, which darkened at pH 3 to 4. Aluminum and iron caused changes in wavelength maxima, absorbance, and color at pH 6 to 7. At pH 7 to 8, aluminum's wavelength maxima had stabilized, but absorbance had increased and pigment color had deepened. Iron at pH 7 to 8 had again increased wavelength maxima and absorbance, and had darkened color. At pH 8 to 9, all treatments varied slightly from the control and were beginning to blacken. Through the following 24 hr, the appearance of a reddish brown precipitant increased with time and pH.

Several concentrations of metallic ions were examined (Table 1). Of these, 50 ppm (iron, aluminum, and tin) was the lowest concentration that affected color. Chlorine also was examined (Table 2) and found to alter color at less than 25 ppm total chlorine.

Discussion

Breaking the trichomes disrupts the epidermal cells and could facilitate the invasion of solutes into the epidermal cells, which, in turn, could alter the color of anthocyanin molecules. The preliminary observation that potassium hydroxide entered and discolored cells surrounding broken trichomes supports this. PSD occurs frequently in the southeast, where large volumes of water are used during packing operations thus providing an opportunity for solutes to enter the damaged area of the epidermis. PSD occurs infrequently in the west where low volume mists are used in packing operations.

The reflectance data indicate that the discolored fruit is about 100% darker than the nondiscolored in the orange-red wavelengths (600–700 nm). However, transmittance readings of the extracts suggest that the pigments are the same, indicating pigment response.

Anthocyanins like cyanidin-3-glucoside, that have ortho-dihydroxyl groups, can form complexes with metallic ions (13). Color intensity can be enhanced when complexing with tin (pH 3 to 4) or aluminum and iron (pH 6–8). The concentration of these metals required to induce color change can be as little as 50 ppm (Table 1).

A common method of disinfecting hydro-systems is by chlorination. Both calcium hypochlorite and sodium hypochlorite caused color loss when total chlorine concentrations were 25 ppm or greater (Table 2).

Other buffer systems (1, 6, 9, 17, 19), as well as our potassium phosphate-oxalic acid system, demonstrate that pH can change anthocyanin color. Also, metallic ion complexing with the anthocyanin can enhance color changes at certain pHs. The buffer system used can have a unique effect on metallic ion complexing (13). Void of a buffered system, metallic ion complexing can alter anthocyanin color, even at a pH where the pigment is most stable (Table 1). Additionally, chlorine, void of a buffered system, can bleach color almost completely at a total chlorine concentration of 25 ppm (Table 2). Chlorine effects in the model were not detectable because of chlorine evolution.

The reviews, observations, and data compiled in this study suggest that PSD can be caused in numerous ways. Certainly the fact that discoloration appears outside the red-pigmented area of the skin suggests multiple causes of PSD. Those causes

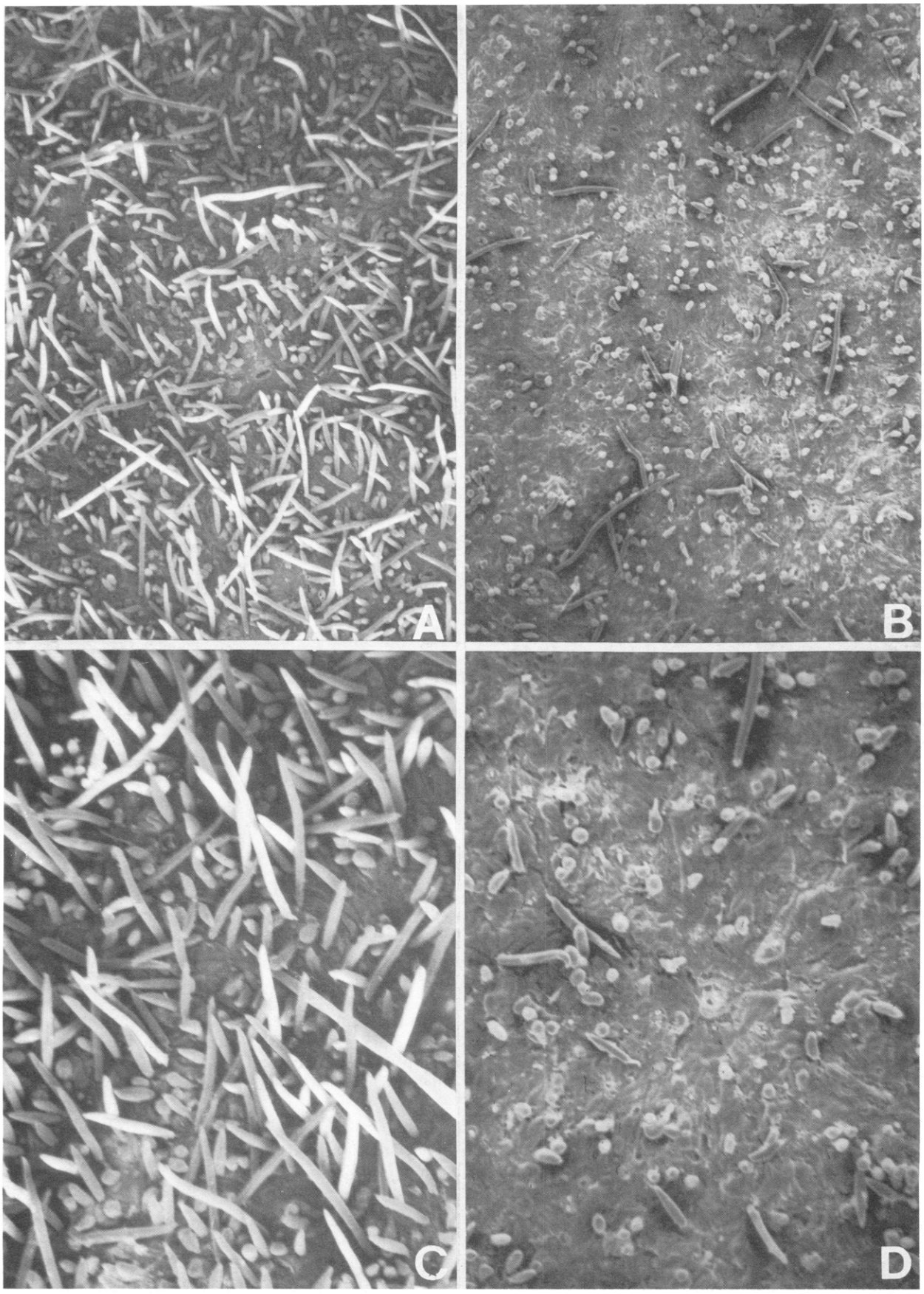

Fig. 1. Effects of defuzzing on the epidermis of a peach. Frames **A–D** are scanning electron micrographs of the peach fruit surface. (**A**) nondefuzzed, ×40; (**B**) defuzzed, ×40; (**C**) nondefuzzed, ×80; (**D**) defuzzed, ×80.

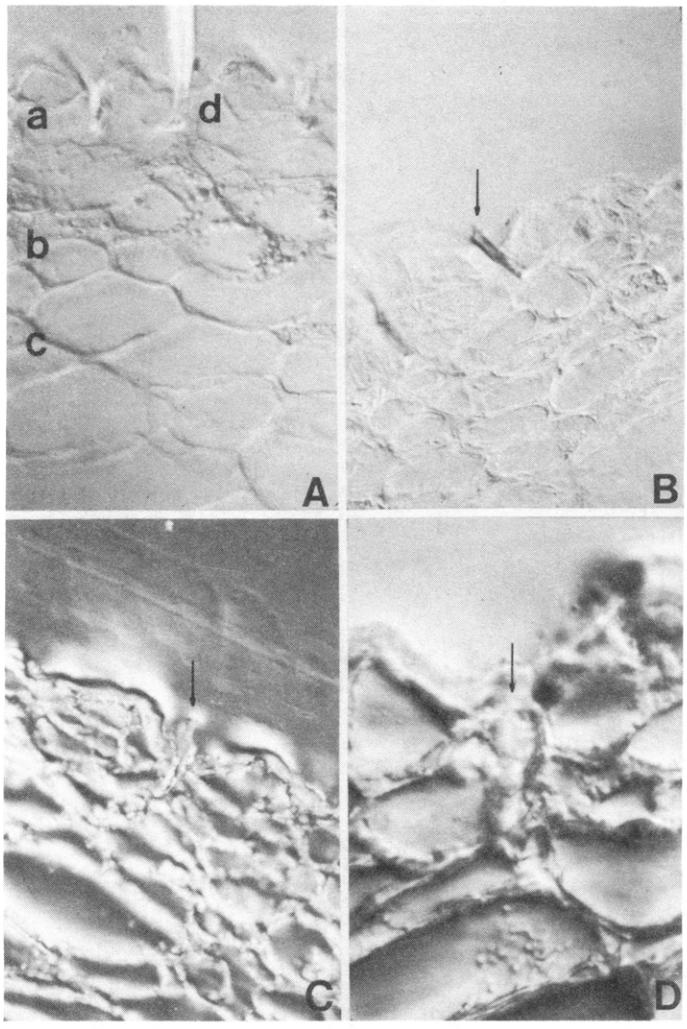

Fig. 2. Frames **A–D** are light micrographs of the peach fruit skin in cross section. (**A**) ×114, (**Aa**) Small epidermal cells are generally 3–4 cells deep, (**Ab**) slightly larger hypodermal cells are usually 2–3 cells deep, (**Ac**) large fruit tissue cells, (**Ad**) trichome is a specialized cell of the epidermis that typically orinates in the second or third layer; (**B**) Cleanly severed trichome stump, ×114; (**C**) jaggedly torn trichome, ×114; (**D**) lacerated epidermis from complete trichome removal, ×276.

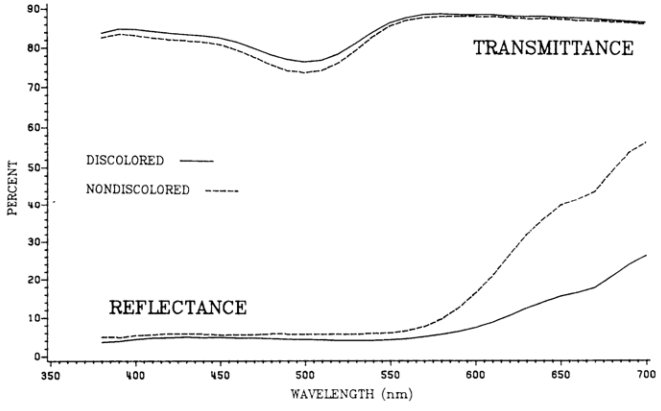

Fig. 3. Reflectance and transmittance spectra of discolored and nondiscolored peach fruit skins.

Table 1. Effect of differing concentrations of metallic ions on cyanidin-3-glycoside in HCl acidified (pH 1.0) distilled deionized water.

Metallic ion	Concn (ppm)	Color[z]
Fe	0	Orange
	10	Orange
	50	Light yellow
	100	Light yellow
A1-1	0	Orange
	10	Orange
	50	Pink
	100	Pink
Sn	0	Orange
	10	Orange
	50	Pink
	100	Pink
Zn	0	Orange
	10	Orange
	50	Orange
	100	Orange
Ni	0	Orange
	10	Orange
	50	Orange
	100	Orange

[z]Visual observations under fluorescent lighting. Hue of color differed with treatment though expressed as having same basic color. Color changes stabilized by 32 hr.

Table 2. Effect of differing concentrations chlorine on cyanidin glycoside in HCl/distilled deionized water acidified to pH 1.8.

Compound	Compound ppm	Total Cl (ppm)	Color[z]
Calcium Hypochlorite	0	0	Orange/pink
	10	04.96	Orange/pink
	50	24.79	Very light orange
	100	49.59	Clear
Sodium Hypochlorite	0	0	Orange/pink
	10	04.76	Orange/pink
	50	23.81	Very light orange
	100	47.62	Clear

[z]Visual observations under fluorescent lighting. Hue of color differed with treatment though having same basic color. Color changes stabilized after 4 hr.

examined and found to affect color changes of anthocyanin include: pH, metallic ion complexing, buffering capacity, and chlorination. Conditions and circumstances, other than those discussed, that may be involved in PSD include: enzymes (6, 12), glycosylation (8), acylation (8), cations (2), temperature (5), copigmentation (1, 13), oxidation (6), and macromolecular association (19). Also, there are other flavanoids that may play a role in PSD.

A peach, with or without surface damage, can absorb water. The tissue could be affected by absorbing characteristics of the water (pH, ions, etc). This exchange could be enhanced by epidermal damage that allows endogenous and/or exogenous reactants previously separated to combine. Consequently, fruit dehydration, fruit surface damage, and/or prolonged contact of fruit with water could increase absorption, increasing the incidence of PSD. At low pHs, cations are in the ionic forms and freely soluble in water. As water enters the peach through dam-

aged areas, ions also enter. These ions could complex with anthocyanins and result in dark coloration.

The black and purple colors associated with PSD in the red pigmented areas could be the result of an increase in the anhydrobase form of the anthocyanin when its cellular environment is above pH 8. The translucent tan color found in PSD could be caused by the conversion of the anthocyanin to the colorless pseudobase, by chlorine bleaching, or by loss of the hydrophyllic athocyanin from damaged skin cells.

Literature Cited

1. Asen, S., K.H. Norris, R.N. Stewart, and P. Semeniuk. 1973. Effect of pH, anthocyanin, and flavanoid co-pigments on the color of statice flowers. J. Amer. Soc. Hort. Sci. 98:174–176.
2. Amerine, M.A. 1958. The inorganic constituents of wine. Adv. Food Res. 8:133.
3. Chastagner, G.A. and J.M. Ogawa. 1976. Injury of stone fruits by preharvest captan sprays followed by postharvest treatment. Phytopathology 66:924–927.
4. Curtis, K.M. 1928. The morphological aspect of resistance to brown rot in stone fruit. Ann. Bot. 42:39–68.
5. Daravingas, G. and R.F. Cain. 1968. Thermal degradation of blackberry anthocyanin pigments in model systems. J. Food Sci. 33:138–142.
6. Eskin, N.A. Michael. 1979. Plant pigments, flavors, and textures: The chemistry and biochemistry of selected compounds. Academic, New York.
7. Harborne, J.B. 1967. Comparative biochemistry of flavanoids. Academic, New York.
8. Harborne, J.B. 1976. Function of flavanopids in plants. In: T.W. Goodwin (ed.). Chemistry and biochemistry of plant pigments (Vol. 1). Academic, New York.
9. Harper, K.A. 1968. Structural changes of flavylium salts. Austral. J. Chem. 21:221–227.
10. Harvey, J.M., Wilson L. Smith, Jr., and Jacob Kaufman. 1972. Market diseases of stone fruit: Cherries, peaches, nectarines, apricots, and plums. USDA Agr. Hdbk. 414 p.44.
11. Hsia, C.L., B.S. Luh, and C.O. Chichester. 1965. Anthocyanin in freestone peaches. J. Food Sci. 30:5–12.
12. Huang, H.T. 1955. Decolorization of anthocyanins by fungal enzymes. Agr. Food Chem. 3(2):141–146.
13. Jurd, L. and S. Asen. 1966. The formation of metal and "co-pigment" complexes of cyanidin-3-glucoside. Phytochemistry 5:1263–1271.
14. Ridley, J.D., L.O. Van Blaricom, and E.T. Sims, Jr. 1976. Postharvest treatment influences discoloration of fresh peaches. S.C. Agr. Expt. Sta. Cir. 560.
15. Mabry, T.J., K.R. Markham, and M.B. Thomas. 1970. The systematic identification of flavanoids. Springer, New York.
16. Van Blaricom, L.O. and J.D. Ridley. 1976. Skin discoloration of fresh market peaches. HortScience 11:225. (Abstr.)
17. Van Blaricom, L.O. and T.L. Senn. 1967. Anthocyanin pigments in freestone peaches grown in the southeast. J. Amer. Soc. Hort. Sci. 90:541–545.
18. Van Buren, J.P., G. Hrazdina, and W.B. Robinson. 1974. Color of anthocyanin solutions expressed in lightness and chromaticity terms: effect of pH and type of anthocyanin. J. Food Sci. 39:325–328.
19. Van Teeling, C.G. 1971. An anthocyanin complex isolated from the syrup of canned blueberries. J. Food Sci. 36:1061.
20. Wrolstad, R.E., T.P. Putnam, and G.W. Varseveld. 1970. Color quali ty of frozen strawberries: effect of anthocyanin, pH, total acidity; and ascorbic acid variability. J. Food Sci. 35:448–452.

J. AMER. SOC. HORT. SCI. 111(4):553–557. 1986.

Effect of Storage on Quality and Sugars in Muskmelon

R.A. Cohen[1] and J.R. Hicks[2]

Vegetable Crops Department, Cornell University, Ithaca, NY 14853

Additional index words. *Cucumis melo*, muskmelon, quality, carbohydrates, soluble solids content, sensory evaluation

Abstract. **Melons (*Cucumis melo*) of 3 cultivars ('Gold Star', 'Saticoy', and 'Superstar') were stored at 5° or 12.5°C for 2, 5, or 9 days and at 20° for 2 and 5 days. 'Gold Star' and 'Superstar' deteriorated less in storage than 'Saticoy'. In general, levels of fructose and glucose decreased with an increase in storage time and temperature. The fructose : glucose ratio increased with storage. No change was detected in soluble solids content (SSC) or in sucrose concentration. Sensory evaluations of stored (7 days at 5° or 12.5°) vs. freshly harvested melons showed no difference in texture, flavor, off-flavor, sweetness, or overall acceptability. SSC and sucrose content correlated well with the latter 4 attributes only in 'Gold Star' melons.**

Soluble solids content has long been used as an indicator of muskmelon quality, sweetness, flavor, acceptability, and maturity (16). The level of SSC reflects not only stage of maturity, but also the quality and grade of the melon (7). Muskmelon must have a SSC level of at least 9% to make U.S. #1 grade (19).

The stem end and ground spot of the muskmelon were shown in 1902 to have poorer eating quality than either the blossom end or the top portion opposite the ground spot (13). The inner flesh of the melon has higher SSC, with a gradual decrease toward the rind, and SSC was as much as 2% lower at the stem end than at the blossom end (17). Lower SSC in the ground spot than in the top of the melon has also been reported (6).

Hartman and Gaylord (12) noted that, while SCC was indicative of muskmelon eating quality, it did not correlate "nearly well enough with taste to be used blindly as a measure of edible quality". Gilbart and Dedolph (11) took this a step further and stated that no single variable could be used to estimate quality, although taste acceptance of muskmelons was found to be dependent on their SSC. Further doubt was brought to the rela-

Received for publication 10 May 1985. Vegetable Crops Department Paper No. 835. This research was supported by ARS/USDA Specific Cooperative Agreement (small farm). The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

[1]Former Graduate Student. Present Address: ARS/USDA, Horticultural Crops Quality Laboratory, Beltsville, MD 20705.

[2]Associate Professor.