J. AMER. SOC. HORT. SCI. 110(1):53–57. 1985.

Ground Color as a Peach Maturity Index

Michael J. Delwiche and Reginald A. Baumgardner

Departments of Agricultural Engineering and Horticulture, Clemson University, Clemson, SC 29631

Additional index words. *Prunus persica*, grade, firmness

Abstract. **Changes in peach ground color were analysed over the periods of growth, maturation, and ripening for an early, mid-season, and late maturing cultivar. Color was measured with a tristimulus colorimeter in Hunter "L", "a", "b" coordinates. Ground color progressions over time were similar for the 3 cultivars. All color coordinates increased during the 3 weeks prior to harvest, with the "a" coordinate showing the largest rate of change with time. Ground color also was compared with a trial series of 6 uniformly spaced color references. High correlations between color reference selection and measured "a" value demonstrated the feasibility of a ground color reference maturity index even when color matches were not exact. Effects of packing house operations on ground color were investigated. Removal of fuzz by brushing had little effect on measured color, whereas wetting of the brushed surface caused a distinct decrease in lightness ("L" value) but little change in chromaticity ("a" and "b" value).**

Development of objective and reproducible maturity indices for fresh market peaches has not kept pace with expansion in the industry. Recent developments in grading and marketing of California fruit, and subsequent actions by the Southeastern fresh peach industry, have underscored the need for uniform and repeatable maturity standards. A range of possible maturity parameters have been suggested in the past. Rood (5) examined 7 peach maturity indices: flesh firmness, skin ground color, flesh color, flesh chlorophyll content, titratable acid, soluble solids, and the acid-to-soluble solids ratio. Maturity ratings were based on edible quality after ripening. The best single maturity indicator over all cultivars tested was flesh firmness, followed by skin ground color, as measured by comparison with painted color charts. Ground color is defined as the green-yellow coloration of the peach skin exclusive of the red pigmented (i.e., blushed) area. As a maturity index, ground color has the advantage of being nondestructive.

Sims et al. (6) examined the relationships between different maturity indices for a single cultivar. Color was indexed using several color charts and measured with a tristimulus colorimeter. A high correlation between flesh firmness and colorimeter readings of ground color led to the suggestion that these be used as coindices of peach maturity. They suggested the development of accurate ground color reference charts from colorimeter data.

Current USDA grade standards for fresh peaches (7), written in 1952, specify that peaches of all grades be mature, but not soft or overripe. No objective measure of maturity is given. Both US Fancy and US Extra No. 1 grades also require a portion of the peach surface to be blushed (i.e., overcolor). Due to overcolor variability, ground color is considered to be a superior indicator of maturity. In 1980, the California Tree Fruit Agreement (CTFA) adopted a series of ground color references as maturity standards supplemental to the U.S. No. 1 grade. No more than 10% of the peach surface may be greener than the designated color reference shade at the time of inspection, and no more than 10% of the lot may fail this requirement.

Received for publication 10 Feb. 1984. South Carolina Agricultural Experiment Station Technical Contribution No. 2262. We express our appreciation to Peter Sites and Kimberly Benson for assistance with the laboratory measurements, and to David Price for help with the maturity analysis. This research was supported in part by the South Carolina Peach Council and Promotion Board, the Georgia Peach Council, the Georgia Commodity Commission for Peaches, the National Peach Council, and Uniroyal Chemical Company. 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.

During the 1982 season, we conducted studies to determine the adaptability of the CTFA color references to peaches grown in South Carolina (2). Samples of 13 cultivars covering a range in maturity were measured for ground color, soluble solids, titratable acid, taste, and appearance. Ground color was measured with a tristimulus colorimeter in Hunter color coordinates ("L", "a", and "b") and compared with a series of color references, including those from the CTFA. Results showed that ground color was a slightly better at-harvest indicator of edible quality after ripening than flesh firmness. Differences for varying maturities occurred primarily in the "a" color coordinate, which increased as maturity advanced. Threshold maturity ground colors for the 13 cultivars tested were narrowly distributed in color space. California color references did not match the ground color measurements of South Carolina peaches. These data suggested that ground color changes during growth and maturation follow a uniform progression in color space, and that a single color path might be identified and used to specify maturity standards.

Similar studies have been made on the relationship of maturity to the quality of canned clingstone peaches. Unlike fresh peach cultivars (i.e., those with "melting" flesh), ground color and flesh firmness are not good maturity indices for processing peach cultivars (i.e., "nonmelting" flesh). Fuleki and Cook (3) used a tristimulus colorimeter to measure flesh color before and after canning over a wide range of maturities. Peaches were sorted into 10 maturity groups based on Hunter "a" values and evaluated by a panel of judges for overall canned quality. Specific "a" value ranges were found to yield the best quality products, but these ranges differed between the 2 cultivars tested.

Our objectives in this study were: 1) to measure changes in fresh peach ground color during growth, maturation, and into

Table 1. Trial color reference series (1983): targeted colors and actual colors used.

Color reference	Target color[z] L	a	b	Actual color[y] L	a	b
1	61.2	−10.0	26.8	60.8	−9.6	26.9
2	61.2	−8.0	26.8	60.6	−7.4	26.8
3	61.2	−6.0	26.8	60.3	−5.8	26.6
4	61.2	−4.0	26.8	60.5	−3.5	26.6
5	61.2	−2.0	26.8	60.6	−1.6	26.6
6	61.2	0.0	26.8	60.3	+0.3	26.7

[z]Based on 1982 data from 13 cultivars (2).
[y]Measured with colorimeter after lamination.

Table 2. Characteristics of fruit rated at threshold maturity, averaged over all trees of each cultivar.

Cultivar	Colorimeter coodinates L	a	b	Taste rating[z]	Visual rating[z]	Soluble solids (%)	Titratable acidity[y]	Firmness (N)
Redhaven	64.8	−4.1	28.5	1.8	2.1	9.5	0.86	60.9
Redglobe	64.5	−4.0	28.8	1.8	2.4	10.9	0.82	71.2
Rio Oso Gem	63.4	−2.8	28.2	1.9	1.5	13.1	0.76	66.8

[z]Average panel rating: 1 = unacceptable, 2 = acceptable, 2 = better than acceptable.
[y]Expressed as malic acid: g/100 ml juice.

Table 3. Comparison of the effects of surface treatments on ground color at the designated harvest times (t = 0), with like trees pooled.

		Surface treatment											
		Dry			Brushed			Brushed & wet					
Cultivar	n	L[z]	a	b	L	a	b	L	a	b	Mass (g)	Firmness (N)	Color ref.[y]
Redhaven	30	64.6	−3.6	29.0	64.5	−4.5	29.4	61.6	−4.5	30.7	112.3	64.5	4.5
(SE)		(0.4)	(0.4)	(0.2)	(0.4)	(0.4)	(0.2)	(0.4)	(0.5)	(0.1)	(3.1)	(1.3)	(0.2)
Redglobe	30	64.8	−4.8	28.5	64.4	−6.2	29.2	61.3	−6.5	30.6	156.8	76.5	3.7
(SE)		(0.4)	(0.4)	(0.2)	(0.4)	(0.4)	(0.2)	(0.5)	(0.5)	(0.2)	(4.8)	(1.3)	(0.2)
Rio Oso Gem	20	63.6	−0.5	29.1	63.6	−1.6	28.7	59.4	−1.0	29.2	118.5	60.5	5.4
(SE)		(0.4)	(0.6)	(0.3)	(0.4)	(0.6)	(0.3)	(0.6)	(0.7)	(0.4)	(3.3)	(1.8)	(0.2)

[z]Hunter tristimulus colorimeter coordinates.
[y]Mean value of the trial color reference numbers (Table 1) visually selected to match most closely the dry, unbrushed surface.

Table 4. Correlation coefficients between time from harvest, measured ground color "a" value, and average color reference selection.[z]

Color reference	Time	"a"[y]	Cultivar
			Redhaven
"a"	0.8878	---	(n = 9)
Color ref.[x]	0.8865	0.9951	
			Redglobe
"a"	0.7692	---	(n = 13)
Color ref.	0.7851	0.9911	
			Rio Oso Gem
"a"	0.8288	---	(n = 14)
Color ref.	0.7600	0.9765	

[z]Data for dry fruit, pooled at each sample time. All correlation coefficients significantly nonzero ($P \leq 0.0001$).
[y]Hunter tristimulus colorimeter coordinate.
[x]Mean value of the selected color reference number.

Table 5. Revised ground color reference series.

Reference	t(day)	L[z]	a[y]	b[x]
0	−12	61.6	−8.6	27.2
1	−9	62.2	−7.2	27.5
2	−6	62.7	−5.9	27.8
3	−3	63.3	−4.5	28.1
4	0	63.9	−3.1	28.4
5	3	64.4	−1.8	28.7

[z]Linear regression: $L = 0.186t + 63.859$ ($R^2 = 0.563$).
[y]Linear regression: $L = 0.639t - 1.007L + 61.147$ ($R^2 = 0.833$).
[x]Linear regression: $b = 0.025t + 0.395L + 3.219$ ($R^2 = 0.704$).

ripening for a range of cultivars; 2) to quantify the effects of packing house operations (i.e., washing and brushing) on ground color; and 3) to determine the feasibility of using ground color references as a nondestructive index of maturity.

Materials and Methods

Fruit handling. Peaches were sampled from 7-year-old trees in a Clemson Univ. orchard managed under typical commercial conditions with no irrigation. Three widely planted cultivars were selected to represent early, mid, and late season: 'Redhaven' (3 trees), 'Redglobe' (3 trees), and 'Rio Oso Gem' (2 trees). At each sampling, 10 fruit of uniform size were picked from random locations on each tree. These peaches were selected to have sufficient ground color surface area for colorimeter measurement, and normally were chosen from the largest fruit. Trees were sampled once a week during fruit growth, and every few days during maturation.

Samples were taken without postharvest cooling to the laboratory and tested within several hours. A circular area, about 2 cm in diameter, was marked on the greenest area of ground color for each fruit. Color measurements first were made with this area dry and unbrushed. Measurements were repeated after removal of the fuzz by brushing the peach on corduroy. Finally, color measurements were made with the brushed surface wetted. Cheek-to-cheek diameter and fruit mass were determined. Firmness was measured with an Effegi fruit pressure tester (Model FT 327, Effegi, 48011, Alfonsine, Italy) using a 8-mm diameter tip and averaging results from both pared cheeks.

Color measurement. Color was measured within the designated area of each peach using a tristimulus colorimeter (Model D25A-2, F, STH, H. Hunter Associates Laboratory, 11495 Sunset Hills Road, Reston, VA 22090) employing 45° diametrically opposed illumination and a 6.4 mm viewing aperture. Due to the directional nature of the colorimeter illumination and small color variations within the designated surface area, each fruit was rotated 90° on axis and a 2nd reading within the same area was averaged with the first. All data are given in the Hunter "L", "a", and "b" coordinate system, referenced to Illuminant C (average indirect daylight) (1, 4).

Comparison of the ground color change over time (i.e., ground color path) for the 3 cultivars is complicated by their different ripening sequences. To adjust for the chronological displacements, color data are plotted as functions of time (in days) before harvest, with data from like trees pooled at each sampling. The harvest date, designated by $t=0$, was determined by the 1st day that all trees of each cultivar had a significant number of threshold mature peaches and a few soft fruit (firmness<27 N).

In addition to the colorimeter measurements, a trial series of 6 green-yellow color references (Table 1) was evaluated visually on the same fruit. Based on the data taken during 1982 (2), these color references were specified to lie at uniform intervals along a straight line in color space intersecting the region of threshold maturity fruit. The color references were made from lacquer coated paper with a matte finish, and laminated in clear plastic. The color reference judged to match most closely ground color in the designated area of each peach before brushing and wetting was determined. All visual ratings were made under indirect daylight.

Maturity analysis. At the time for harvest of each cultivar, 100 peaches covering a range in maturity were selected from each tree. This sample was evaluated to determine the ground color corresponding to the onset of physiological maturity, termed threshold maturity. Physiological maturity has been defined as the stage of development when a peach will continue ontogeny after detachment (8). Note that for fully developed fruit, the onset of physiological maturity corresponds to or slightly preceeds the onset of horticultural maturity. Immature peaches are considered in this report to be fruit that have nearly ceased physical growth but have not reached physiological or horticultural maturity and, hence, will not undergo proper ripening after harvest.

As described in the previous section, ground color of each fruit in the maturity sample was measured with the colorimeter. Based on the "a" color coordinate, samples from each tree of the cultivar being tested were sorted into 5 maturity categories using the following criteria: 1) $a \leq -9$, 2) $-9 < a \leq -7$, 3) $-7 < a \leq -5$, 4) $-5 < a \leq -3$, and 5) $a > -3$. These categories were intended to cover the maturity range represented by each color reference in Table 1. After measuring firmness on a subset of each category, the remaining fruit were allowed to ripen in a 27°C room. Ripe categories of each sample were kept in storage at 2° until all categories had ripened (or softened for immature peaches). Soluble solids, titratable acid, taste, and visual appearance were measured using the procedures described in our previous report (2). A threshold maturity category was selected for each tree, based on the ratings of taste and visual appearance. Average color data for fruit in these threshold categories were considered to estimate threshold maturity ground color for each tree. Individual tree averages were pooled by cultivar to produce an overall estimate of the ground color corresponding to threshold maturity.

Results and Discussion

Figures 1, 2, and 3 show plots of the color coordinates over time for unbrushed peaches, with data from like trees pooled at each sampling time. Note that color measurements were continued after the designated harvest date ($t=0$) for each cultivar. Both the "L" and "b" values of peach ground color (Fig. 1 and 3) increased steadily during growth and maturation. Over the final month before harvest, these increases appear roughly linear, corresponding to the ground color becoming increasingly light and yellow. In contrast, ground color "a" value (Fig. 2) changed very little up to about 3 weeks before harvest, after which time it increased sharply. This change indicates that the ground color was becoming visually less green. Both the "L" and "b" values tended to level off and even decrease slightly after harvest, whereas the "a" value continued to increase.

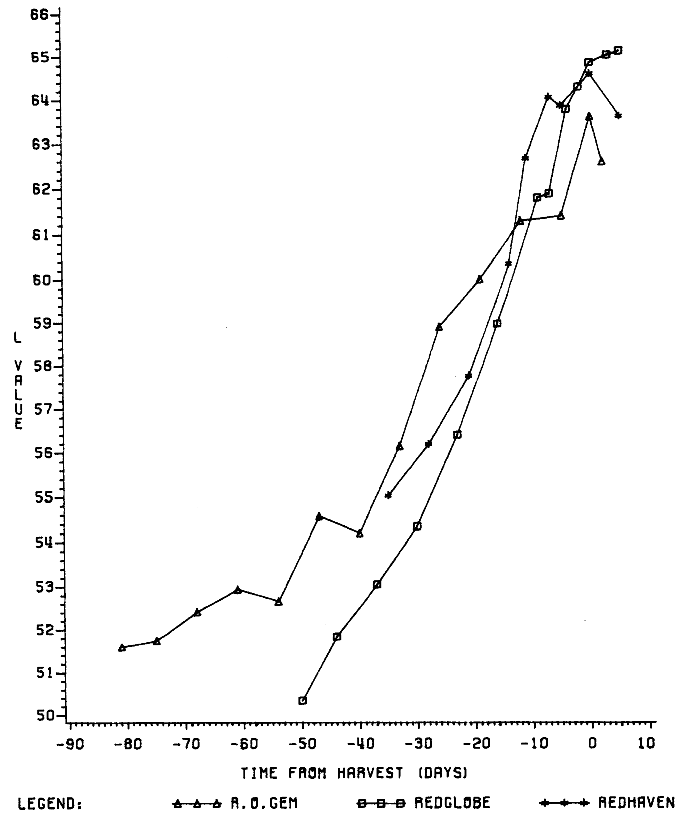

Fig. 1. Changes in ground color "L" value over time (harvest at $t=0$). Range of SE over all sample times: Redhaven– 0.3 to 0.6 ($n=30$), Redglobe– 0.3 to 0.6 ($n=30$), and Rio Oso Gem– 0.4 to 0.9 ($n=20$).

These data substantiate our previous finding (2) that "a" value is the primary coordinate of change near harvest. Those results were based on samples at harvest selected to cover a range in fruit maturity. The data showed that peaches of threshold maturity had about the same "L" and "b" values as mature fruit. The curves in Fig. 1 and 3 indicate that "L" and "b" values tend to level off near the time of harvest, but the increase in ground color "a" value shows no moderation (Fig. 2).

Changes in ground color over time are clearly similar among cultivars. However, several factors must be considered when comparing the 3 curves. Time of harvest was chosen when the trees first showed a significant number of threshold mature fruit and, hence, was not a predetermined point in time for each cultivar. A shift in the designated harvest date for any one cultivar would cause a corresponding horizontal shift in the color coordinate curves. Within a range of several days around harvest, the shape of the curves also is a measure of similarity. Although the colorimeter had a resolution of 0.1 unit for each

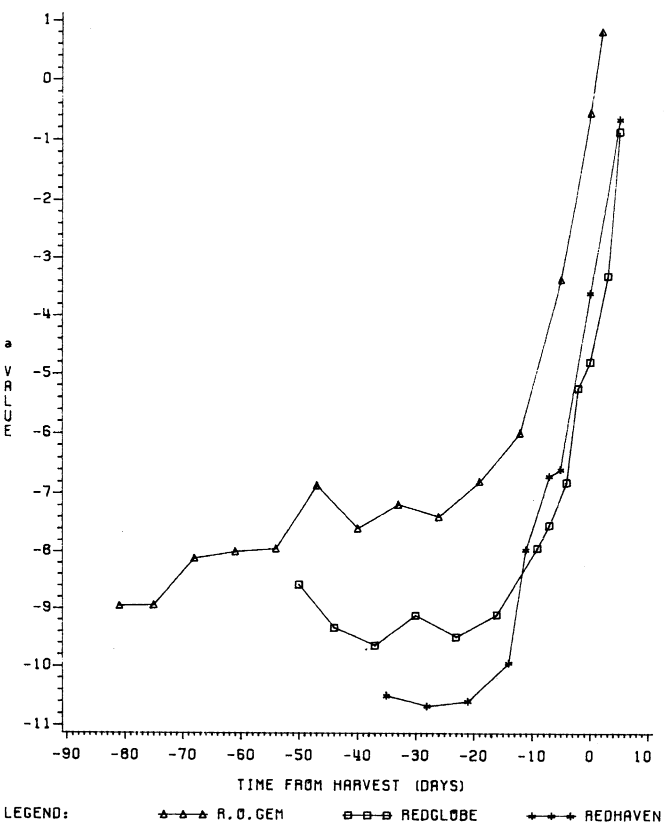

Fig. 2. Changes in ground color "a" value over time (harvest at t=0). Range of SE over all sample times: Redhaven–0.1 to 0.5 (n=30), Redglobe–0.01 to 0.5 (n=30), and Rio Oso Gem–0.2 to 0.7 (n=20).

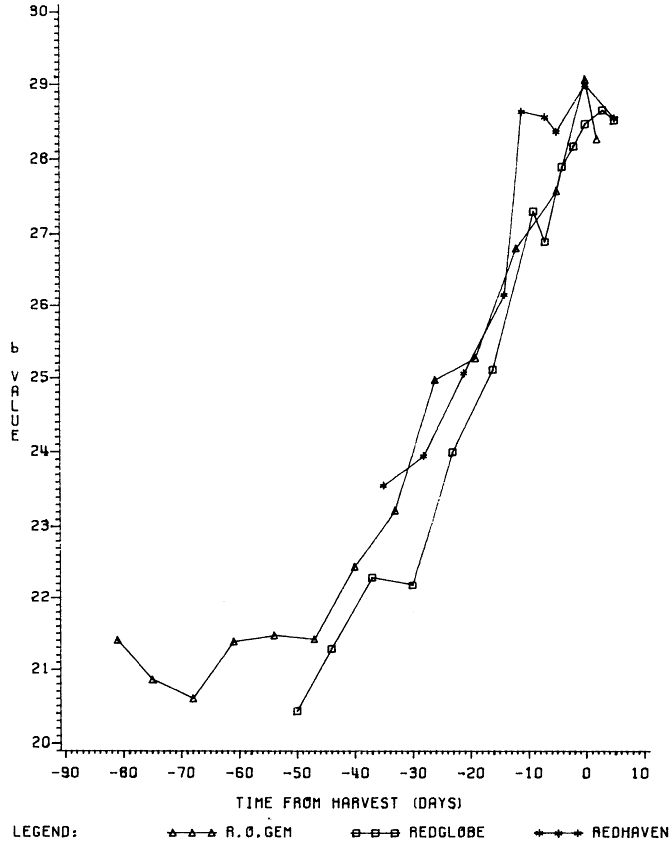

Fig. 3. Changes in ground color "b" value over time (harvest at t=0). Range of SE over all sample times: Redhaven- 0.2 to 0.3 (n=30), Redglobe– 0.2 to 0.3 (n=30), and Rio Oso Gem– 0.3 to 0.4 (n=20).

coordinate, our experience has shown that color differences of less than 1.0 are visually insignificant. Considering both of these factors, the progression of ground color over time was similar for the early, mid, and later maturing cultivars.

The point of physiological maturity on the ground color progression curves was determined from a maturity evaluation at harvest. Results for each cultivar are summarized in Table 2. Ground colors at threshold maturity were similar for the 3 cultivars, with 'Rio Oso Gem' showing a slightly higher "a" value. These results are consistent with our previous determinations of ground color "a" value at threshold maturity (2) and corresponding formulation of the trial color reference series. Dry weather and inadequate thinning delayed the harvest date of 'Rio Oso Gem' about 1 week, resulting in smaller than normal fruit and probably causing the increased "a" values. This effect is evident from the curve in Fig. 2. Percentage of soluble solids at threshold maturity increased with growth length, while titratable acid decreased.

Packing house operations in the United States generally include water or forced air cooling, washing, brushing, waxing, and drying. Effects of different surface conditions on ground color are summarized in Table 3 for peaches sampled at the designated harvest times (i.e., t=0 in Fig. 1–3). Mean ground colors for dry unbrushed 'Redhaven' and 'Redglobe' peaches match the maturity analysis results in Table 2, indicating that the harvest dates were about at the point of average physiological maturity. The 'Rio Oso Gem' harvest date was slightly past this point. Removal of the fuzz by brushing lowered ground color "a" values by about one unit, but had little measurable effect on "L" and "b" values. Wetting the brushed fruit surface caused a distinct decrease in "L" value of 3 to 4 units. The net visual effect of washing and brushing operations is a darker ground color with about the same chromaticity as an untreated peach. This effect could explain the slightly reduced "L" values measured on threshold mature fruit in 1982 (2), when peaches were stored in a cooler over night and measured the following morning. Moisture condensation on the peach surface would have lowered "L" value readings.

Evaluation of ground color references as an index of peach maturity was a specific objective of this research. The trial color reference series in Table 1 was formulated to progress in uniform chromatic steps by maintaining constant "L" and "b" values and varying the "a" value in 2.0 unit increments. Actual ground color measurements shown in Fig. 1–3, and the maturity analysis results in Table 2 indicate that the "L" and "b" values of the color references (Table 1) were slightly low. Figures 1 and 3 also indicate that color reference "L" and "b" values should be incremented to follow more closely the progression of actual ground color during the latter stages of growth and into maturation. These data confirm field reports that the greener color refences (numbers 1–3) were better color matches for actual peaches than the less green references (numbers 4–6).

Although the color references did not fall precisely on the actual ground color paths, selection of the color reference most closely matching ground color "a" value was possible because of the uniform color increment between references. Using the average color reference selections in Table 3 to estimate fruit "a" values by linear interpolation between color reference "a" values in Table 1, estimated "a" values are −2.5 ('Redhaven'), −4.2 ('Redglobe'), and −0.8 ('Rio Oso Gem'). These visual estimates are within about 1 unit of the measured "a" values for dry peaches in Table 3. To assess further the effectiveness of ground color references as an indicator of actual peach ground color and, hence, maturity, correlation coefficients were calculated between the time from harvest, measured "a" value (data for dry fruit, pooled at each sample time), and average color reference selection. High correlations between average color reference selection and measured ground color "a" value in Table 4 indicate the ability to match "a" values. The linear relationship between "a" value and time over the final 2 weeks before harvest (Fig. 2) demonstrates the feasibility of a ground color maturity index. Note that correlation coefficients between time and average color reference are reduced due to the nonlinear relationship of time and "a" value over the entire period of growth and maturation (Fig. 2).

Specification of a single color reference exactly matching the threshold mature ground color is complicated by differences due to cultivar, orchard management, region, and season (2, 5). Although we generally have found these differences small, visual selection of a color match is difficult without a uniform gradient of color references for comparison. This factor limits the adaptability of the CTFA ground color standards.

Based on the data reported here, a revised series of color references can be specified to follow more closely the progression of peach ground color during late growth and early maturation. Starting 14 days before harvest and pooling cultivars, linear regressions were computed for each color coordinate on time. Although the "L" coordinate is strictly a function of the tristimulus Y value, the "a" coordinate is a function of both X and Y, and the "b" coordinate is a function of Z and Y (4). Hence, the regression models for "a" and "b" were written to include effects due to "L" value. (Technically the tristimulus X, Y, and Z variables are not independent, since they are calculated from the same diffuse reflectance curve with different weighting functions.) Linear equations were chosen to maintain constant color increments for a fixed time increment. A revised color reference series was calculated from these parametric equations using 3-day intervals (Table 5). This revised series covers the same range in "a" value as the trial series (Table 1) and begins at about the same "L" and "b" values, but both of the latter are slightly incremented. Reference number 3 or 4 corresponds to the average threshold maturity point on this color path.

Conclusion

Changes in peach ground color were analyzed over the periods of growth, maturation, and ripening for an early, mid-season, and late ripening cultivar. Ground color was measured with a tristimulus colorimeter in Hunter coordinates and plotted as functions of time before harvest. The progression of ground color over time was similar among the 3 cultivars. All color coordinates increased during the 3 weeks prior to harvest, with the "a" coordinate showing the largest rate of change with respect to time.

Ground color also was compared with a trial series of color references based on previous data. High correlations between visual color selection and measured "a" value demonstrated the feasibility of ground color references as a peach maturity index, even when color matches were not exact. A series of ground color references in uniform color increments were specified to match the ground color paths measured during the final 2 weeks before harvest.

The effects of packing house operations on ground color were investigated by comparing color measurements of dry fuzzy peaches with measurements after brushing and wetting. Removal of the fuzz by brushing had little effect on measured ground color. Wetting of the brushed surface caused a distinct drop in "L" value (i.e., surface lightness), but little change in "a" and "b" values (i.e., chromaticity).

Literature Cited

1. Birth, G.S. 1983. Optical radiation, p. 9.01–9.25. In: B.W. Mitchell (ed.). Instrumentation and measurement for environmental sciences. Amer. Soc. of Agr. Engr., St. Joseph, Mich.
2. Delwiche, M.J. and R.A. Baumgardner. 1983. Ground color measurements of peach. J. Amer. Soc. Hort. Sci. 108(6)1012–1016.
3. Fuleki, T. and F.I. Cook. 1976. Relationship of maturity as indicated by flesh color to quality of canned clingstone peaches. Can. Inst. Food Sci. Technol. 9(1):43–46.
4. Hunter, R.S. 1975. The measurement of appearance. Wiley, New York.
5. Rood, P. 1957. Development of objective maturity indices for California freestone peaches. Proc. Amer. Soc. Hort. Sci. 70:104–112.
6. Sims, E.T. Jr. and D. Comin. 1963. Evaluation of objective maturity indices for Halehaven peaches. Proc. Amer. Soc. Hort. Sci. 82:125–130.
7. United States Standards for Grades of Peaches. 18 FR 7116, 11 Nov. 1953. USDA Food Safety and Quality Service, Washington, D.C.
8. Watada, A.E., R.C. Herner, A.A. Kader, R.J. Romani, and G.L. Staby. 1984. Terminology for the description of developmental stages of horticultural crops. HortScience 19(1):20–21.