Color Quality of Oregon Strawberries—Impact of Genotype, Composition, and Processing

T. Ngo, R.E. Wrolstad, and Y. Zhao

ABSTRACT: This investigation was to evaluate fruit color and study the effect of processing on color quality of strawberry products. Three color instruments with different viewing angles, viewing areas, and sample presentation geometries were compared for their effectiveness in measuring CIEL*ab color values for fresh fruits of 6 strawberry genotypes. There were significant differences between genotypes as well as between instruments. Fruits from the Totem genotype were frozen, canned, and made into jam. Color changes were measured along with the following compositional determinations: total monomeric anthocyanins (ACN), total phenolic content (TPC), and percent polymeric color. ACN in fresh strawberries ranged from 37.1 mg to 122.3 mg per 100 g of fresh fruit. Freezing resulted in an apparent increase in ACN and transfer of 70.2% of the anthocyanins from the berries into juice. Physical transfer of pigments to syrup also occurred with canning: there was approximately 70% loss in ACN, about 20% increase in polymeric color, and 23.5% decrease in TPC. Pronounced color change and substantial losses in ACN and TPC of strawberry jams occurred during processing and 9 wk of storage. Storage of jams at 38 °C compared to 21 °C over a period of 9 wk resulted in marked losses of ACN and TPC.

Keywords: canning, color, freezing, genotype, jam, strawberries

Introduction

Strawberries are a rich source of polyphenolics (Sun and others 2002; Aaby and others 2005), with anthocyanin pigments being responsible for their appealing, bright red color (pelargonidin-3-glucoside is the major pigment; Garzón and Wrolstad 2002). Studies on strawberry extracts have shown that strawberry phenolic extracts have high antimicrobial activities (Nohynek and others 2006) and high levels of antioxidants (Aaby and others 2005; Rababah and others 2005). The phytochemicals present in strawberry extracts have also been found to have a potent inhibitory effect in vitro on HepG2 cell proliferation (Meyers and others 2003).

Unfortunately, the attractive color of fresh strawberries does not normally prevail during processing and storage (Garzón and Wrolstad 2002). Compared to other berries, strawberries are relatively low in pigment content (Skrede and others 1992; Clifford 2000), ranging in total anthocyanin (ACN) from 10 to 80 mg/100 g of fresh weight (Rein 2005). Thus degradation during processing and storage can have a major impact on the color of finished products.

The freezing process triggers the formation of ice in cellular fruits, which increases the volume of the fruit (Fennema 1996) and damages the integrity of the cell, leading to fruit structure breakdown. Large drip loss found in the thawed product (Han and others 2004) will have a major effect on the appearance of the product. Another adverse consequence of freezing is that nonaqueous constituents become concentrated in the unfrozen phase (Fennema 1996). Thus, besides lowering reaction rate by lowering temperature, freeze-concentration can increase reaction rates, resulting in decreased anthocyanin and ascorbic acid contents in frozen stored strawberries (Larsen and Poll 1995; Sahari and others 2004).

Processing strawberries by canning or manufacturing into jam necessitates high-temperature treatments that can alter and damage color quality of the finished product. Normal commercial exhaust and sterilization procedures during canning have been shown to have little effect on anthocyanin degradation; the process, however, caused leaching of anthocyanins out of the berries into the syrup (Adams and Ongley 1973). During jam manufacture at atmospheric pressure, anthocyanin losses in the final product varied from 10% to 80% when boiling time ranging from 10 min to over 15 min (García-Viguera and Zafirilla 2001). Under vacuum pressure conditions, loss was approximately 40% during a 15-min process (García-Viguera and others 1999). Maillard reaction products, ascorbic acid, glucose, and fructose with their degradation products may accelerate the color loss catalyzed by high temperature and oxygen (von Elbe and Schwartz 1996; Stintzing and Carle 2004 Wrolstad and others 2005).

Since color is a critical quality parameter in food purchases, color measurement has gained much attention from food scientists and industry. To investigate color quality in a systematic way, it is necessary to objectively measure color as well as pigment concentration. The method for measuring total anthocyanins and indices for polymeric color and browning (Bakker and others 1994; Giusti and Wrolstad 2005) have been well established and used in research and in industrial control applications (Wrolstad and others 2005). The instrumental specification of color using CIEL*ab system is most commonly performed by the use of tristimulus colorimeters and spectrophotometers. Color perception often alters when viewing angles and illumination change and when the sample is rotated, where changes in color, gloss, or surface texture pattern might occur (Hutching 1999). Francis (1987) stated that one of the major problems in comparison of tristimulus data obtained from food is the use of instruments with different designs. In addition, food samples are not flat, or perfectly opaque/transparent, and or of a single uniform color; the physical environment can sometimes be more influential than the colorant itself (Joshi 2001). Previous studies have evaluated color measurement of food in liquid (Kent 1987) and powder forms (Brimelow 1987; McDougall 1987). For anthocyanin-containing fruits and fruit products, investigators have emphasized
methods that monitor anthocyanins rather than instrumental color measurements. This is particularly true for fresh and processed strawberries.

The major objective of this study was to compare the effectiveness of 3 color measurement instruments that have different optical geometric arrangements (observation and illumination angles) and different features for sample presentation (viewing port size and location) for measuring strawberry color. Another objective was to measure the color and total pigment changes that occur when strawberries are processed into frozen, canned, and jam products. Changes in polymeric color, browning, and total phenolics were also monitored.

Materials and Methods

Chemicals and reagents

Folin-Ciocalteu’s phenol reagent (FC), gallic acid, and sodium carbonate were obtained from Sigma Chemical Co. (St. Louis, Mo., U.S.A.). Ascorbic acid was from Mallinckrodt Baker Inc. (Phillipsburg, N.J., U.S.A.). Sodium bisulfite was from Mallinckrodt Inc. (Paris, Tex., U.S.A.). 1,1-diphenyl-2-picrylhydrazyl (DPPH) was from TCI America (Portland, Oreg., U.S.A.). Anhydrous citric acid was from Integra Chemical Co. (Renton, Wash., U.S.A.). Sugar was from C&H Sugar Co. (Crockett, Calif., U.S.A.). Pectin was Pacific 150 grade from Integra Chemical Co. (Renton, Wash., U.S.A.). Ascorbic acid was from Mallinckrodt Baker Inc. (Phillipsburg, N.J., U.S.A.).

Strawberry samples

Three commercial strawberry (Fragaria x ananassa) genotypes, Ovation, Totem, and Puget Reliance, and 3 experimental selections, 2273-1, 1843-1, and 1723-1 (2.5 kg/each genotype) were obtained at their commercial ripeness in June 2005 from the Oregon State Univ. (OSU) North Willamette Research and Extension Center, Aurora, Oreg. These samples were selected because they represented a wide range in visual lightness/darkness and hue from panel assessments of thawed frozen experimental selections the previous season. Another lot of Totem was purchased from a commercial berry farm in Dayton, Oreg., for the processing trials. Fruit was picked at commercial harvest maturity and immediately transported to the Dept. of Food Science and Technology pilot plant, OSU, Corvallis, Oreg., and stored at 2 °C before subsequent sampling and processing.

Freezing process and storage

Strawberries were washed, carefully sorted to remove any damaged ones, individually quick frozen (IQF) in an air-blast freezer at −37 °C, subsequently transferred into glass jars, and stored at −23 °C. Frozen fruits from the Totem genotype were stored for 1 mo before color measurement and extraction, and for 6 mo before making into jam. Samples were stored for 1 mo before extraction and compositional determinations.

Canning process

The canning process was adapted from processing procedures described by Chaovalakit and Wrolstad (2004). Fresh fruits of the Totem genotype (2 kg) were washed and placed into cans (nr 303 × 406 with dark fruit enamel), hot filled with sucrose syrup (C&H sugar diluted to 20 °Brix with water) at 95 °C. Cans with lids on were placed on a running belt and exhausted in a steam tunnel before being sealed on a manual can seamer (Automatic Canning Devices, Inc., Manitowoc, Wis., U.S.A.). The cans were immersed in boiling water for 15 min, then immediately put in running water (20 °C) to be cooled to room temperature before being stored at room temperature for 60 d. The process was replicated twice.

Manufacture of strawberry jams

Jams were made from strawberries of the Totem genotype following a procedure similar to the one described by Kim and Padilla-Zakour (2004). Frozen berries (14 kg) were thawed overnight at 2 °C and manually crushed into puree by the use of a potato smashed. The jam formulation was 52% fruit, 47.5% sugar, and 0.5% pectin. Crushed berries were continuously stirred and brought to 50 °C in a steam kettle before sugar addition. The pH was measured and adjusted to 3.2 by addition of citric acid. The mixture was boiled within 20 min to a concentration of 66 to 67 °Brix (approximately 104 °C) before adding pectin, previously mixed with a small amount of sugar. The jam was hot-packed in 250-mL mason jars, immediately sealed with plastisol lined metal lids, and inverted for 3 min to sterilize the lids, then returned to normal position for air-cooling. Manufacture of jam was replicated twice.

Color measurement of fresh strawberries

The 3 color instruments evaluated in this study were Minolta CR-300 colorimeter (Minolta Corp., Ramsey, N.J., U.S.A.), LabScan II, and ColorQUEST spectrophotometers (Hunter Associates Laboratories Inc, Reston, Va., U.S.A.). The features of these colorimeters are presented in Table 1. The instruments were calibrated every 2 h by the use of standard white/black calibration plates included with the instruments. The L* a*b* coordinate system was used for LabScan II and ColorQUEST. Undamaged whole fresh fruits from each genotype were randomly selected, grouped into 2 sets containing 40 to 50 fruits per set, and used for all color measurements with the 3 instruments. For the Minolta CR-300 and LabScan II, single measurements were made on the reddest area of individual berries. For the ColorQUEST, a circular optical glass cell 130 mm in diameter × 50 mm in height was used. The cell was filled with berries from each set (from 2 to 3 layers of fruit), with their reddest area facing the port view before taking the color reading. A box with its interior covered with black absorbing paper was used to cover the sample. After the 1st reading, the cell was emptied and refilled with another sample of fruit to make a total of 3 readings.

Color analysis of processed Totem strawberries

All color measurements of frozen and canned fruits and jams utilized the glass cell and the ColorQUEST instrument (Table 1). For

<p>| Table 1 – Features of the 3 instruments (ColorQUEST, LabScan II, and Minolta CR-300) |</p>
<table>
<thead>
<tr>
<th>Colorimeter/ Spectrophotometer</th>
<th>Sample presentation</th>
<th>Optical feature (degree/degree)</th>
<th>Illuminant</th>
<th>Viewing port diameter (mm)</th>
<th>Viewing angle (degree)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ColorQUEST</td>
<td>Glass cella</td>
<td>45/0°</td>
<td>D65</td>
<td>88.90</td>
<td>10</td>
</tr>
<tr>
<td>LabScan II</td>
<td>Berry surfaceb</td>
<td>0/45°</td>
<td>D65</td>
<td>6.35</td>
<td>10</td>
</tr>
<tr>
<td>Minolta CR-300</td>
<td>Berry surfaceb</td>
<td>d/0°</td>
<td>D65</td>
<td>8.00</td>
<td>2</td>
</tr>
</tbody>
</table>

*a* An optical cylinder glass cell (120 mm × 70 mm, diameter × height) was used to present samples.

*b* The berries were in direct contact with the instrument view port and were individually read.

*c* Illuminating from an angle of 45 ± 2° and detecting light at 0 ± 10° (specular light excluded).

*d* Illuminating from the direction of 0 ± 10° and detecting light at 45 ± 2° (specular light excluded).

*e* Illuminating the sample diffusely and detecting light at 0 ± 10° (specular light included).
Color of strawberries...

frozen berries, the same 40 to 50 fruits that were measured for color prior to processing (in fresh form) were reanalyzed with the same method of sample presentation as done on fresh fruit. The frozen berries taken from the freezer were kept in sealed jars to prevent moisture condensation onto the fruit surface, and were exposed to the air only for less than 45 s when filling the glass cell for color measurement. About 400 g of frozen fruit was thawed overnight at 2 °C in plastic bags. Thawed berries were then drained and weighed. Canned berries were also drained, and both the drained berries and the liquid weighed. For color measurement of drained frozen and canned fruits, the cell was filled with 2 layers of fruit. Color of drained liquids (from thawed frozen berries) and canned syrup was determined using a 2.5-mm pathlength optical glass cell (Hellma, Müllheim, Germany) utilizing the ColorQUEST sphere instrument with a view port of 25.4 mm. For jam measurements, 210 g of jam was placed in the large cell, with approximately 12-mm depth and read using the ColorQUEST (Table 1).

pH measurement

Six strawberries were blended with deionized water (1:9 fruit:water, w/w) for 1 min. The pH of filtered juice was determined using a Corning pH meter 125 with an Orion Epoxy body, nonrefillable pH electrode (Thermo Electron Corp., Waltham, Mass., U.S.A.).

Extraction of anthocyanins and polyphenolics

A modified method described by Rodriguez-Saona and Wrolstad (2005) was used. One hundred grams of frozen and canned berries were thoroughly homogenized by powdering in liquid nitrogen. About 5 g of powder was mixed with 20 mL of acetone. The mixture was centrifuged and the supernatant was collected. An additional extraction of the residue was done with aqueous acetone (30:70 v/v). Supernatants were combined and partitioned with 50 mL of chloroform and centrifuged for better separation between the organic and aqueous phases. The aqueous phase containing ACN was recovered and transferred to a rotovaporater to remove residual acetone at 40 °C. The extract was diluted with MillIQ water to 25 mL. For jams, about 200 g of sample was homogenized in a 0.25-L glass jar using a 12-speed Osterizer blender (Sunbeam-Oster Co., Fort Lauderdale, Fla., U.S.A.). After blending, 10 g of MillIQ water was added to approximately 5 g of sample and vortexed before addition of acetone. Subsequent additional extractions were done as described for fresh berries above.

Analysis of total monomeric anthocyanins and polymeric pigments

Aqueous extracts were diluted to a known volume with deionized water. The total anthocyanin content was determined by using the pH differential method described by Giusti and Wrolstad (2005) and expressed as mg pelargonidin-3-glucoside per 100 g of initial fresh weight with molecular weight of 433.2 g/mol and a molar absorptivity of 15,600.

Percent polymeric color (PPC, sum of the absorbance at 420 nm and 496 nm of bisulfite–treated extract/sum of the absorbance at 420 nm and 496 nm of berry extract) and browning index (absorbance at 420 nm of bisulfite–treated extract, reported as absorbance per 100 g of initial fresh materials) were determined using the method described by Giusti and Wrolstad (2005).

Analysis of total phenolic content

Total phenolic content (TPC) was determined using the FC method (Waterhouse 2005). Aqueous extracts were diluted to a known volume with deionized water. A 750 µL volume of diluted extract was mixed with 0.5 mL of FC reagent in 7.5 mL of deionized water. The samples were held for 20 min at room temperature before 0.5 mL of 20% sodium carbonate (w/v) was added. The well-mixed samples stood for another 30 min at 40 °C before the absorbance was measured at 765 nm by a Shimazu UV160U spectrometer (Shimazu Corp., Kyoto, Japan) with 1-cm disposable cells. Gallic acid monohydrate was used as a standard and expressed as gallic acid equivalents (GAE) in mg per 100 g of initial fresh materials.

Shelf-life evaluation of Totem jam

Twelve randomly selected jars of jams were assigned to 1 of the 3 different storage temperatures (10 ± 3 °C, 21 ± 2 °C, 38 ± 2 °C) for evaluation over a 9-wk period in the dark. Jams were analyzed for anthocyanin content, PPC, and browning index as well as CIE *L* ×*a* ×*h* color values. The measurements were replicated twice.

Experimental design and statistical analysis

A completely randomized design with 2 replications was used. Statistical analysis was performed using SAS (SAS Inc., Cary, N.C., U.S.A.). Multifactor analysis of variance was applied with source of variance being genotypes and color measurement instruments. Differences between means were tested for significance by using GLM (general linear model) procedure with Duncan test, using a level of significant of P < 0.05.

Results and Discussion

Color of fresh strawberries

Preliminary experiments on berry color measurements were conducted with the main objective to determine the most appropriate means for berry presentation. It was noticed that some berries have both yellow-colored and red-colored areas with very different local *L* *, *C* *, and *h* color values. In common practice, the overall color presentation of a fruit is more important than a single area of color on the fruit. While using an instrument with small view port to obtain average color of fruits with both red and yellow areas, it is advised to rotate a single fruit and make multiple readings (Francis 1987). In this study, most samples had uniform color distribution dominated by red with very limited yellow areas (Figure 1). In addition, the high fragility of some selected genotypes did not permit excessive manipulation. To compare the performance of the color measurement instruments in monitoring the color of the 6 strawberry genotypes, it was decided to make readings only on the reddest area of a fruit.

Using instruments with small port view diameter, less red areas on a fruit were ignored and the collected data represented, in fact, the average of the reddest area of a fruit pool. Tests on the ColorQUEST using the large cell showed that 3 readings would be sufficient to acquire data with small standard deviations. The surface of individual berries was measured on the LabScan II with its small viewing port. Color measurements of 20 compared with 50 berries yielded data with almost the same means and standard deviations (data not shown). Readings from 40 to 50 berries were done in this study, since that number of fruits was needed to take 3 readings using the large cell, and the authors’ desire was to use the same sample for all instruments.

Figure 2 shows *L* *, *C* *, and *h* values generated by the Minolta CR-300 and LabScan II for single fruit of the 6 different genotypes, and by the ColorQUEST for whole fruit pools of each genotype. All 3 instruments show a general trend for reduction in *L* *, *C* *, and *h* in the order of Ovation, 2273-1, 2384-1, Puget Reliance, Totem, and 1723-2. There are obvious differences, however, in color values among the instruments (Figure 2). *L* * values generated by the Minolta CR-300 were higher than that by LabScan II. As shown in Table 1, the 2 instruments have small viewing port area (8 mm in Minoltad CR-300 and
6.35 mm in LabScan II), but different degrees of viewing angle (2° in Minolta CR-300 and 10° in LabScan II). According to Hutchings (1999), the 2° and 10° observers should give close tristimulus values, and thus they are unlikely to be the significant cause of the difference in L∗ values. In this case, it was believed that the differences are the result of different optical features in these 2 instruments. With a d/0 geometry characterized by a diffuse illumination and observation angle of 0° in the Minolta CR-300, the reflected light from the sample would include some specular light, which is reflected without becoming selectively absorbed by the sample surface pigments. Unlike the d/0 geometry, a 0/45 geometry, standing for illumination and observation angle of 0° and observation angle of 45°, in the LabScan II excluded specular light. The higher L∗ values reported by the Minolta CR-300 were thus mainly due to the integrated specular light that increased the brightness of the light reflected on the sample surface. While the LabScan II and ColorQUEST have similar optical features, 45/0 compared with 0/45 (Table 1), the L∗ values from LabScan II were higher than those obtained by the ColorQUEST (Figure 2). Even though both instruments had specular light excluded, there might still be a considerable variation between the 2 instruments when specular component was excluded (Kent and Smith 1987). However, the fact that the ColorQUEST has a view port area significantly larger than that of the LabScan II (89.9 mm compared with 6.9 mm) could be the main explanation for the differences in their reported color values. On the other hand, C∗ and h° values reported by the 3 instruments were very similar (Figure 2). The similarity suggests that the average color of a fruit pool of the studied genotypes was close to the average color of reddest area on fruits or there was limited color variance on the red side of studied fruits as was assumed earlier.

For smaller view port size, that is, LabScan II and Minolta CR-300, measurements can only be conducted on a single fruit. The surface area of strawberries is not flat and includes yellow achenes and reddish hair-like structures. There is considerable berry-to-berry variation for the same genotype, as illustrated by the 2273-1 or 2284-1 genotype (Figure 1). Fruit surface characteristics varied considerably from berry to berry. Instrumental color values generated by LabScan II and Minolta CR-300 fluctuated accordingly and resulted in large standard deviations (Figure 2). For high precision, multiple readings on different individual objects are thus needed when taking measurement on single berries, whereas with the large viewing port of ColorQUEST, readings were done on a group of objects. This variation was thus averaged, and data showed small standard deviations (Figure 2) with as few as 3 readings. Still, the curved shape, pillowing form, and size variation of berries (Figure 1) can modify and complicate the direction of reflected light, and thus affect the amount of light projected from fruit onto the sensors to some extent.

In the composite picture of all 6 genotypes (Figure 1) taken with the same camera under the same condition of D2 light, camera view angle, and distance, it can be seen that the visual appearance of berries varies from berry to berry and from genotype to genotype. Actually, these genotypes were selected because they represented a wide range in visual lightness/darkness and hue from panel assessments of thawed frozen experimental selections the previous season. As it can be seen in Figure 1, 1723-2 berries had the darkest and reddest color and Ovation the brightest and the most orange-colored.

It was anticipated that L∗, C∗, and h° values of the 6 strawberry genotypes would be in a reasonably wide range. Figure 2 shows that the color values measured by ColorQUEST were significantly different (P < 0.05). L∗ values increased from 21.3 to 29.1, C∗ from 24.3 to 41.9, and h° from 24.4 to 32.6 in the order of Ovation, 2273-1, 2284-1, Puget Reliance, Totem, and 1723-2 with a few exceptions (Figure 2). Within this area on the solid color sphere, the lower L∗ and h° values represent darker sample color with a bluish-red hue while higher values are lighter and more orange. It can be concluded from Figure 2 that 1723-2 was the bluish genotype and Ovation the most orange-colored, which is affirmed by the results described above.

The pH and total ACN values of 6 selected strawberry genotypes varied significantly (Table 2), which was not surprising because of the wide range in visual appearance. The observed pH values in the range of 3.25 to 3.80 agree with the results described by Wrolstad and others (1970). The total ACN content of strawberries in this study, 37 to 122 mg/100g fresh weight, was higher than the range of 30 to 100 mg/100 g reported in a study of over 18 genotypes (Wrolstad and others 1970). The total ACN content among 6 tested genotypes is in the decreasing order of Ovation→Puget Reliance→2384-1→2273-1→Totem→1723-2. Interestingly, the 1723-2 selection with the highest ACN had the lowest L∗ and h° value and the Ovation with the lowest ACN and the highest L∗ and h° value. However, as expected, no significant linear correlations were observed between anthocyanin content or pH and color values (Pearson’s r2 was less than 0.7, data not shown). As anthocyanin color is from different parts of the fruits, including the pericarp of whole uncomminuted material as shown in Figure 1, the achenes, and the inner part of

Figure 1 – Photos of 6 fresh strawberry genotypes harvested in 2005 season at the Oregon State Univ. North Willamette Research and Extension Center (Aurora, Oreg., U.S.A.)
the fruit (Aaby and others 2005), there was a difference between the anthocyanin color of whole fruit samples and the anthocyanin nitrogen powders. Visual assessment showed that all samples, except for Ovation, had pigmentation within their flesh.

Effects of processing on color, pigment content, and antioxidant properties of strawberries

Table 3 compares the color values of fresh and processed fruits from the Totem genotype; all measurements being taken on the ColorQUEST with the large cell except for the liquid (drip from thawed fruits and syrup from canned berries), which was measured with the ColorQUEST sphere. The compositional data of processed products are presented in Table 4. As in the earlier analysis of ACN, all chemical analyses in this study were based on nitrogen-powdered material and the results are expressed as per 100 g of berries in the various products. The content expressed in 100 g of finished products can be obtained from these values through a simple conversion associated with each product given in the footnote of Table 4.

Frozen berries. There were marked differences in the visual appearance of frozen berries compared to fresh fruit with respect to “gloss” that is not evident from \( L^* \), \( C^* \), or \( h^* \) data presented in Table 3. Gloss is the property by which a material appears shiny or lustrous as a high proportion of light impinging on the food surface reflected. Thus, gloss is dependent on the refractive indices and on the size of discontinuities present on the involved food surfaces (Hutchings 1999). Wax layers and deposits are the components of the surface cuticle of fruits having natural gloss (Nussinovitch and others 1996).

During freezing process and frozen storage, the berry surface characteristics must have changed, such as more discontinuities in the cuticle layers because of the crystallization and fruit volume increase. All made the frozen fruits much less shiny compared to the fresh fruits, which was not reflected on the \( L^* \), \( C^* \), and \( h^* \) measurement. The glossiness of fruits and vegetables can be measured by a glossimeter (Nussinovitch and others 1996). The ACN of frozen fruits from the Totem genotype (69.7 mg/100 g, Table 4) is higher than the 50.3 mg/100 g reported by Pilando and others (1985) for fresh Totem genotype. TPC fell in the range of 300 to 341 mg GAE/100 g fresh weight reported by Aaby and others (2005). An assumption was made at the beginning of the study that no major compositional or pH changes would occur in frozen strawberries during short-term storage at low storage temperature. While the temperature of \(-12\) °C may not be sufficiently low, no analysis of fresh berries was conducted to permit comparisons for any compositional changes with short-term storage. Thawed berries had significantly higher \( L^* \) and lower \( h^* \) values than that of fresh or frozen berries (\( P < 0.05 \)) (Table 3), indicating a light red color compared to frozen or fresh ones. This higher hue angle value might suggest that ACN in thawed fruits (61.7 mg/100 g, data not shown) may be concentrated on the fruit surface when the juice leached out during thawing. An increase in lightness may be attributed to the physical changes resulting from collapse of thawed berry structure. The drip solution had an ACN value of 11 mg/100 g (data not shown).

Canned berries. Canned fruits analyzed after 60 d of storage at room temperature had similar \( L^* \) (\( P > 0.05 \)) but higher \( h^* \) values.

Table 2—Total anthocyanin content and pH of different berry genotypes\(^\text{a}\)

<table>
<thead>
<tr>
<th>Berry genotype</th>
<th>ACN(^\text{b})</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ovation</td>
<td>37.1 ± 4.4</td>
<td>3.28 ± 0.07</td>
</tr>
<tr>
<td>2273-1</td>
<td>71.8 ± 2.3</td>
<td>3.25 ± 0.01</td>
</tr>
<tr>
<td>2384-1</td>
<td>62.1 ± 0.4</td>
<td>3.80 ± 0.09</td>
</tr>
<tr>
<td>Puget Reliance</td>
<td>50.9 ± 2.8</td>
<td>3.40 ± 0.02</td>
</tr>
<tr>
<td>Totem</td>
<td>76.0 ± 4.0</td>
<td>3.58 ± 0.01</td>
</tr>
<tr>
<td>1723-2</td>
<td>122.3 ± 2.3</td>
<td>3.46 ± 0.02</td>
</tr>
</tbody>
</table>

\(^\text{a}\)Frozen whole fruits were used in the analysis to represent the fresh fruits.  
\(^\text{b}\)Total anthocyanin content was expressed as mg of pelargonidin-3-glucoside per 100 g of initial materials, determined by a pH differential method.

Table 3—CIEL\(\text{C}^*\)\(\text{h}^*\) color values of fresh fruit from the Totem genotype and processed products (frozen, thawed, canned, and jam)

<table>
<thead>
<tr>
<th>Sample</th>
<th>(L^*)</th>
<th>(C^*)</th>
<th>(h^*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh fruit(^\text{cd})</td>
<td>23.35 ± 2.18</td>
<td>31.1 ± 0.740</td>
<td>27.38 ± 0.23</td>
</tr>
<tr>
<td>Frozen fruit(^\text{de})</td>
<td>25.03 ± 0.05</td>
<td>31.13 ± 0.44</td>
<td>26.90 ± 0.45</td>
</tr>
<tr>
<td>Thawed fruit(^\text{de})</td>
<td>30.64 ± 0.59</td>
<td>30.60 ± 0.14</td>
<td>24.79 ± 0.11</td>
</tr>
<tr>
<td>Drip(^h)</td>
<td>66.54 ± 0.22</td>
<td>88.96 ± 0.09</td>
<td>49.44 ± 0.03</td>
</tr>
<tr>
<td>Canned product</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fruit(^\text{cd})</td>
<td>23.39 ± 0.25</td>
<td>28.58 ± 0.46</td>
<td>31.73 ± 0.01</td>
</tr>
<tr>
<td>Syrup(^h)</td>
<td>80.91 ± 2.81</td>
<td>38.40 ± 4.69</td>
<td>35.84 ± 0.64</td>
</tr>
<tr>
<td>Jam(^h)</td>
<td>3.47 ± 0.31</td>
<td>12.46 ± 0.59</td>
<td>12.46 ± 0.87</td>
</tr>
</tbody>
</table>

\(^\text{a}\)Measurement with the ColorQUEST 4500, view port diameter of 89.9 mm using a cell to present samples.  
\(^\text{b}\)Measurement cell was filled up with fruits (about 2 to 3 layers of fruits).  
\(^\text{c}\)Measurement cell was filled with 2 layers of fruit.  
\(^\text{d}\)210 g of jam was used (approximately 1.2 cm in depth).  
\(^\text{e}\)Measurement with the ColorQUEST sphere, view port size of 25.4 mm using a cuvette (2.5 mm in length).
Color of strawberries...

(P < 0.05) compared to those of fresh berries (Table 3), representing a shift from red toward more orange color. Total ACN in canned strawberries (8.8 mg ACN/100 g initial weight) was lower than in the syrup (13 mg ACN/100 g initial weight) (Table 4). Compared to ACN values in the fresh samples, the total level of combined ACN in canned strawberries and in the syrup decreased markedly, the reduction being as high as 68.8%. The great loss and leaching of anthocyanin explain well the change to yellow-colored appearance of the canned berries.

Table 4 shows that along with the canned berries, the syrup also contained considerable high levels of total phenolics. Compared to 100% of TPC (313.6 mg GAE/100g) in frozen berries, the calculated TPC of combined canned fruit and syrup (239.7 mg GAE/100g) represents a loss of 23.5%, of which anthocyanin degradation would be a major contributor.

Heat processing and storage also increased PPC content in the final products, leading to a total PPC of 33.2% in canned fruits, while the value was 7.16% on frozen berries. An increase in PPC was indicative of condensation reactions of anthocyanins with other polyphenolic compounds such as procyanidins to form colored polymer pigments (Monagas and others 2005), reducing ACN in canned fruits. A significant increase in browning index was also found in canned liquid and fruits compared to that of frozen fruits (Table 4).

As anthocyanins are thermally labile, an extended heating at 100 °C for 15 min would be the main reason causing significant degradation of red pigments. Adams and Ongley (1973) found that anthocyanin degradation can take place to an important extent if fruits are heated at 100 °C for over 12 min at commercial canning conditions. Ascorbate degradation could also be significantly involved in the color and chemical changes of canned product. Studies have shown that most ascobic acid in strawberries is destroyed during thermal process (Skrede and others 1992) and furfural is a major product (Tatum and others 1969). Catechin and anthocyanins, which are flavonoids available in large quantity in strawberries (Aaby and others 2005), have been shown to form condensed dimeric products mediated by furfural (Es-Safi and others 2000). In nature, dimeric complexes between anthocyanidin and flavanols in strawberries have been found recently (Fossen and others 2004). These reactions can eventually contribute to the darkening of the fruits (Es-Safi and others 2000). During storage of canned products, pelargonidin-3-glucoside, the main anthocyanin in strawberries, can still be hydrolyzed by acid to pelargonidin and further broken into hydroxybenzoic acid (Stintzing and Carle 2004).

Jam. L*, C*, and h° color values of jam were distinctly lower than those of fresh and other processed products (P < 0.05) (Table 3), indicating an increase in darkness, decrease in chroma, and hue angle caused by jam manufacture. Besides compositional and chemical changes, one of the main factors to take into account when comparing the colors of jam and fruits is the physical differences between these 2 forms of products. When made into jam, the product’s light reflectance properties are no longer similar to that of berries.

Table 4—Total phenolics, antioxidants, anthocyanins, and browning and polymeric pigment in canned, frozen, and jams of strawberries from the Totem genotype*

<table>
<thead>
<tr>
<th>Samples</th>
<th>Total Phenolics*</th>
<th>ACN*</th>
<th>Browning Index*</th>
<th>Percent Polymeric Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frozen fruit*</td>
<td>313.6 ± 17.7</td>
<td>69.7 ± 4.2</td>
<td>1.14 ± 0.13</td>
<td>7.16 ± 0.68</td>
</tr>
<tr>
<td>Canned product (total)</td>
<td>239.7 ± 18.1</td>
<td>21.7 ± 3.4</td>
<td>2.10 ± 0.7</td>
<td>33.20 ± 2.5</td>
</tr>
<tr>
<td>Fruit</td>
<td>118.9 ± 13.4</td>
<td>8.9 ± 1.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Syrup</td>
<td>120.9 ± 4.6</td>
<td>13.0 ± 1.7</td>
<td>1.91 ± 0.05</td>
<td>27.4 ± 1.9</td>
</tr>
<tr>
<td>Jam</td>
<td>262.1 ± 4.9</td>
<td>20.6 ± 1.4</td>
<td>5.00 ± 0.7</td>
<td>27.7 ± 3.3</td>
</tr>
</tbody>
</table>

*Values are presented in mean ± SD of 2 replicates.

Total phenolics was determined by the use of FC method and expressed as equivalent mg of gallic acid per 100 g of initial fresh materials.

Total anthocyanin content was expressed as mg of pelargonidin-3-glucoside per 100 g of initial materials, determined by a pH differential method.

Browning index was expressed as calculated absorbance unit based on 100 g of initial fresh materials.

Data reported for canned fruit are based on fresh fruit. Contents per 100 g of finished product can be obtained from values in the table by a division of the latter by a conversion factor of 0.49, 1.03, and 1.41 for canned fruit, syrup, and jam, respectively.
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temperatures. While the ACN in the fresh jams was about 20.1 mg/100 g of initial fruits, the jams stored after 9 wk at 10 °C, 21 °C, and 38 °C contained significantly lower ACNs (P < 0.05), about 12.9, 11, and 5.4 mg/100 g of initial fruits, respectively. Thus, the stability of anthocyanins in jams was markedly influenced by temperature (von Elbe and Schwartz 1996; Garcia-Viguera and others 1999). Figure 3c and 4a show that a major loss of anthocyanins had occurred before any significant changes in hue angle of the jams was observed. These results would indicate that ACN is not a good measure of color quality of strawberry jam, as concluded by Abers and Wrolstad (1979). Instead, the role of browning pigment formation was emphasized over the amount of ACN loss as the major cause of the color deterioration of jams (Abers and Wrolstad 1979).

Storage time and temperature had significant effects on PPC and BI of jams, which increased with storage time and temperature (Figure 4b, c). Abers and Wrolstad (1979) proposed that catechin and proanthocyanins played an important role in degradation of anthocyanins and in polymeric browning of strawberry jam. It is possible that the products of ascorbic acid oxidation during jam making could induce browning of catechin during product storage under anaerobic condition (Bradshaw 2001). The condensations between flavonols and anthocyanins as described earlier (Abers and Wrolstad 1979; Monagas and others 2005) might explain the increase in PPC of jams after processing and during storage. Some of these products could form black compounds (Es-Safi 2000). Sugars at high concentrations as found in jams are known to stabilize anthocyanin, presumably by lowering water activity (von Elbe and Schward 1996). This protective effect might operate here but is counterbalanced or offset by sugar degradation as the reducing sugars produced during processing can react with free amino acids (Abers and Wrolstad 1979), accelerating Maillard browning.
Conclusions

Total monomeric anthocyanins, TPC, PPC, browning index, and CIE L*C*h* color values were usefuly combined to represent the color of fresh strawberry and strawberry products and to track the anthocyanin changes during processing and storage. It was found that the pigment content was not the dominant indicator of the color of strawberry and processed strawberry products. The red pigment in strawberry is very labile and easily degraded during processing and storage.

When measuring color of similar samples using color measuring instruments, the measurement system and sample presentation must be carefully matched and standardized since there are interactions between instruments and samples as defined by sample presentation and instrument geometry. The sample glossiness is not represented by the CIE L*C*h* color system, thus a glossimeter is necessary when monitoring similar samples that are different in gloss as found on fresh and frozen fruits. When measuring color of samples with unevenly colored surfaces, it is advisable to use a large-area color measuring instrument to minimize manipulative acts. For products without flat surfaces, there is most likely a complication for supplying strawberry samples. Special thanks to Mr. Brian Ross and Henriik U. Stotz for allowing us to use their color measurement instruments and to Ian McLaughlin for the photograph.

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References