EFFECTS OF LIGHT AVAILABILITY AND CANOPY POSITION ON PEACH FRUIT QUALITY

by

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(ABSTRACT)

Two experiments were conducted to determine the influence of light on ‘Norman’ and ‘Cresthaven’ peach fruit quality characteristics. Of primary interest was the relationship between ground color and flesh firmness. Light levels were manipulated by use of shade cloth, reflective mulch, and aluminum foil. ‘Norman’ trees, with a randomly chosen half of the canopy covered with 73% shade cloth, had fruit with lower levels of red color, soluble solids concentration (SSC), specific leaf weight, and average photosynthetic photon flux (PPF) than did non-shaded trees. Foil-covered ‘Cresthaven’ fruit were larger, less firm, and had lower SSC than non-covered fruit. Covered fruit developed yellow but not red color.

Position of the fruit within the canopy of the tree also affected fruit quality characteristics. Inside fruit on both ‘Norman’ and ‘Cresthaven’ trees were smaller and firmer, had lower SSC, and were less red than fruit from the canopy exterior. The position effect was probably due to the degree of light exposure and not to the distance from the roots. Fruit on the inside of the tree canopies received much lower average PPF than outside fruit.

Relationships were evaluated between ground color and firmness for both cultivars. At a given hue angle, fruit developing in high-light environments were firmer than fruit from low-light environments for ‘Cresthaven’, but the opposite was true for ‘Norman’. Therefore, canopy position or the light environment in the vicinity of the developing fruit does not consistently influence the relationship between hue angle on the non-blush side of the fruit, and flesh firmness.

Dedication

Dedicated to all who supported me in the completion of this thesis. I would especially like to dedicate this to my parents (Garold and Karen Senger) and other family members who gave me the confidence to pursue this degree, as well as to my husband, David, for his continuous strength and understanding.

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Introduction

Peaches are harvested on the basis of ground color, which is the background color of the peach skin. Ground color typically turns from green to greenish-yellow and then to a deep yellow as the fruit matures and ripens. Fruit firmness is a key issue in wholesale peach production and marketing. If a peach is too soft, it will not ship well, nor will it have adequate shelf life. Color chips, green colored “chips” of plastic, were developed in the 1980s in California [California Tree Fruit Agreement (CFTA) (Delwiche and Baumgardner, 1985) and South Carolina (Delwiche and Baumgardner, 1983) to establish a minimum ground color as a basis for deciding when to harvest. Using ground color as a basis for fruit maturity assumes that, within a geographical region, the relationship between ground color and flesh firmness is similar for all cultivars and for fruit developing in different regions of the canopy.

Fruit quality is related to the amount of light in the vicinity of the developing fruit. Fruit quality indices influenced by light include fruit size, soluble solids concentration (SSC), acid concentration, and surface color. The experiments in this study were designed to help determine the extent to which the light environment affects color development and flesh firmness of peach fruit. Another objective was to compare the relationships between ground color and flesh firmness for fruit developing in different parts of the canopy and for fruit receiving different amounts of light.

Normally, the amount of light intercepted by a fruit is a function of canopy position, so light level and canopy position are confounded. In previous studies, light levels intercepted by fruit were varied by shading individual fruit within a canopy position, or different canopy positions were selected to obtain a range of light levels. The experiments in this study were designed to separate the effects of light levels and canopy position. This information may help peach producers harvest fruit with optimum quality and adequate firmness for shipping.

Review of Literature

There are three stages of peach fruit development. Following bloom, Stage I is a period of cell division and rapid fruit growth, during which the endocarp accounts for most of the size increase (Ryugo, 1988). Stage I ceases about 50 to 60 days after bloom. Stage II, which can last for varying lengths of time, is marked by pit hardening and slow fruit growth, whereas rapid growth until harvest occurs in Stage III. Fruit growth during the final period is through enlargement of the mesocarp cells (Ryugo, 1988). Stage III usually lasts approximately six weeks.

As peach fruit development is completed, the fruit become mature and subsequently ripen. In this study, the terms "mature" and "physiological maturity" refer to the stage of development where a fruit has the ability to "ripen". Maturity must occur on the tree, while ripening can occur on or off the tree. Mature is synonymous with completeness of development, while the term ripe implies readiness for use (Haller, 1952). Changes that occur during maturation and ripening include a gradual decrease in flesh firmness, a change in ground color from mainly green to mainly yellow, increases in the area and intensity of overlying red color (blush), a change in flesh color from whitish green to pale yellow, and a marked increase in flavor. Changes in quality occurring during maturity and ripening include increases in sugar concentration and aromatic compounds, decreases in acid concentration, and development of a less crunchy texture (Lott 1965-66). For acceptable fruit quality, Seymour et al. (1993) suggested that soluble solids concentration should exceed 10% at harvest.

Attempts have been made to develop maturity standards for determining the optimum harvest maturity. The fruit need to be mature when picked to ensure edible quality (Robertson et al., 1992); but for wholesale, fresh-market growers, who have to factor in the time their fruit has to travel to distant markets, shipping firmness also must be considered.

There is great variability in time to maturity among different cultivars of peaches. Variability among cultivars adds to the need for finding objective maturity indices for each cultivar that are correlated with that cultivar's physiological maturity (Luchsinger and Walsh, 1993). Differences among cultivars are expected, but maturity indices also differ among fruit within a single tree. Fruit-to-fruit variation in time of maturity on a tree is greater for peaches than for most other fruit (Marini and Trout, 1984). In their attempt to develop sampling procedures for estimating fruit quality indices, Marini and Trout (1984) found that differences among fruit on the same tree accounted for more than half the variation even when fruit were harvested with similar ground color. Genard and Bruchou (1992) discussed many of the within-tree factors accounting for variation in peach fruit quality. Among the components discussed were light exposure, fruit position in the canopy, total leaf area, and leaf area per fruit. Broschat (1979) reported that the attributes affecting quality are usually highly interrelated. This is not encouraging in the search for establishing maturity indices, even within a single cultivar.

This review will focus on the effects of light on various indices of peach fruit maturity. Special emphasis will be given to the effects of light on the development of color and the decrease in flesh firmness.

Light Distribution in Canopies

Marini and Marini (1983) reported that tree size, spacing, row orientation, canopy shape, and training system influence light distribution within fruit trees. Sansavini and Corelli-Grappadelli (1997) suggested that the training system for peach and apple trees determined the amount of photosynthetically active radiation (PAR) intercepted by the canopy. PAR is that portion of the electromagnetic spectrum between 400nm and 700nm (Hopkins, 1999). PAR is quantified as photosynthetic photon flux (PPF), and the units are umols of PAR$\cdot\text{m}^{-2}\cdot\text{sec}^{-1}$. According to Grossman and DeJong (1998), a goal for highest production was to have a system that increased light interception and decreased or at least did not increase vegetative growth potential. PPF was higher within the canopy at midday than in the morning or evening and increased as the season progressed (Grossman and DeJong, 1998). However, the percentage of PPF that was intercepted by the tree was lowest at midday and highest in the morning and evening. Even though light interception differed among various training systems, there were no significant differences in fruit production (Grossman and DeJong, 1998).

Lakso and Musselman (1976) found that the highest interior light levels within apple trees occurred when total light was between 60 and 90% of full sun. This corresponded to a hazy day with high levels of diffuse light. Jackson et al. (1971) reported that the level of light exposure was an important factor for apple fruit development, but diffuse light was more important than direct light.

Seeley et al. (1980) found that estimates of total light from an instantaneous measurement were correlated with apple fruit quality characteristics. Campbell and Marini (1992 b) measured light on clear, hazy, and overcast days and compared instantaneous measurements with cumulative PPF for the season measured at various apple canopy positions. They recommended making instantaneous light measurements in the eastern United States during uniformly overcast conditions because such data correlated best with cumulative measurements. Lakso and Musselman (1976) found that apple canopy light relationships that were developed in arid regions might not apply to humid regions due to differences in diffuse light exposure.

Shade treatments increased chlorophyll content on a leaf-area basis in peach leaves, and specific leaf weight (SLW) was positively related to PAR (Kappel and Flore, 1983). SLW is partially a measure of leaf thickness and a relatively good indicator of the photosynthetic potential of peach leaves through mid-August (Marini and Marini 1983).

Light and Fruit Quality

Solar radiation, according to Jackson (1989), is the key factor in overall apple crop quality. Fruit size, firmness, soluble solids, anthocyanin and starch content, pH, and acidity were all affected by light in apple and peach (Proctor and Lougheed, 1976; Erez and Flore, 1986). Pruning increased light interception by apple fruit and leaves, which in turn increased fruit dry matter (Palmer, 1989; Wagenmakers, 1995). Sansavini and Corelli-Grappadelli (1997) suggested that pruning was a powerful factor in controlling peach fruit quality. They suggested that pruning would optimize photosynthetic efficiency and lessen the adverse effects of shading on carbon partitioning by increasing light interception through greater exposure of leaves within the canopy. For peach fruit quality, shade is most detrimental during the second half of Stage III in fruit development (that is, the final three weeks before harvest) (Marini et al., 1991).

Covering fruit trees with shade cloth to reduce the amount of available light reduces fruit quality. Shading suppresses soluble solids concentration and fruit weight of apples (Seeley et al., 1980). Shading peach trees delays harvest, increases preharvest drop, reduces soluble solids and firmness, and changes the relationship between firmness and ground color (Marini et al., 1991). Marini et al. (1991) concluded that fruit near non-shaded leaves developed optimum quality. However, photosynthates translocated from non-shaded portions of the canopy are important for the development of fruit in shaded parts of the tree. These authors also suggested that different ground color references might be needed to determine harvest dates for fruit developing at different canopy positions.

Apples from the outer and inner zones of the tree and within the upper and lower sections of the tree canopy belonged to different populations (Jackson et al., 1971). Peach fruit at treetops receive the most light (Chalmers et al., 1975; Marini, 1985). Marini et al. (1991) suggested that PPF at interior peach canopy positions might be most limiting for fruit development in regions with little diffuse light. Dann and Jerie (1988) studied the gradient of fruit maturity and sugar levels of fruit within peach trees. Flowers open first at the base of young trees, while fruit ripens first at the treetop. However, distance from the roots, regardless of limb orientation, was the most important factor in determining the length of time from bloom to harvest maturity within the canopy (Dann and Jerie, 1988). Fruit low in the canopy may be delayed in reaching physiological maturity compared to upper fruit (Dann and Jerie, 1988).

Flesh Firmness

Flesh firmness is an important quality index, because soft fruit do not ship well and have a short shelf life. Rood (1957) found that pressure-tests made on both pared cheeks, ground color, flesh firmness, chlorophyll content of the flesh, titratable acidity of the juice, and percentage of soluble solids in the juice provided information needed to make a maturity assessment, but he suggested that firmness was the best single indicator of peach fruit maturity. As peaches approach maturity, the flesh softens as water-soluble pectin is solubilized (Pressy and Avants, 1973) and cell wall integrity is lost (Fishman et al., 1993). Rom et al. (1984) found that a decrease in firmness directly correlates with a decrease in protopectin, cellulose, and thickness of cell walls. In other words, flesh softening is probably correlated with the breakdown of cell wall (Fishman et al., 1993). Pressey and Avants (1973) thought the changes in polysaccharides that lead to the destruction of the cell wall structure are probably responsible for softening during ripening, mainly because of the appearance of polygalacturonase activity when the fruit begins to ripen (Pressey et al., 1971). However, they were not able to determine whether the polysaccharides were the initiators of cell wall degradation. Fishman et al. (1993) found that the loss of cell wall integrity could occur by means other than by degradation by polygalacturonase alone. They thought that softening could be caused by a change in the ionic strength of fluids in contact with the cell wall.

Covering apple fruit with a foil bag inconsistently affects fruit firmness (Proctor and Lougheed, 1976). Apple flesh firmness is not affected by light levels in the vicinity of the fruit (Campbell and Marini, 1992 a). However, peach firmness is significantly related to the percentage of PPF in the vicinity of the fruit and the ground color index (Marini et al., 1991).

The relationship between flesh firmness and ground color index varies with the stage at which shading occurs (Marini et al., 1991). Firmness was not related to ground color for fruit from trees shaded until the end of Stage III. Covering peach fruit with foil decreased firmness and the temperature under the foil was 1^{o}C cooler than that near non-covered fruit (Erez and Flore, 1986). Loreti et al. (1993) obtained smaller peach fruit by covering with foil, but they thought this result was due to darkness and not altered temperature under the foil. Peaches covered with foil had higher fresh weight and water content, reduced firmness, smaller diameter, and less anthocyanin synthesis (Loreti et al., 1993).

Tree nutrition and fruit acid concentrations can also affect firmness. Peaches on high-carbohydrate/low-nitrogen trees (trees with no additional application of nitrogen) became soft ripe 10 days before those with high-nitrogen/low-carbohydrate (trees with additional applications of nitrogen) (Cooper, 1955). Fruit on high-carbohydrate trees also had about 100% more protopectin than fruit on high-nitrogen trees. High-nitrogen trees had greater vegetative growth that caused increased shading.

Peaches continue to increase in size as long as they remain on the tree (Morris, 1932). The rates of softening and growth that co-exist vary from year-to-year and tree-to-tree depending on the weather and growth conditions (Morris, 1932). Cloudy and wet periods are often followed by an increase in rate of growth and a decrease in firmness (Blake et al., 1931).

Fruit Surface Color

As peaches mature, ground color changes from green to yellow as chlorophyll concentrations decline and carotenoids increase (Addoms et al., 1930). Seymour et al. (1993) found that carotenoids are localized in the chloroplasts. Marini et al. (1991) found that ground color development varies with the PPF in the vicinity of the fruit. Fruit developing in shade develop yellow ground color later than fruit developing in high light. Marini et al. (1991) found that the relationship between red intensity and ground color varies with differing percent PPF. Red color changed from orangle/red to purplish/red with increasing PPF. Marini et al. (1991) also reported that the relationship between red intensity and percent PPF varies with ground color.

In apple, soluble solids are precursors for anthocyanin synthesis (Siegelman and Hendricks, 1958). Light was one of the main factors responsible for anthocyanin synthesis in apple fruits (Chalmers and Faragher, 1977 b). Intensity of red pigmentation of ‘Delicious’ apples increases linearly with cumulative hours of PPF above 250 umol$^{\cdot}$ m$^{-2\cdot}$ s^{-1} (Campbell and Marini, 1992 a). Proctor and Lougheed (1976) found that more anthocyanin is formed in ‘McIntosh’ apples that are first covered and then exposed to full sun 20 to 30 days before harvest, than in those fruit that are continually exposed to full sun. UV light, wounding

(Chalmers and Faragher, 1977 a), and low night and day temperatures (Creasy, 1968) all favor red color development in apple fruit. Fan and Mattheis (1998) found that specifically excluding UV-B light impairs red color development of ‘Fuji’ apples. Siegleman and Hendricks (1958) found a light-dependent lag or induction period in the appearance of anthocyanin in apple.

Anthocyanins, the primary red pigment in the vacuoles of peach skin cells (Salunkhe and Kadam, 1995; Seymour et al., 1993), also occur in the epidermal hairs of some cultivars, while varying amounts may occur throughout the flesh in other cultivars with a concentration near the pit (Addoms et al., 1930). The main anthocyanin in many peach cultivars is cyanidin-3-monoglucoside (Van Blaricom and Senn, 1967). Anthocyanin is derived from flavenoid compounds (Seymour et al., 1993). Mancinelli (1984) and Thomas (1981) reported that the photoreceptors phytochrome and cryptochrome are involved in anthocyanin biosynthesis of peach.

Less red color developed in peach with increasing amounts of shading by screen cloth (Erez and Flore, 1986). Erez and Flore (1986) found that 6,280 $J^{\cdot} cm^{-2}$ (~ 30% full sun), during the last 18 days before harvest, is sufficient for the production of greater than 70% of the red color obtained by the fully exposed control fruit (18,003 $J^{\cdot} cm^{-2}$). Marini (1985) found that the amount of blush on a peach increased with height in the tree. Peach fruit in the upper canopy are more purple and less orange-red than fruit in the lower canopy (Genard and Bruchou, 1992). Rom et al. (1984) also found that red peach color is greatest in the top third of the tree, decreases down the canopy, and is significantly correlated with the percent full sun at harvest. Haller (1952) found that red color is not a reliable index of maturity, because it varies with variety and light exposure, and the amount of red color is not always correlated with the stage of maturation

(Lott, 1965-66). Bible and Singha (1993) found that peach maturity varied with canopy position. found low night and day temperatures to favor red color development in nectarine.

Other factors affecting the color of peaches are temperature (Basiouny and Buchanan, 1977) and moisture level during the last period of fruit development and rainfall (Murneek, 1941). Final size and red color production will be negatively affected by lack of soil moisture. Red flesh pigments of peach were more strongly controlled genetically than regulated or altered culturally (Rom and Arrington, 1968). Dann and Jerie (1988) and Genard and Bruchou (1992) both found that leaf area per fruit did not influence color development.

Color Measuring Techniques

Several nondestructive methods have been developed to estimate maturity as it relates to pigments, including Delayed Light Emission (DLE) and colorimetry. DLE is based on the fact that low-intensity light (fluorescence) is emitted from chlorophyll, including that of peach fruits for several seconds or minutes after the fruit has been illuminated (Forbus and Dull, 1990). Because chlorophyll content declines as yellow pigments increase (Addoms et al., 1930), Forbus and Dull (1990) evaluated DLE as a technique to estimate peach maturity. Data using this system correlated fairly well with variables related to peach maturity except yellow pigments. Because yellow ground color is usually used as a primary indicator of maturity, DLE may not be a good measure of peach maturity. If a peach were picked when it is too immature, the chlorophyll would not entirely disappear and the carotenoid would not fully develop (Kramer and Haut, 1948).

Another method of measuring color, which might be used to establish a maturity standard, is with a photoelectric tristimulus colorimeter. This device functions best in measuring color differences, as opposed to a spectrophotometer, which measures the reflectance of a specimen throughout the visible spectrum from 380 to 780 nm (Voss, 1992). The problem with many of the color measuring systems is that they cannot distinguish between ground color and blush. This is the case with the colorimeter that integrates color over an area and reports color coordinates based on integrated spectral responses (Voss, 1992). Ground color can be almost totally obscured by red blush (Willison, 1941).

The photoelectric tristimulus colorimeter measures color using the CIELAB (International Commission on Illumination) color coordinates (McGuire, 1992). Figure 1 represents the CIELAB color coordinates (Minolta, 1994). These coordinates define a color solid within a 3-D space (Francis, 1980). L* is a measure of lightness on a scale from zero to 100. Zero represents black and 100 equals white. The a* axis goes from red (positive values) to green (negative values). The b* axis goes from yellow (positive values) to blue (negative values) (Genard and Bruchou, 1992). L* values can be presented without manipulation. However, a* and b* values should not be used alone, because they are not independent variables (McGuire, 1992). The a* and b* values can be used to quantify color by calculating hue angle. Hue [red, orange, yellow, green, etc. (McGuire, 1992)] angle is the arctangent of b*/a* in the first quadrant. A 90^o hue angle represents yellow, 180^o represents bluish/green, 270^o represents blue, and 0^o (360^o) represents red/purple (McGuire, 1992). Chromaticity is the degree of departure from gray or white towards the pure hue color or pure chromatic color (McGuire, 1992) and is calculated as the square root of the sum of the squares of a* and b* for a given color (Voss, 1992). Color measurements can be affected by the condition of the fruit surface. The amount of trichomes can affect the color measurement, and moisture on the fruit surface can decrease the L* value (Delwiche and Baumgardner, 1985).

The specification of a single color reference exactly matching the threshold maturity ground color, using one of the aforementioned methods, is complicated by differences due to cultivar, orchard management (pruning), region, and season (Delwiche and Baumgardner, 1983; Rood, 1957). However, Delwiche and Baumgardner (1983) found that variations in threshold ground color, measured using a colorimeter, among 13 cultivars of peach were very small.

Firmness and Color Relationships

Amoros et al. (1989) documented that peaches commenced softening as red color increased in the skin. Firmness and ground color indices of maturity are usually linearly and negatively related (Delwiche and Baumgardener, 1983). Simply stated, as firmness declines, ground color becomes more yellow and less green (Marini et al., 1991). Genard and Bruchou (1992) stated that only yellow color was well correlated with firmness.

As mentioned, both firmness and color are influenced by canopy position. Fruit with similar ground color harvested from different positions within the canopy may not have similar flesh firmness (Marini et al., 1991). This may be due to differences in PPF (Marini and Trout, 1984). Tree vigor, shading, and weather all affect the subsequent range of color and flesh firmness (Willison, 1941). These same factors can cause color and firmness measurements to vary from year to year (Willison, 1941). Thus, one color cannot be selected as a standard applicable either from year to year, from orchard to orchard, from tree to tree, or even within a tree; because in some years, some peaches would be too soft. For this reason, Morris (1932) thought pressure tests should be used to confirm suitable color maturity standards for each picking. The processes governing changes in firmness and those governing changes in color, while more or less parallel, are actually independent and may take place at the same rate and time in some fruits and in some seasons, but at different rates and times in others (Willison, 1941). This conclusion led Willison (1941) to a similar view as Morris (1932) regarding the use of pressure tests together with color standards. Sims et al. (1963) thought color and firmness should be used as co-indices of maturity.

Materials and Methods

‘Norman’ Studies.

Own-rooted, ‘Norman’ peach trees, planted in 1988 at the Virginia Tech College of Agriculture and Life Sciences Kentland Farm near Blacksburg, Virginia, were used in 1999. The trees were trained to the open vase form and were spaced 5x5.5 m apart. The trees were approximately 2.1 m in height and 3.5x4.8 m in diameter. The experiment was a 3x3x5 factorial experiment in a randomized complete block design.

There were three trees in each of six blocks. One side of each tree, chosen at random, was divided into three positions: inside, mid (intermediate), and outside. The innermost portion of the canopy, with the least amount of light, was designated “inside,” while the intermediate portion of the canopy (“mid”) had medium light exposure, and the “outside” had maximum light exposure. Inside fruit were at least 200 cm from the periphery of the tree and about 75 to 125 cm aboveground. Mid fruit were 50 to 150 cm from the tree periphery and 100 to 175 cm aboveground. Outside fruit were on the periphery in full sun, and were 150 to 210 cm aboveground.

On 7 July 1999, five fruit per position per tree were tagged and numbered randomly 1 to 5. One of three treatments was randomly assigned to one tree per block on 14 July (nine days before the first harvest date). The treatments were: control, 73% neutral-density black polypropylene shade fabric (E.C. Geiger, Harleysville, PA); and aluminum-coated plastic mulch with a silver reflective appearance [1.5 mil (0.038 mm) thickness, silver over black] (Clarke Ag. Plastics, Greenwood, VA). Shade treatment consisted of covering one side of the tree with shade cloth. PVC pipe, held in place with rebar steel, was arched (X pattern) over the canopy and used to support the shade cloth, with cinder blocks to anchor the corners of the cloth. Shade cloth was used to form a complete covering over the portion of the tree being used in the experiment. There were no leaves in the shade treated portion exposed to sunlight. The reflective mulch was about 3 m in length and was tacked to the ground with its edge against the trunk running parallel to the row. It extended into the row middle to within one meter of the drip-line of the tree. Metal spikes and bamboo were used along the edges of the mulch to keep it in place.

Photosynthetic photon flux (PPF) was measured on 21 and 22 July, with a LI-COR LI-250 light meter (LI-COR, Lincoln, NE) and a quantum sensor (LI-COR, Lincoln, NE). PPF was measured on six sides of each fruit, following a reference measurement made above the tree. PPF was measured by placing the sensor, facing away from the fruit, on the top, bottom, north, east, south, and west sides of each fruit. These six measurements were averaged for each fruit.

On 23 July 1999, one fruit per position per tree was harvested. Two leaves per fruit were also removed from as close to the fruit as possible. Fruit and leaves were then harvested every other day, for a total of five harvest dates. By the final harvest date (31 July) six fruit had abscised, resulting in an unbalanced experiment.

Each fruit was weighed, and its diameter was measured on an axis perpendicular to the suture. Flesh firmness was measured on two sides of each fruit with an Effigi penetrometer fitted with a 9 mm tip (Model FT 327; McCormick Fruit Tech., Yakima, WA). The first firmness measurement was made approximately 45^o from the suture. A second measurement was then taken 90^o from the first measurement. Soluble solids concentration was measured using a Lafayette 99-70369L hand-held refractometer with juice collected while measuring firmness. L*, a*, and b* values were measured with a Minolta CR-200 chroma meter (Minolta, Ramsey, NJ) for both the red and green sides of each fruit. Hue angle and chromaticity were calculated from the a* and b* values (McGuire, 1992).

For each leaf with petioles, area was measured with a LI-COR (LI-3000, Lincoln, NE) portable leaf area meter, and dry weight was recorded after drying at 93°C for four days. Specific leaf weight was calculated by dividing the dry weight by the leaf area.

‘Cresthaven’ Studies.

‘Cresthaven’/Halford peach trees, planted in 1988 at the Virginia Tech College of Agriculture and Life Sciences Kentland Farm near Blacksburg, Virginia, were used in 1999. The trees were trained to the open vase form. A 2x2x4 factorial experiment was used in a randomized complete block design. There were 12 trees in the experiment and each tree was considered to be a block. Each tree was divided into two positions, “inside” and “outside,” to obtain two light environments. Inside fruit were in the lower canopy about 2 m from the tree periphery where there was the least light. Fruit from outside positions were exposed to direct sunlight.

On 4 Aug. 1999 (16 days before the first harvest), four pairs of fruit per position per tree were tagged and treatments were applied. Fruit within a pair were no more than 20 cm apart. Treatments were fruit covered with aluminum foil versus non-covered fruit. The foil was wrapped around the fruit to prevent any light intrusion, but not so tightly as to disturb growth. One fruit per pair was covered and the other remained non-covered. Each pair of fruit was randomly numbered from 1 to 4, which referred to the harvest date. Fruit were not picked on the basis of ground color, but were picked by harvest date number. Thus, a range of fruit maturities was obtained on each harvest date.

On 9 and 11 Aug., PPF was measured on six sides of each non-covered fruit, as reported for ‘Norman’. The corresponding covered fruit was assumed to have similar light exposure. References above the tree were recorded before each set of measurements.

On 20 Aug., one pair of fruit per position per tree was harvested. Two leaves were also removed from next to each non-covered fruit. Fruit and leaves were then harvested every other day for a total of four harvest dates. Fruit size and quality variables were measured as reported for ‘Norman’.

Statistical Analysis

For each response variable, an analysis of variance (ANOVA) was performed with SAS’s GLM Procedure (SAS Institute, 1985). The model included block, harvest date, treatment, position, harvest date*treatment, harvest date*position, treatment*position, and harvest date*treatment*position.

Least squares means (LSmeans) were calculated for ‘Norman’, because the experiment was unbalanced. LSmeans were compared with the Probability of the Difference at the 5% level (PDIFF), which is the Least Significant Difference (LSD) modified for unequal sample size. The ‘Cresthaven’ experiment was balanced, so means were compared with Tukey’s HSD ($P=0.05$). In some cases, analyses of covariance were performed to account for the variation due to another variable. For example, hue angle of the non-blush side of the fruit may account for some of the variation in flesh firmness. Therefore, hue angle was included as a covariate, and the interaction term for hue angle*treatment or hue angle*position was also included in the model. In cases where the covariate was significant ($P<0.05$), LSmeans, adjusted for the covariate, were reported. When the hue angle*position interaction was significant, polynomial regression was performed for each position to determine if flesh firmness was linearly or quadratically related to hue angle for each position.

Results

Measurements of PPF are traditionally made near a fruit, with the sensor pointing skyward. However, in this experiment, PPF was measured with the sensor pointing in six directions from each fruit (top, bottom, north, east, south, west), and analysis was based on the average PPF of these six measurements per fruit. It was thought that an average of six PPF measurements was more descriptive of the PPF being received by a whole fruit. Figure 2 shows the relationship between average PPF of a fruit and PPF measured above the fruit. Averaged PPF was approximately half of the PPF measured above the fruit.

'Norman' Studies. Main effect means and P-values from analysis of variance (ANOVA) for 'Norman' are presented in Table 1. PPF was significantly affected by treatment and position. Average PPF was similar for the control and reflective mulch treatments, which received greater PPF than the shaded trees. PPF measured around fruit at inside and mid positions were similar, but both were lower than for fruit at the outside of the trees.

PPF measured above each fruit was significantly affected by position but not by light treatment. As with the averaged PPF, PPF above the fruit was similar for inside and mid fruit, but less than for outside fruit. PPF measured below each fruit was significantly affected by light treatment and canopy position (p=0.056 for position). Shaded trees and control trees were similar, whereas PPF measured below each fruit was highest for reflective mulch-treated trees. PPF measured below inside and outside fruit was similar, whereas PPF was highest below fruit in the intermediate region of the canopy.

Specific leaf weight (SLW) was significantly affected by light treatment and canopy position; and there was an interaction between harvest date*treatment*position. SLW was higher for outside leaves than for the intermediate region or inside leaves. Within canopy position, SLW fluctuated from day to day (Fig. 3).

Both fruit weight and fruit diameter were significantly affected by harvest date, light treatment and canopy position; and there was an interaction between harvest date*treatment (Table 1). In general, fruit weight and diameter increased over time (Fig. 4). However, fruit weight and diameter sometimes declined for control and shaded trees. Fruit from the outside of the tree had the highest weight and largest diameter, followed by fruit from the intermediate position; and inside fruit had the lowest weight and smallest diameter.

Flesh firmness was significantly influenced by harvest date and canopy position. Flesh firmness decreased from the first harvest date to the last. Fruit from the inside and intermediate position were similar, but both were firmer than the outside fruit. Average flesh firmness was not affected by treatment (Table 1).

Soluble solids concentration (SSC) was significantly affected by harvest date, light treatment and canopy position; and there was an interaction between date*treatment. SSC was similar for the first four harvest dates, then dropped approximately 20%. The interaction of harvest date*treatment was significant but weak, because all of the treatments followed the same trend (Fig. 4). All positions differed from each other in SSC. Fruit on the outside of the tree had the highest SSC, while fruit from the inside had the lowest SSC.

The L* (lightness) value and the hue angle for the red side of the fruit were significantly affected by harvest date, light treatment and canopy position; and there was an interaction between treatment*position (Table 1). Over time, L* on the red side of the fruit decreased (became darker), as did the hue angle (became redder). There was not a consistent decrease in the L* value or the hue angle for fruit harvested from the inside to the outside of the trees for the light treatments. Fruit from reflective mulch-treated trees and those from shaded trees had a consistent decrease in L* and hue angle, but fruit from the intermediate region of control treated trees had an increase in L* (became lighter) and hue angle increased (became less red). Relative to the hue angle and L* on the inside of the reflective mulch-treated trees, fruit in the intermediate position decreased more than the other treatments (Fig. 5).

Chromaticity (brightness) on the red side was significantly affected by light treatment and canopy position; and there was an interaction between harvest date*treatment. Within treatments, chromaticity on the red side fluctuated randomly across harvest date (Fig. 4). Fruit from shaded trees had higher chromaticity than fruit from the other treatments, and chromaticity for fruit from the outside of the tree was lower than for fruit from other canopy positions.

The L* value, hue angle, and chromaticity on the non-blush side of the fruit were significantly affected by harvest date, treatment, and position. From the first harvest date to the last, the blush side of fruit became darker and changed from yellow to orange, while the chromaticity increased. All three treatments differed from each other with the lightest, greenest, and brightest fruit being those from shaded trees, whereas the darkest and reddest fruit were from the reflective mulch-treated trees. Fruit from the reflective mulch-treated trees and control trees were similar with a low degree of brightness. As on moves from the outside to the inside of the canopy, L* values, chromaticity, and hue angles increased (Table 1).

The relationship between hue angle on the non-blush side of the fruit and flesh firmness was not influenced by treatment, but the relationships varied for the three canopy positions. The relationship between hue on the non-blush side and firmness was quadratic for all three positions (Fig. 6). This relationship became more variable as fruit sampling progressed from the inside to the outside of the tree; coefficients of determination were 0.65, 0.60, and 0.50 respectively for fruit harvested from the inside, intermediate and outside positions (Fig. 6). At hue angles greater than 50^o, fruit from the outside of the canopy were the softest. At a given hue angle, firmness was similar for intermediate fruit and the inside fruit.

‘Cresthaven’ Studies. Main effect means and P-values from ANOVAs for ‘Cresthaven’ are presented in Table 2. Averaged PPF was significantly affected by position. Outside fruit intercepted about four times as much PPF as fruit developing inside the canopy (Table 2). Canopy position, but not harvest date, influenced SLW. Because SLW was not measured for leaves near covered fruit, treatments could not be compared. Leaves from the outside had higher SLW than from the inside.

Fruit weight was significantly affected by harvest date, treatment, and position. Fruit weight increased as the harvest season progressed. Fruit covered with foil were heavier and larger than non-covered fruit, and outside fruit were heavier than inside fruit. Fruit diameter was significantly affected by harvest date, treatment, position, and date*position. Outside fruit varied in diameter among harvest dates (Fig. 7).

Flesh firmness was significantly affected by harvest date, treatment, and position. Firmness was greatest on the first two harvest dates (Table 2). Fruit covered with foil were less firm than non-covered fruit, and outside fruit were less firm than inside fruit.

Treatment and position significantly affected SSC. SSC did not differ among harvest dates. Non-covered fruit had higher SSC than covered fruit, and outside fruit had higher SSC than inside fruit.

The L* value and chromaticity on the blush side of the fruit were significantly affected by treatment, position, harvest date*position, and treatment*position (Fig. 7).

Hue angle on the blush side was significantly affected by treatment, position, and the interaction of treatment*position. Hue angle did not differ for fruit collected on different harvest dates. Hue angle indicated that covered fruit were orange-yellow, whereas non-covered fruit were dark red (Fig. 9). Fruit from the outside of the tree were more red than fruit from the inside, but hue angles of non-covered fruit were affected by position more than were covered fruit (Fig. 9).

L* on the non-blush side was significantly affected by treatment and position, but not by harvest date. Non-covered fruit were darker than covered fruit, and outside fruit were darker than inside fruit. Hue on the non-blush side was significantly affected by harvest date, treatment, position, and harvest date*treatment (Table 2). Hue angles indicated that the non-blush side of covered fruit remained yellow for all harvest dates, whereas non-covered fruit changed from yellow to orange (Fig. 8).

Chromaticity on the non-blush side was significantly affected by harvest date, treatment, and position. Over time, the fruit became slightly brighter. Non-covered fruit were less bright than covered fruit, and inside fruit were less bright than outside fruit (Table 2). Chromaticity on the blush side of the fruit for both cultivars did not change over time, and was negatively related to light availability. Chromaticity on the non-blush side of the fruit of both cultivars slightly increased over time, and was negatively related to the amount of light hitting the fruit. To the contrary, the chromaticity on the non-blush side was greater for fruit sampled from the outside than the inside of the tree.

The relationship between hue on the non-blush side and firmness differed among treatments and positions for ‘Cresthaven’ fruit. The relationship was linear for covered fruit from the inside. The remaining three position/treatment combinations (outside/covered, inside/non-covered, and outside/non-covered) had quadratic relationships between green hue and firmness. However, the three quadratic curves were not homogenous (Fig. 10). Covered fruit had less variation among positions than did non-covered fruit. When light was eliminated by covering the fruit, the relationships between hue angle and firmness were similar for both positions. At a given hue angle, fruit from both positions had similar firmness. The lowest hue angle recorded for covered fruit was about 78°, which corresponded to an orange-yellow color; non-covered fruit had hue angles < 45°, corresponding to red (Fig. 10). The firmness of fruit with hue angles at 65° to 90° was greater for fruit development at the outside position.

Discussion

Average PPF was reduced by shading trees and by selecting fruit from inner and intermediate positions of the canopy. Average PPF received by 'Cresthaven' and 'Norman' fruit on the inside of the canopy was much less than fruit from the outside of the canopy, which was previously reported for peach (Marini and Marini, 1983). There were fewer fruit in the inside positions of the canopy to choose from, so samples may not have been located directly over the mulch. This, and the fact that the interception of light by the outer canopy would prevent reflection of light off of the mulch to hit inside fruit, could be why PPF measured below intermediate fruit was highest. Outside fruit would have light reflection reduced by the canopy below them blocking the rays that would bounce off the reflective mulch.

SLW is related to cumulative light exposure of a leaf until September in Virginia (Marini and Barden, 1982; Marini et al., 1991). In this study, differences in SLW verified that light levels were successfully altered by treatments in the 'Norman' experiment and by selecting different canopy positions in both experiments. The three-way interaction of date*treatment*position for SLW was significant for 'Norman' (Fig. 4).

Fruit weight and diameter increased over time for both 'Norman' and 'Cresthaven' fruit, but artificial shading did not influence fruit size. These data support a previous report where shading non-girdled branches did not influence fruit weight (Marini et al., 1991). In my study, covered 'Cresthaven' fruit increased more in weight and diameter than the non-covered fruit. This finding might be due to reduced transpiration rates, rather than a direct effect of light. These results conflict with those of Erez and Flore (1986), where covering fruits with foil for varying lengths of time did not affect fruit weight.

Flesh firmness changed with canopy position for both ‘Norman’ and ‘Cresthaven’ fruit (Tables 1 and 2). This is in agreement with Marini et al. (1991), where peach firmness was significantly related to the percentage PPF in the vicinity of the fruit. In this experiment, the position of the fruit determined the amount of light in the vicinity of the fruit. Flesh firmness of ‘Norman’ was not affected by shade cloth and reflective mulch. However, covered ‘Cresthaven’ fruit were significantly less firm than non-covered fruit, which supports the results of Erez and Flore (1986). Loreti et al. (1993) reported that the increased water content, greater fruit weight, and reduced fruit flesh firmness of covered fruit suggested that deprival of solar radiation [by covering fruit with foil] interfered with the formation and composition of flesh cell walls, making them more elastic and enabling them to swell and contain more water. Covered fruit may have been softer than non-covered fruit because: 1) the foil may have prevented ethylene from diffusing away from the fruit, resulting in advanced maturity of covered fruit; or 2) the foil may have reduced transpiration, a hypothesis supported by the fact that the fruit were larger. Erez and Flore (1986) found that covering fruit with foil did not significantly affect ethylene biosynthesis.

There was no appreciable increase in SSC during the harvest period for either ‘Norman’ or ‘Cresthaven’ fruits. Haller (1952) suggested that there was no consistent change in SSC in relation to peach fruit maturity. Precipitation probably increased fruit water content and diluted SSC on the last harvest date for ‘Norman’ fruit, because as Lott (1965) found, variation in SSC can be caused by weather. In this study, the light environment of fruit was altered by shading trees, placing reflective mulch under the trees, harvesting fruit from different canopy positions, and covering individual fruit. Regardless of the method employed to alter light levels, SSC was positively related to light level. Dann and Jerie (1988) reported that because light is a primary resource for photosynthesis, fruit lower in the tree may be disadvantaged by lower assimilate supplies from adjacent leaves and by distance from well-lit leaves near the top of the tree. This could explain the lower SSC in fruit from different areas of the canopy or in fruit from treatments that altered light levels.

Development of anthocyanins, the pigment responsible for red color development in the skin of peach fruit, was influenced by solar radiation (Loreti et al., 1993). In this experiment, red color (hue on the blush side of the fruit) was greatest in positions with the highest average PPF (Table 1 and 2). Red color is positively related to PPF in the vicinity of the fruit (Erez and Flore, 1986; Marini et al., 1991). The loss of green color and the development of yellow pigment were independent of light level, as seen in Table 2. The covered 'Cresthaven' fruits developed a yellow ground color in the absence of light.

Due to the effect of PPF on red color development, PPF was viewed as the key factor in determining the relationship between ground color and firmness. Those fruit receiving the least amount of PPF, and in turn developing the least amounts of red color, had the most linear relationships between ground color and flesh firmness. The less light received by a fruit, the less red color it developed, and the better the relationship was between ground color and firmness. The colorimeter integrates color over an area (Voss, 1992). The development of red color, which had no relationship to firmness, skewed the colorimeter reading of the background color.

The effects of PPF and position were confounded, but by covering the fruit with foil, the two components were separated. When fruits were covered, the effect of position was due to factors other than light hitting the fruit (e.g., distance from leaves). The results of this experiment indicate that when using the available colorimeter, the ability to determine the relationship between ground color and firmness is altered by PPF and the presence of anthocyanin.

Although fruit develop red color and soften as they mature, the two processes are independent of each other. The amount of light intercepted by a fruit influences the relationship between color of the non-blush side of the fruit and flesh firmness. Fruit growing in high-light environments develop red color. Even on the non-blush side, the color varies from orange-yellow to red-orange. The presence of red color makes the relationship between ground color and flesh firmness more variable using this particular colorimeter.

There are three pigment systems in peach fruit. Anthocyanins (red pigments) are light dependent and are not related to firmness or maturity. Carotenoid synthesis (yellow pigments) is not light dependent and corresponds to firmness and maturity. Chlorophyll degradation (loss of green pigments) is related to light and fruit maturity.

Samples in this experiment were selected randomly on each date and this may have contributed to inconsistencies in fruit maturity trends over time. Also, the sample size on each date was small, which could have contributed to this as well.

Conclusion

1. If the red color is eliminated by shading the fruit, there is a fairly good linear relationship between ground color and flesh firmness.
2. Covering the fruit with foil effectively separated the effects of light and canopy position.
3. Light, not canopy position, influences the relationship between fruit surface color and flesh firmness.

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