J. Amer. Soc. Hort. Sci. 105(5):645–657. 1980.

'Delicious' Apple Fruit Size and Quality as Influenced by Radiant Flux Density in the Immediate Growing Environment[1]

E. J. Seeley, W. C. Micke,[2] and R. Kammereck
Tree Fruit Research Center, Washington State University, Wenatchee, WA 98801

Additional index words. Malus domestica, soluble solids, light, starch

Abstract. **Fruits of 'Delicious' apple (*Malus domestica* Borkh.) were grown under differing radiant flux densities (rfd $\frac{400}{700}$ nm) from 45 days post-bloom until harvest. The rfd $\frac{400}{700}$ nm affected red fruit color, soluble solids, starch content and size, but not firmness, pH or total acidity at harvest or after 105 days of storage at −0.5°C. Levels of rfd $\frac{400}{700}$ nm sufficient to enhance red color development in red sports of 'Delicious' were not necessarily sufficient to insure flesh quality.**

The role of the micro-climate within an apple tree in determining tree growth patterns, fruit quality and cropping stability has long been recognized. Schrader and Marth (13) found that slight shading adversely affected fruit color. Later workers found that shading individual fruits (14) and entire bearing trees (5, 6, 7) adversely affected red color development, size and storage quality.

As 'Delicious' apples have gained in popularity and plantings have been established in widely separated localities, the influence of radiant energy distribution within canopies has become an increasing concern (3, 8, 11). The increasing number of "high coloring" strains of 'Delicious' being planted and the trend toward higher tree densities suggest a need for additional information on the effect of inter- and intra-tree shading on fruit quality and color. We therefore initiated an experiment to determine the effects of artificial shading on red color development, size and internal quality of 'Miller Sturdeespur Delicious' apples. Such knowledge is vital in view of the known effects of environmental factors on fruit quality parameters (4, 5, 7, 12, 14) and the demand for fruit which can be stored for long periods.

Materials and Methods

Fiberglass-covered wood frame shelters were placed over matched limbs of 'Miller Sturdeespur Delicious' (a high coloring cultivar) apple trees growing in a commercial block in north central Washington 45 days after full bloom in 1977. Attempts were made to provide 4 levels of radiant flux densities (rfd $\frac{400}{700}$ nm). Single limbs in the tops of 3 trees were selected and positioned at an angle of about 45° so they would receive the maximum rfd possible for the entire day. Three additional limbs on each of the same 3 trees were placed under shelters covered with either 1 or 2 layers of translucent fiberglass (Structo-glass white 1.41 kg m^{-2}), or 1 layer of fiberglass covered with reflective aluminum paint. Care was exercised in selection of covering materials so that attenuation of the radiation was uniform for all wavelengths between 400 and 1600 nm.

The shelters were closed on 2 sides, the top and the distal end. The bottom was open as was the proximal end which was lowered and placed so that direct sunlight would not enter the shelter. The top of the shelter was wider than the rest of the structure and a continuous 5 cm vent between the sides and the top prevented excessive heating. Under unobstructed sunlight, air temperature in the shelters ranged from 1 to 4°C higher than the external ambient temperatures.

A pyranometer was placed on a platform about 60 cm above the top of the tree canopies to record total global radiation at tree top level during the experimental period. This pyranometer was calibrated against a LI-COR quantum sensor-integrator and was read weekly to obtain the total radiant flux (trf $\frac{400}{700}$ nm) at the tree top level.

The percentage of the trf $\frac{400}{700}$ nm received by the leaves and fruits in each of the shelters was determined by measuring the rfd $\frac{400}{700}$ nm hourly from sunrise to sunset on 2 clear days (mid-July and late August), using an ISCO SR spectroradiometer equipped with a remote probe. Readings (50 nm increments) obtained under each shelter were integrated, summed and divided by the average of 2 full sun readings, one taken before and one immediately following the reading period. The 11 spectra, one under each of 9 shelters and 2 full sun readings, were generally completed in 15 to 18 min to minimize the influence of changing solar angles.

Fruits were thinned so that 50% of the spurs were bearing single fruits and 50% were non-bearing. At harvest the fruits from each limb (number of fruits varied from 24 to 72) were picked, numbered, weighed and the circumference measured. Fruit color was determined both photometrically using an "Agtron" meter and visually according to Washington state grades. Numerical values were assigned for fruit color as follows: extra fancy = 1, fancy = 2 and cull = 3 (Table 1). The photometric measurements were used only to verify the accuracy of the visual grading. This was because the Agtron model used gave suspect readings for fully colored fruit with intense red color. Some of these fruits had higher values (less red color) than some obviously more poorly colored specimens.

Because of a record hot period (20 consecutive cloudless days with high temperatures of 36°C+) during the first 21 days of August, some fruits on limbs exposed to full sunlight were sunburned. These fruits were all rated as extra fancy, as it was assumed rfd $\frac{400}{700}$ nm was not a limiting factor in red color development. Fruits from each test limb were ranked according to red color and segregated into 2 lots (12 to 36 fruits per lot), one to be analyzed at harvest for internal quality parameters, the other stored at −0.5°C for 105 days and then analyzed

The distribution of starch within individual fruits was determined by immersing a transverse equatorial slice in an aqueous IKI solution and allowing color to develop (2, 9). Relative starch content was determined by rating the distribution pattern of starch in the fruit in a manner similar to the method of Blanpied (1) but with an expanded scale of 1

[1]Received for publication January 27, 1979. Scientific paper no. 5273, College of Agriculture Research Center, Washington State University, Pullman, WA 99164. We thank the Columbia River Orchards Foundation, the Washington State Tree Fruit Research Commission and Wells and Wade Fruit Company for supporting this research.

The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper must therefore be hereby marked *advertisement* solely to indicate this fact.

[2]Present address: Pomology Department, University of California, Davis CA 95616.

Table 1. The effects of radiant flux density on size, color and internal quality of 'Miller Studeespur Delicious' apples.

Limb no.	rfd $\frac{400}{700}$ nm	Mean fruit wt (g)	Visual color	At harvest: Soluble solids (%)	Starch rating	Firmness (kg)	pH	Acidity[z] (ml)	After 105 days at −0.5°C: Soluble solids (%)	Starch rating	Firmness (kg)	pH	Acidity[z] (ml)
1	100.0	135	1.29	10.26	4.0	10.36	3.82	3.46	12.76	2.5	8.54	3.72	3.29
2	100.0	120	1.48	10.20	4.0	10.59	3.85	3.25	12.41	2.5	8.29	3.78	2.95
3	100.0	97	1.31	10.61	4.0	10.95	3.81	3.18	12.78	2.5	8.89	3.73	3.12
4	37.0	113	1.88	9.59	4.0	10.23	3.93	3.06	11.30	2.5	8.54	3.68	2.74
5	25.0	89	1.68	9.02	3.0	10.27	3.84	2.75	10.85	2.0	8.53	3.69	3.01
6	14.0	98	1.81	9.38	2.7	11.13	3.78	2.88	11.04	1.8	7.98	3.61	2.92
7	14.0	98	2.05	8.79	3.0	10.32	3.87	2.91	10.30	2.0	9.08	3.68	3.10
8	14.0	89	2.25	9.12	2.7	10.50	3.82	3.14	10.47	2.0	8.64	3.61	2.89
9	9.0	105	1.91	9.21	2.0	10.27	3.87	3.13	11.07	1.8	7.93	3.67	2.99
10	0.4	85	2.96	8.32	2.0	10.55	3.88	3.89	10.29	1.0	8.83	3.73	2.50
11	0.3	77	3.00	8.06	2.0	10.55	3.81	3.44	9.65	1.0	9.24	3.68	3.38
12	0.2	93	3.00	8.29	2.0	10.23	3.90	2.90	9.46	1.0	9.11	3.55	3.05
r^2		52%	78.1%[y]	81.5%		n.s.	n.s.	n.s.	86.5%		n.s.	n.s.	n.s.

[z]ml of 0.1 N KOH required to titrate 10 ml juice to pH 7.

[y]Correlation excludes limbs 10, 11 and 12 which were below light intensities required for initiation of color formation.

to 4. A rating of 1 indicated an absence of starch, 2, starch distributed in the outer layers of the apple flesh, 3, starch extending inward to vascular bundles, and 4, starch extending into the core area.

Fruit firmness was measured with a Magness-Taylor penetrometer (10.9 mm tip) by averaging 2 readings taken on opposite sides of the fruit. Following the firmness determination the entire apple was ground, the juice was extracted and soluble solids, pH and total acidity were determined.

Red fruit color was estimated visually in each shelter periodically throughout the growing season. Red color typical of 'Miller Sturdeespur Delicious' began to develop during the latter part of the first week of August. Correlation coefficients were calculated for fruit color at harvest (Sept. 15) vs. trf $\frac{400}{700}$ nm from August 4 to Sept. 15, using color values for individual fruits.

Results and Discussion

Fruit color vs. rfd $\frac{400}{700}$ nm. The threshold rfd $\frac{400}{700}$ nm for red color development was about 5 Jm^{-2} sec^{-1}; below this level no persistent color developed (Table 1). This result compared favorably with previously published reports (10) and confirms the concept of a threshold requirement below which no red color forms. Total trf $\frac{400}{700}$ nm of 1 MJ m^{-2}, which resulted in persistent red color development when administered over a 48 hr period (10), failed to do so in this experiment when accumulated over 43 days. Color data from fruit from limbs 10, 11 and 12 (Table 1) were excluded from this analysis because trf $\frac{400}{700}$ nm values were substantially below the 5 Jm^{-2} sec^{-1} required to initiate red color development. On the remaining limbs, fruit color correlated well with the percent of trf $\frac{400}{700}$ nm received (r^2 = 78.1%). The slope (2.04-0.00696 · rfd $\frac{400}{700}$ nm [%]) was not great, however, suggesting that visibly detectable color differences were induced only by relatively large changes in the rfd $\frac{400}{700}$ nm. Substantial reductions in total rfd $\frac{400}{700}$ nm may therefore have little effect on red color of a high red coloring sport of 'Delicious', but, as discussed later, may reduce internal fruit quality appreciably.

Starch content vs. rfd $\frac{400}{700}$ nm. Starch deposits were detectable in all fruits at harvest time, even in fruits from limbs which had been continually below the photosynthetic (rfd $\frac{400}{700}$ nm) compensation point. Iodine staining illustrated that the flesh of fruit exposed to higher rfd $\frac{400}{700}$ nm levels stained darker and the stained area extended farther into the core than in fruits from shaded limbs (Table 1). Fruit grown at lower rfd $\frac{400}{700}$ nm had little starch in the core area and low concentrations in the flesh outside the coreline.

All fruit lost the starch from the area within the vascular bundles during storage at −0.5°C for 105 days. Fruit grown under full rfd $\frac{400}{700}$ nm still had a substantial amount of starch in the flesh exterior to the coreline, but those grown at the lowest rfd $\frac{400}{700}$ nm level (less than 1% of full sun) were essentially depleted of starch (Table 1).

Soluble solids vs. rfd $\frac{400}{700}$ nm. Percent soluble solids was highly correlated with percent rfd $\frac{400}{700}$ nm in the immediate growing environment (r = 0.903 at harvest and 0.952 after 105 days in storage). After 105 days of cold storage the percent soluble solids had increased and content was highly correlated with rfd $\frac{400}{700}$ nm (Table 1). In addition the slope of the line increased (significant at 99%). These data together with those for starch indicate that during storage starch was hydrolyzed more rapidly than the soluble solids were depleted by respiration. In addition the increase in slope suggests that a positive relationship existed between rfd $\frac{400}{700}$ nm level in the growing environment, starch and soluble solids content. This indicates that even though as little as 9% full sunlight allowed red color development sufficient for fancy and extra fancy grades (Table 1), such fruit was low in soluble solids at harvest and in both starch and soluble solids after a comparatively short storage period.

Fruit weight vs. rfd $\frac{400}{700}$ nm. Weight of fruit at harvest was directly correlated with rfd $\frac{400}{700}$ nm. The association was significant (95%) even though the coefficient of correlation was relatively low (r = 0.718). Approximately 52% of the variation in weight can be explained by differences in rfd $\frac{400}{700}$ nm during the experimental period. Thus other factors, some of which have been thoroughly reviewed elsewhere (15) also influence fruit weight.

When the inter-tree differences were removed the association between rfd $\frac{400}{700}$ nm and fruit weight was greater. On an individual tree basis the coefficients of determination (r^2) were 88.1, 99.2 and 73.5%. Data for number of shoots per scaffold and average length of shoots measured during the preceding winter (data not shown) indicated that the vigor of the 3 trees used in this work differed. Weight of fruits on limbs on the highest vigor tree (limbs no. 1, 4, 9 and 12, Table 1) were

consistently greater than fruit from the lowest vigor tree (limbs 3, 5, 8 and 11) indicating that tree vigor also contributes to fruit size.

Acidity and pH vs. rfd $\frac{400}{700}$ nm. No statistically significant differences were found at harvest time or after storage in either level or variance of acidity of fruits grown under the different light intensities. During the storage period, however, pH significantly (95%) decreased by 4.4%.

Fruit firmness vs. rfd $\frac{400}{700}$ nm. Fruit firmness was not related to rfd $\frac{400}{700}$ nm (Table 1), regardless of extremes. During the storage period the firmness dropped 17.4% (from 10.45 to 8.66 Kg) but this drop occurred uniformly for all treatments. The high variability may have masked any existing differences.

Of considerable significance to the 'Delicious' apple industry is the finding that rfd $\frac{400}{700}$ nm sufficient to produce fancy and extra fancy fruit is not sufficient to produce the highest quality fruit in terms of size, starch content and soluble solids. The fact that the slope of the correlation between red coloration and rfd $\frac{400}{700}$ nm received is trivial while there is a positive correlation between soluble solids and rfd $\frac{400}{700}$ nm suggests that a grading system based on 3 red color grades does not necessarily segregate fruit on the basis of internal quality.

Literature Cited

1. Blanpied, G. D. 1974. A study of indices for earliest acceptable harvest of Delicious apples. *J. Amer. Soc. Hort. Sci.* 99:537-539.
2. Fidler, J. C., B. G. Wilkinson, K. L. Edney, and R. O. Sharples. 1973. The biology of apple and pear storage. Commonw. Agr. Bur. pp. 11-13.
3. Heinicke, D. R. 1964. The micro-climate of fruit trees. III. The effect of tree size on light penetration and leaf area in Red Delicious apple trees. *Proc. Amer. Soc. Hort. Sci.* 85:33-41.
4. _____. 1966. Characteristics of McIntosh and Red Delicious apples as influenced by exposure to sunlight during the growing season. *Proc. Amer. Soc. Hort. Sci.* 89:10-13.
5. Jackson, J. E., R. O. Sharples, and J. W. Palmer. 1971. The influence of shade and within-tree position on apple fruit size, color and storage quality. *J. Hort. Sci.* 46:277-287.
6. _____ and J. W. Palmer. 1977. Effects of shade on the growth and cropping of apple trees. II. Effects on components of yields. *J. Hort. Sci.* 52:253-266.
7. _____, _____, M. A. Perring, and R. O. Sharples. 1977. Effects of shade on the growth and cropping of apple trees. III. Effects on fruit growth, chemical composition and quality at harvest and after storage. *J. Hort. Sci.* 52:267-282.
8. Looney, N. E. 1968. Light regimes within standard size apple trees as determined spectrophotometrically. *Proc. Amer. Soc. Hort. Sci.* 93:1-6.
9. Phillips, W. R. and P. A. Poapst. 1952. Storage of apples. *Can. Dept. Agr. Bul.* 776.
10. Proctor, J. T. A. and L. L. Creasy. 1971. Effect of supplementary light on anthocyanin synthesis in 'McIntosh' apples. *J. Amer. Soc. Hort. Sci.* 96:523-526.
11. _____, W. J. Kyle, and J. A. Davies. 1975. The penetration of global solar radiation in apple trees. *J. Amer. Soc. Hort. Sci.* 100:40-44.
12. _____ and E. C. Lougheed. 1976. The effect of covering apples during development. *HortScience* 11:108-109.
13. Schrader, A. L. and P. C. Marth. 1931. Light intensity as a factor in the development of apple color and size. *Proc. Amer. Soc. Hort. Sci.* 28:552-555.
14. Smock, R. M. 1953. Some effects of climate during the growing season on keeping quality of apples. *Proc. Amer. Soc. Hort. Sci.* 62:272-278.
15. Tukey, L. D. 1974. Some relationships in the growth and development of apple fruits. *Proc. 19th Intern. Congr.* 3:35-45.

J. Amer. Soc. Hort. Sci. 105(5):647–650. 1980.

The Effect of Artificial Aging on the Concentration of Ca, Mg, Mn, K, and Cl in Imbibing Cabbage Seed[1]

Edward L. Loomis and Orrin E. Smith[2]

Department of Horticulture and Landscape Architecture, Washington State University, Pullman, WA 99164

Additional index words. Brassica oleracea

Abstract. **Unimbibed seeds of cabbage (*Brassica oleracea* L. Capitata group, cv. Early Jersey Wakefield, were artificially aged at 40°C in 100% relative humidity for up to 20 days. Aged seed and non-aged seed were imbibed in H_2O at 25° in the dark up 0, 1, 4 or 16 hours, after which concentrations of Ca, Mg, Mn, K, and Cl in the whole seed were determined by neutron activation analysis. Concentrations of Ca, Mg, and Mn did not significantly change during the imbibition period for either control or aged seed. However, as the aging time increased, seeds lost increasing amounts of K and Cl during imbibition. The concentration of K decreased continually throughout the imbibition period in both aged seed and control seed. The decrease was significantly greater in the aged seed. Cl, too, was lost during imbibition and like K, the greater loss occurred in aged seed.**

Loss of seed viability and vigor as a result of aging has been well established (22). During the aging process, a number of physiological and biochemical changes occur within the seed, including reduced respiration (9, 24), increased chromosomal aberrations (15), determinations of cellular membranes (2), reduced enzyme activity (4, 7), and reduced protein synthesis (6). The deterioration of cellular membranes in aged seed is reflected by increasing amounts of sugars, amino acids and inorganic seed constituents in leachate of imbibing seeds. When conductance of the seed leachate is measured, high conductance is correlated with low germination and reduced seedling vigor, while low conductance is correlated with high germination and vigorous seedlings. This relationship has been established for many crops including corn (21), cotton (3), lima beans (14) and rape (20). Low germination and vigor has frequently been

[1]Received for publication November 19, 1979. Scientific Paper No. 5510. College of Agriculture. Washington State University, Pullman. Project No. 0188.

The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper must therefore be hereby marked *advertisement* solely to indicate this fact.

[2]Assistant Professor, Clemson University, Sandhill Experiment Station, Elgin, South Carolina; Professor of Horticulture, respectively.