PHOTOELECTRIC COLOR SORTING OF CITRUS FRUITS
PREFACE

The joint research was conducted by the Transportation and Facilities Research Division, under the general supervision of Earl K. Bowman, industrial engineer, and Joseph F. Herrick, Jr., investigations leader, and the Market Quality Research Division, under the general supervision of P. L. Harding, investigations leader, retired. In the approach and procedure, consideration was given to earlier sorter tests arranged by John N. Yeatman, Market Quality Research Division. The staffs of the Citrus Experiment Station and the Agricultural Engineering Department of the Institute of Food and Agricultural Sciences, University of Florida, gave advice and encouragement.

Acknowledgment is made to C. J. Beckwith of Electric Sorting Machine Division, Mandrel Industries, Inc., for his helpfulness in arranging the lease of the sorter and interest in the progress of the work. Fruit for the tests was purchased from Chase and Company, Windermere, Fla. Russell C. Hofmann, Market Quality Research Division, assisted in conducting the experiments. Most of the statistical work was done by the staff of Biometrical Services, Agricultural Research Service, Beltsville, Md.

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Photoelectric Color Sorting of Citrus Fruits

By Otto L. Jahn, research horticulturist, Market Quality Research Division, and Jerome J. Gaffney, agricultural engineer, Transportation and Facilities Research Division, Agricultural Research Service

SUMMARY

A photoelectric color sorter was used in controlled studies on citrus fruit during one season of operation. The degreening response of sorted Hamlin oranges was measured in a series of seven tests. Once the chlorophyll level began to decline in the fruit on the tree, good sorting was obtained, and differences in the time required to degreen the fruit were shown. The greenest fruit took 1 to 2 days longer to degreen than the yellowest fruit, and it was more likely to fail to reach a good color during as much as 4 days' degreening.

Analyses of fruit from each color class of each test showed a trend toward lower soluble solids in juice of fruit in the greenest class than in the other classes. There was no general relationship between chlorophyll level and internal quality in these tests, however.

The degreened fruit was held for a total of 4 weeks at 70° F. to study effects on decay. The length of the degreening period was found to affect the subsequent occurrence of stem-end decay, but apparently it had no influence on decay due to Penicillium. Generally, the amount of stem-end decay increased progressively as the degreening period was increased from 0 to 4 days. These differences tended to persist throughout the 4-week holding period. However, the amount of decay also increased as the length of the holding period increased; this tended to obscure some of the affects of the length of the degreening period. In two tests, fruit in the greenest class tended to decay more rapidly than fruit in the other classes.

Washing of Hamlin oranges improved the uniformity of the resulting color classes and did not hinder degreening of the fruit. Successful separations of limes and of Valencia oranges into classes with different chlorophyll levels were made. Other successful sortings for uniformity were made on yellow-orange pigments in Hamlin and Temple oranges. One sorting for defects was made. This sorting on rust-mite injury showed that large defects of this type could be separated by machine by the same procedure as used for chlorophyll sorting.

Observations on the operation of the sorter, as well as the actual sorting results, indicate that the use of a machine for several sorting
problems is possible and practical. Because of economic considera-
tions, flexibility is desirable since it would permit the equipment
to be used during a longer season than would be possible with any
single application.

INTRODUCTION

Color uniformity is as important in the marketing of fruit as it
is in most other agricultural or nonagricultural products. In citrus
this has been most clearly defined in the marketing of limes (32)
and lemons, where color sorting is a regular practice. With oranges,
color sorting has not generally been used. However, the extensive
use of color-adding processes and the insistence of some markets
on “color-added” fruit (24) indicate that the color of oranges also
is important in marketing.

The importance of color in the marketing of citrus is apparent in
the practice of degreening to improve color (19, 38, 42). Bates in
1933 (4) noted that degreening improved the attractiveness and
value of fruit by giving them a better and more uniform color.
However, he also noted that degreening did not ripen the fruit; it
had to be mature enough when harvested to develop good color in
a reasonable time. Other work has also shown a relationship be­
tween initial color and the percentage of fruit that could be packed
(1, 3, 13, 14, 16, 21, 30). Undesirable fruit color may be a major
defect in grading fruit (15, 20), averaging as high as 43 percent
of the total defects in one series of studies on oranges (15).

Dегreening as now practiced has generally been found to in­
crease subsequent fruit decay, especially when ethylene was used
(8, 9, 12, 18, 19, 25, 26, 27, 33, 38). Dегreening may increase stem­
end rot, but it has little effect on (4, 27), or in some instances has
reduced the incidence of (26), Penicillium decays. Increasing the
length of the degreening period resulted in increased losses from
decay (17, 26, 33, 38).

Since ethylene tends to increase the incidence of stem-end decay,
the concentration of ethylene used in degreening is important. The
recommended concentration has ranged from 1 to 200 p.p.m. (parts
per million) (1, 4, 13, 16, 33, 41). However, the optimum concen­
tration for rapid degreening probably lies between 4 and 20 p.p.m.
(1, 10, 11, 19).

Since degreening may have harmful effects on the fruit, the length
of this period should be minimized. Color sorting of fruit would
help by producing narrow color classes, with fruit in each class

1 Italic numbers in parentheses refer to Literature Cited. p. 48.
degreened for its optimum period. The potential for color sorting citrus has been noted by several workers (8, 25), and some limited studies have been made (3, 14, 17). Except for the earlier phases of this work (30), no extensive tests have been reported. In other crops several types of sorters have been used experimentally, including the use of X-rays (23), light reflectance (34, 35, 37), and light transmittance (6, 7, 48). By 1966, electronic color sorting was being used extensively in the sour cherry industry (39, 40). Color sorters (2) have been used on lemons for many years.

Earlier studies with hand-sorted fruit showed that color sorting would help to increase the efficiency in degreening oranges (30). The present studies were undertaken to obtain results on a commercial color sorter and also to explore the use of color sorting for other purposes including color uniformity and defect sorting. As in the earlier studies, the effectiveness of the sorting was evaluated by both light transmittance and color plaque measurements.

MATERIAL AND METHODS

In these tests, all fruit was sorted with a commercial photoelectric sorting machine, ESM Model G (fig. 1) (2) except one test made in 1967. Samples from the color classes produced were then evaluated by a light transmittance difference meter and, in most instances, also by a visual color plaque rating system. Except for a few tests run in 1967, the tests reported were initiated from September through December 1966.

The color sorter was capable of sorting continuously, at the rate of up to 420 fruit per minute, into two to five color classifications. The incoming fruit was separated and dropped one at a time at a fixed interval through an illuminated viewing chamber (fig. 2). Reflected light was collected by a system of lenses and mirrors from three points on the fruit 120° apart. These three beams were combined and then split into two beams which were individually passed through optical filters to a photomultiplier tube. For sorting based on the chlorophyll content, an interference-type filter with peak transmission at 680 nm (nanometers) and one-half band width of 20 nm was used. For sorting based on the carotenoid level, a filter with peak transmission at 550 nm and a half band width of 20 nm was used. In most tests only the filter and photomultiplier tube for chlorophyll was used, but in other tests both systems were used to control the sorting.

The output from the photomultiplier tube or tubes was amplified and sent to a classifier unit where limits of each color class had been set up. Variable controls on this unit allowed for changes in
the number of classes and the range in color to be included in each class. Where two filters were used, it was also possible to vary the proportionate influence of each wavelength on each color class independently.

The signal from the classifier was stored in a memory device to allow for the time delay between the viewing of the fruit and the actual sorting operation. After the fruit passed through the viewing chamber, it fell into a padded pocket on the rotating delivery wheel (fig. 1). When this pocket was above the proper delivery point, the signal stored in the memory unit activated the trip mechanism to put the fruit on the proper conveyor.

After the fruit was sorted by the Model G machine, differences and changes in pigment concentrations in sorted fruit were measured during degreening by a light transmittance difference meter.
FIGURE 2.—Diagram of sample viewing chamber of color sorter in horizontal cross section. Sample is illuminated by three lamps above and three below the plane shown.
Earlier studies showed that this instrument was suitable for following changes in chlorophyll in citrus as the fruit matured and also during degreening (29, 30). In the present studies an integrating sphere sample presentation system was used for light transmittance measurements of chlorophyll levels (29). Measurements were recorded as the difference in optical density of the fruit at the two wavelengths of light used, or \( \Delta OD \) at 665-740 nm. Increasing chlorophyll levels were registered as higher \( \Delta OD \) readings with this system. Since fruit orientation is important, the fruit was placed so that the light beam entered through the stylar end (14-inch-diameter area). The light left the fruit in all directions and was collected by the integrating sphere for measurement.

In the degreening work, a standard of 0.200 \( \Delta OD \) was established as the maximum final acceptable rating with the difference meter. This standard represents the approximate point at which chlorophyll in the rind is no longer visibly detectable; hence, it was used in estimating the point at which individual fruits were satisfactorily degreened. The standard of 0.200 \( \Delta OD \) was higher than the 0.080 \( \Delta OD \) used previously (30). The present standard represents a more "practical" chlorophyll level that most fruit of the size studied would be expected to attain and still show good color. For a sample to be considered acceptable, 90 percent of the fruit were required to pass the standard.

A light reflectance attachment to the difference meter was used for measurements of carotenoids, since these were not measured satisfactorily by the above transmission methods. This unit (5), which utilizes a flexible light-conducting cable, measures an area of about 3/4 inch in diameter. In these tests, single measurements were made of a spot on the equator of each fruit. Data were recorded as relative reflection 540-650 nm.

Plaque color ratings were based on plate No. 3 in U.S. Department of Agriculture Technical Bulletin 753 (22). Colors A to G were given values of 1.0 to 7.0, with 7.0 (yellow) being considered as a fully degreened fruit. Consideration was given to both area and intensity of chlorophyll but not to changes in carotenoids as was done in earlier studies (30). For purposes of comparison, a "practical" standard of 6.5 was used as the minimum acceptable color for individual fruit. Although a value of 6.5 indicates the presence of visible chlorophyll, the level is low enough to be ignored in commercial operations. As for the difference meter standard, at least 90 percent of the fruit in the sample were required to pass the plaque standard to achieve an acceptable color.

The majority of the data obtained was evaluated by appropriate analysis of variance procedures. As has been indicated, tests varied
widely in size and complexity; hence, the use of various procedures for statistical analyses were required. All analyzed data were evaluated by Duncan's multiple range comparisons based on the 5-percent level of significance.

DEGREEING RESPONSE

Procedure

Most of the color-sorting work was with the degreening response of Hamlin oranges. Fruit for these tests were representative samples from mature trees on rough lemon rootstock. Seven tests were initiated at 2-week intervals beginning on September 19, 1966. Fruit was harvested, washed, and sorted into four color classes on the Model G sorter. Samples of 40 fruit from each color class were numbered individually for identification. Difference meter and color plaque measurements were made on the initial fruit color and daily during the 4-day degreening period. Fruit weight was recorded initially and at the end of the degreening period in tests 1, 3, 5, and 7. All seven tests included three replications with each replicate consisting of independent samples from trees in adjacent rows in the grove.

In the degreening work with sorted fruit, observations suggested the possibility of differences in final carotenoid levels. This was not tested on machine-sorted fruit, but on October 31, 1967, a test was set up with hand-sorted Hamlin oranges. Four classes, ranging from green to yellow, were used, with 20 fruits per class. Chlorophyll and carotenoid measurements were made with the difference meter initially and then daily during 3 days of degreening.

The degreening room was operated at about 85°F. and 90 percent relative humidity. Because of problems in regulating the ethylene concentration in the degreening room, it was planned to maintain the level at 20 to 25 p.p.m., or slightly above the optimum of 4 to 20 p.p.m. (1, 10, 11, 19). In this way variations in concentration would not be expected to effect the degreening response. It was later discovered that the measurement system used on the gas chromatograph was in error, and the actual level was around 40 p.p.m. in all tests. Although this level was higher than recommended, no apparent influence on the degreening was noted. Lime was placed in the degreening room to minimize any buildup of carbon dioxide.

Results and Discussion

The initial color measurements on the four color classes obtained with the Model G sorter and the changes occurring during successive days of degreening are shown in figure 3. The differences
Figure 3.—Changes in chlorophyll levels in color-sorted Hamlin oranges during 4 days of degreening as shown by: A, Difference meter measurements; B, plaque color measurements.
between color classes on September 19 were small but significant for both difference meter and plaque color measurements. Very little change in the color had appeared by this time, which made sorting difficult. As the natural color change proceeded, a wider range of color developed; this permitted better separation by the sorting machine. Since sorting was based on chlorophyll level, a point was eventually reached where again there was an insufficient color range to obtain a satisfactory separation of fruit. Differences between color classes were statistically significant in tests 1 to 6 for both difference meter and plaque measurements. The data for test 7 were not included in the statistical analyses because of missing data resulting from a difference meter breakdown.

Rapid changes in chlorophyll levels occurred during degreening, especially during the first 2 days. Changes occurred even in test 1, where the fruit had not reached a fully degreened state after 4 days' degreening. The failure of fruit in tests 1 and 2 to reach a satisfactory color illustrates the problem in attempting to degreen such fruit. It is doubtful whether dark-green fruit can be degreened to a satisfactory color and appearance, regardless of the internal quality. This conclusion is in agreement with conclusions of other workers (1, 4, 13, 21, 25). Although the fruit in tests 1 and 2 were not mature according to present standards, they were included to provide a full range in color development for the studies. The results indicate that there was no marked change in the pattern of degreening as the fruit matured.

During degreening, fruit of similar color changed at a similar rate. As the chlorophyll levels became minimal, differences between color classes disappeared as shown by difference meter and plaque measurements. This interaction between color classes and days of degreening was especially evident in tests 5 and 6, but statistical analyses showed it to be significant in all tests except for the plaque data in tests 1 and 2 (appendix tables 6 and 7).

The similarity between the plaque and difference meter curves in figure 3 is evident. This supports results of previous work indicating the suitability of the difference meter for following chlorophyll changes in citrus (29, 30). Since most of the chlorophyll in citrus is localized in the surface layers of the rind, such a relationship would be expected. However, visual classification of fruit color within narrow classes is difficult (31), and this is further complicated when an effort is made to standardize these over a period of time. These problems are evident in the correlations between initial plaque and difference meter measurements of individual fruit in the various tests. When data from all color classes were considered, this correlation was only $-0.46$ in test 1 but increased to $-0.88$
in tests 4 to 6. The higher correlations in the latter tests were due to the broader color range in the fruit at harvest, which made visual color observations easier.

Differences between color classes in the time required to degreen the fruit to an acceptable color are shown in figure 4. The percentage of fruit passing the standards previously described, 6.5 for plaque color and 0.200 ΔOD for the difference meter, were used as the basis of color acceptance. No fruit met the difference meter standard in test 1, and not until test 5 did any of the samples attain the desired 90 percent acceptable color. In all tests, the greenest color class took longer to reach a good color than the yellowest class. Fruit in the green class required about a day longer to reach 90 percent acceptable color than fruit in the yellowest class. This difference in degreening time was similar to that found in earlier tests (30).

Data for the plaque color measurements showed results similar to those obtained with the difference meter except that fruit passed the plaque color standard earlier. This difference was particularly evident in tests 2 and 3. As others have found (3, 13), and as expected, the yellowest class degreened to a passing color first and the greenest last. Differences between color classes were variable, but there was often as much as 2 days' difference between the greenest and yellowest classes in degreening time. Some of the better-colored fruit in tests 6 and 7 passed the standards without degreening. This difference between color classes in the time needed to reach an acceptable color supports the results of earlier hand-sorting tests (30). As with the earlier work, these results indicate that color sorting would increase the efficiency in use of degreening rooms and equipment since better colored fruit could be degreened 1 to 2 days less than the greener fruit.

As noted in earlier studies (30), difference meter chlorophyll measurements from small fruit tend to be higher than those from large fruit of the same apparent color. This weight variable did not affect the results obtained in the current studies, since only a narrow size range was included. The presence of internal "chlorophyll" (28) early in the season also may affect the apparent degreening response. Studies suggest that this chlorophyll in the vesicles is not so responsive to ethylene as is that in the rind. This variance in response may account for the tendency of visual color measurements to reach the acceptable level before the difference meter measurements in the earlier degreening tests. With the Model G reflectance sorter, internal color would not affect the sorting operation. Fruit size also should have no influence on the sorting operation, and only small differences in average fruit weight were found between color classes (table 1).
Figure 4.—Changes in percentage of color-sorted Hamlin oranges passing the minimum color standards during degreening as indicated by: A, Difference meter measurements; B, plaque color measurements.
The data shown in Table 1 indicate that a considerable increase in fruit weight occurred between tests 1 and 7. Weight losses were moderate in all but test 3, where they were unusually low. No indication of any effect of maturity or fruit color on these losses was apparent. These shrinkage losses are slightly higher than those observed in earlier degreening studies (30).

Results of the degreening test made on hand-sorted Hamlin oranges are shown in figure 5. Differences in chlorophyll levels had disappeared during 3 days' degreening (fig. 5, A), while consistent differences in carotenoid levels were still evident (fig. 5, B). These results indicate that sorting fruit on chlorophyll level before degreening may result in some differences in final color between classes due to differences in level of carotenoids. However, neither measurement showed statistically significant differences between color classes after 1 day of degreening (table 2).

FRUIT QUALITY

The fall degreening season is also the period when problems of fruit failing to meet the minimum maturity standards are most apparent. These problems are largely due to the fruit-to-fruit variation in the soluble solids and acid content of the juice. A nondestructive procedure that would separate fruit into several quality classes would be useful. For this reason, data were obtained on various internal quality factors in fruit sorted for color.

Procedure

Fruit-quality evaluations were made on 5-fruit samples from each color class obtained in the degreening studies. On these fruit, chlorophyll measurements from the difference meter were recorded at the
time of sorting. Further analyses, completed within a few days, included fruit weight, juice weight, and percentage of acid and of soluble solids in the juice. Percentage of juice, weight of solids per fruit, and solids-to-acid ratio were then derived from these analyses. All analyses were made on an individual fruit basis.

Figure 5.—Changes in difference meter measurements of hand-sorted Hamlin oranges during degreening: A, Chlorophyll A/D 695–740 nm; B, carotenoids relative reflectance 540–650 nm.
TABLE 2.—Changes in chlorophyll and carotenoid measurements of hand-sorted Hamlin oranges during degreening, October 1967

<table>
<thead>
<tr>
<th>Color class</th>
<th>Chlorophyll, ( \Delta \OD 695-740 ), after degreening for</th>
<th>Carotenoids, relative reflectance 540–650 nm, after degreening for</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 day</td>
<td>1 day</td>
</tr>
<tr>
<td>1 Green</td>
<td>0.473 a</td>
<td>0.299 cd</td>
</tr>
<tr>
<td>2</td>
<td>0.373 b</td>
<td>0.245 def</td>
</tr>
<tr>
<td>3</td>
<td>0.324 bc</td>
<td>0.220 efg</td>
</tr>
<tr>
<td>4 Yellow</td>
<td>0.282 cde</td>
<td>0.211 efg</td>
</tr>
<tr>
<td>C. V. range, percent</td>
<td>8.71 to 17.64</td>
<td>4.14 to 11.06</td>
</tr>
</tbody>
</table>

1 Values in the same column or same row within each measurement followed by any letters in common are not significantly different at the 5-percent level.
The difference meter color measurements for the fruit samples used for analysis (fig. 6) were essentially the same as for the degreening samples (fig. 3), except for the low chlorophyll levels in test 2. Significant differences in chlorophyll levels were found between color classes in tests 2 through 6 (test 7 data were not analyzed).

![Figure 6](image_url)

**Figure 6.**—Average chlorophyll levels in analyses samples of color-sorted Hamlin oranges, September through December 1966.
Data on fruit weight are shown in figure 7. Some variation between color classes occurred, but these differences were not significant in any test. The growth of the fruit on the tree during the harvest period was evident in the increased size of fruit, especially
through the first five tests. Fruit size in these samples was similar to that in the samples used for the degreening studies (table 1), except for greater variability resulting from the smaller samples. Data for juice weight (fig. 8) showed changes similar to those for fruit weight. The differences in juice weight between color classes were significant in test 1, but the differences may have been due to the small size of fruit in class 4.

Figure 8.—Average juice weight of color-sorted Hamlin oranges, September through December 1966.
No significant differences in percentage of juice by weight (fig. 9) were found in any test. However, when tests 1 to 6 were combined in one statistical analysis, the greenest fruit class had significantly lower average juice content than the other classes. The percentage of juice declined later in the fall, but the overall range was relatively small for this measurement.

Data for percentage of soluble solids are presented in figure 10. Beginning in test 3, there was a trend toward lower solids in the
greenest fruit. Significant differences were found in test 6 and in the combined tests 1 to 6 (appendix table 8). All classes in test 1 averaged less than the presently required 9 percent solids, and only one class was passing in test 2.

Results for weight of soluble solids per fruit (fig. 11) showed less difference between color classes than was found for percentage of soluble solids. As with juice weight, significant differences were present in test 1. More consistent relationships between color classes
were evident in test 6, but these were not significant. In the combined analysis, color class 1 averaged significantly lower in weight of solids than classes 2 and 3.

As shown in figure 12, the percentage of acid was essentially the same for all color groups in each test. The ratio of soluble solids to acid (fig. 13) also shows little variation between color classes in the first five tests. In test 6, the greenest fruit had a significantly lower ratio than the other classes, and this difference was also significant.

![Graph](image-url)

**Figure 11.**—Average weight of soluble solids per fruit in color-sorted Hamlin oranges, September through December 1966.
Figure 12.—Average percentage of citric acid in color-sorted Hamlin oranges, September through December 1966.

in the combined analysis. Fruit in tests 1 and 2 were well below the presently required minimum ratio of 10.0, and only one class in test 3 met the maturity standards. Fruit in test 4, therefore, were the first mature fruit to be handled in this series. The 1966 season was late in both time of natural color change and high acid levels, with the latter resulting in low solids-to-acid ratios. Although some of the earlier samples did not meet the legal maturity stand-
ards in these tests, this is not considered to have affected the general results of the degreening tests.

The results obtained in this study and those from a more extensive study (28) do not show chlorophyll levels to be an adequate basis for quality separation although some differences were found. The sample size used in these tests was small but apparently adequate as indicated by the consistent maturity changes found for most variables.

**Figure 13.**—Average solids-to-acid ratio of color-sorted Hamlin oranges, September through December 1966.
DEGREEING AND DECAY

Procedure

Additional Hamlin oranges were harvested and sorted in tests 2, 4, and 6 of the degreening studies to provide fruit for studying the effects of time in degreening and of fruit color on the incidence of decay. After the fruit was sorted, five samples of 40 fruit each were prepared from each color class within each of the three replications. (No color measurements were made on these fruit. However, the sortings were made at the same settings on the color sorter as the associated color tests, so that chlorophyll levels in comparable color classes were similar.) One of the five samples was placed directly in 70° F., and the remaining four were degreened. Each day a sample was transferred from the degreening room to 70°, which gave, eventually, a range of 0 to 4 days’ degreening within each color class. All fruit was held at 70° for a total of 4 weeks from harvest. Records were taken weekly on the number of fruits lost to *Penicillium* and stem-end rots.

Results and Discussion

Two general types of citrus fruit decay occur in Florida, those commonly called stem-end rot and those caused by *Penicillium* spp. As indicated earlier, the latter type is not greatly affected by degreening practices (4, 27). In these tests no relation between the incidence of *Penicillium* decay and any treatment was found. There was a marked increase in this type of decay from test 2 to test 4; but even in test 6, where the greatest loss occurred, the average was still below 2.5 percent. Degreening resulted in an increase in stem-end decays, especially those caused by *Phomopsis* and *Diplodia* but also some caused by *Colletotrichum*. These were not separated in this study.

The effect of increasing periods of degreening on stem-end decay in test 2 is shown in figure 14. Degreening for 2 to 4 days resulted in a significant increase in the rate of decay in the fruit. Degreening for 1 day had relatively little effect, however. After longer holding periods, losses were extensive in all treatments, so that after 4 weeks less effect of degreening on decay was evident.

The results of the decay study in test 4 (fig. 15) also show greater decay losses with longer degreening periods. Here greater losses occurred after 3 and 4 days' than after 2 days' degreening, but again degreening for 1 day had no significant effect. The rate of decay resulting from 3 and 4 days' degreening decreased after 2 weeks' storage, but significant effects of degreening remained throughout the test.
Figure 14.—Percentage of stem-end decay of color-sorted Hamlin oranges in relation to days in degreening and length of holding time at 70° F. Test 2, October 1966.
FIGURE 15.—Percentage of stem-end decay of color-sorted Hamlin oranges in relation to days in degreening and length of holding time at 70° F. Test 4, November 1966.
In test 6, the decay studies showed a significant increase in stem-end decay from 1 day’s degreening (fig. 16). Longer periods of degreening resulted in greater initial decay losses, but after 2 weeks’ storage there was no difference between the effects of 2, 3, or 4 days’ degreening.

These results, which show that degreening has a marked effect on the incidence of decay in Hamlin oranges, support the results of other workers (8, 9, 12, 18, 26, 27, 38). The present studies, however, show surprisingly little advantage of using 2 days’ over 4 days’ degreening. The color sorting of fruit for degreening would still be beneficial in reducing decay, however, if classes of fruit requiring 1 day or less degreening were removed.

Comparison of tests 2, 4, and 6 shows a gradual increase in decay with increasing maturity of the fruit. This increase was significant between tests 4 and 6 (appendix table 9). Differences between tests were apparent also in significant interactions between tests and days of degreening and tests and weeks of storage and also tests x days x weeks (appendix table 10).

No effect of fruit color on the incidence of decay was found in test 2 (fig. 17). In tests 4 and 6 (figs. 18 and 19), there was a trend toward greater decay in the greenest class than the other classes when degreened for the same period of time, and these differences were significant in test 6. In test 6 it is probable that most of the greenest class came from the interior of the trees, and such fruit would be more likely to be inoculated with the decay organism.

Ethylene has been reported to increase stem-end decay (9, 17, 26), and the level used here may have contributed to the great amount of decay found. Also, holding conditions for the fruit in these tests were intended to allow decay and not to resemble desirable commercial handling. Commercial fruit should be waxed, treated for decay control, stored at a lower temperature, and held for a shorter period than fruit in these tests. These procedures are effective in greatly reducing the amount of decay, and also shrinkage, occurring during marketing. However, these treatments do not eliminate the need for proper handling procedures that are necessary for maximum fruit quality. Also these treatments would not be expected to affect the general pattern of response found in these tests.

(Text continues on page 32)
Figure 16.—Percentage of stem-end decay of color-sorted Hamlin oranges in relation to days in degreening and length of holding time at 70° F. Test 6, November 1966.
FIGURE 17.—Percentage of stem-end decay of color-sorted Hamlin oranges in relation to color class and length of holding time at 70° F. Test 2, October 1966.
Figure 18.—Percentage of stem-end decay of color-sorted Hamlin oranges in relation to color class and length of holding time at 70° F. Test 4, November 1966.
Figure 19.—Percentage of stem-end decay of color-sorted Hamlin oranges in relation to color class and length of holding time at 70° F. Test 6, November 1966.
EFFECTS OF WASHING ON COLOR SORTING AND DEGREEING

Procedure

In the above studies, all fruit was washed before sorting with the Model G sorter. Since fruit normally is washed after degreening, studies were set up to evaluate the effects of time of washing on the results obtained. The effect of washing on the color sorting obtained was determined by first sorting samples of unwashed fruit into four classes. Each color class was then washed separately and a sample of 50 fruit selected. The chlorophyll level was determined for each fruit with the difference meter. The fruit was then mixed and resorted on the Model G sorter, and samples from each color class were again measured on the difference meter. In this way the same fruit were sorted unwashed and washed; and, although dirt does not affect the measurement, all difference meter measurements were made on washed fruit. Dirt does affect the pattern of light reflection from the fruit; this made it necessary to readjust the Model G sorter to obtain comparable sortings on both washed and unwashed fruit. This test was run on November 15, 1966, and included two replications.

Two tests, beginning on November 14 and 28, were run to determine the effect of washing on the subsequent degreening response. For each test, two lots of 40 fruit each were selected; one was washed and the other left unwashed. The chlorophyll level was measured by the difference meter and the fruit placed in degreening for 4 days. Daily observations on the chlorophyll level in each fruit were made as in the regular degreening series. Since differences in color existed between treatments initially, the groups were selectively reduced to 30 fruit each so that the average initial chlorophyll levels were similar.

Results and Discussion

The effect of washing the fruit on the color sorting obtained is shown in table 3 and figure 20, A and B. Sorting after washing the fruit gave better uniformity than sorting unwashed fruit, as indicated by the coefficient of variation, within each color class except class 2. Chlorophyll levels in all classes were significantly different, whether washed before or after sorting, but the generally increased uniformity in washed fruit would appear to justify washing before sorting. Since the Model G sorter is affected by dirt on the fruit, optimum sorting requires the use of different machine settings for washed and unwashed fruit. Dirt would be expected to have a greater effect on the sorting of more mature than on greener fruit.
Figure 20.—Effect of washing on color sorting of Hamlin oranges: A, Fruit sorted on level of chlorophyll before washing; B, fruit from same lot as A, sorted after washing, November 15, 1966.
FIGURE 21.—Effects of washing on degreening response of Hamlin oranges: Fruit harvested on (A) November 14, 1966, and (B) November 28, 1966.
Table 3.—Effect of washing on the uniformity of color sorting obtained on Hamlin oranges

(Difference meter chlorophyll measurements made November 15, 1966)

<table>
<thead>
<tr>
<th>Time of sorting</th>
<th>ΔOD for color class 1 —</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Before washing</td>
<td>0.448 c</td>
</tr>
<tr>
<td>After washing</td>
<td>0.470 f</td>
</tr>
<tr>
<td>C.V.:</td>
<td></td>
</tr>
<tr>
<td>Before washing</td>
<td>16.48</td>
</tr>
<tr>
<td>After washing</td>
<td>13.89</td>
</tr>
</tbody>
</table>

1 Values in the same column or same row followed by the same letter are not significantly different at the 5-percent level.

This theory is supported by table 3, which shows that the greatest improvement in uniformity by washing was found in the yellowest fruit, class 4.

As shown in figure 21, washing fruit before degreening did not greatly affect the rate of chlorophyll loss, except differences were significant in the first test. In comparison with the Model G sorter, the difference meter is relatively insensitive to the presence of dirt on the fruit, so that the washing of fruit before measurement is not necessary. Although washing fruit before degreening has not been recommended (19), these results indicate that, if properly done, no influence on the degreening rate should result.

COLOR-UNIFORMITY SORTING

In the previous sections, emphasis has been placed on sorting in relation to the degreening of oranges. Although this resulted in uniform color classes of varying shades of green, the primary objective was to improve the efficiency of the degreening operation. Degreening is not a factor in some citrus varieties and in some aspects of fruit color in varieties like Hamlin oranges. In these instances, uniformity of color may have a direct value in fruit marketing.

Limes

Limes are normally marketed green (32); this practice makes some sorting to remove the mature-yellow fruit necessary. Several sorting tests were run in 1966, but no data were obtained except on the December 1 test. For this test, fruit was sorted by the Model
G machine into four classes based on chlorophyll level. Samples of 20 fruit from each color class were selected for chlorophyll measurements with the difference meter.

Figure 22, A, shows the results obtained in this test. No problem was found in separating yellow from green fruit with the Model G sorter. Fruit in color classes 2 and 3 appear to be similar because of the variability in color on individual fruit. Data on difference meter measurements (table 4, sorting 1), however, show that all classes were significantly different. These results indicate that at least three color classes could be readily obtained in the sorting of limes.

**Valencia Oranges**

For further experience with different varieties of fruit, a sample of Valencia oranges was sorted on December 12. Chlorophyll measurements from the difference meter were recorded for samples of 10 fruit from each color class. A good separation of color classes was obtained (fig. 22, B). Difference meter data (table 4, sorting 2) also show good separation of the color classes. The range in color within the sample was much less than that for limes. The variation in color on individual fruit was also less than for limes; and this resulted in good separation even with the narrower color range. This fruit was not mature and would not normally be handled at this stage of development. However, these results indicate that where regreening of mature Valencia oranges is a problem photoelectric color sorting may be useful.

**Hamlin Oranges**

As oranges mature and the chlorophyll level declines, carotenoid pigments generally increase. The carotenoid level, therefore, may also be used as a basis for color sorting. One test was run on December 1, 1966, to explore the sorting of degreened Hamlin oranges. Fruit that had been degreened 2 days was sorted on the basis of carotenoids only, to separate yellow from orange fruit. Samples of 40 fruit from each color class were selected, and carotenoid levels were measured on the difference meter with the reflectance attachment.

The two classes resulting from the color sorting of degreened Hamlin oranges are shown in figure 23, A. Although the differences were small, the increased uniformity improved the appearance of the fruit. Difference meter measurements of the carotenoid levels in the fruit (table 4, sorting 3) also show a significant difference between the two color classes. The use of the sorter before degreen-
Figure 22.—A, Chlorophyll sorting of Persian limes; B, Chlorophyll sorting of Valencia oranges, December 12, 1966.
FIGURE 23.—Color sortings of Hamlin oranges: A, Sorting based on carotenoid level in degreened oranges, December 1, 1966; B, combined sorting, class 1 sorted on basis of chlorophyll and classes 2, 3, and 4 on both chlorophyll and carotenoid levels, December 15, 1966.
### Table 4.—Difference meter measurements of chlorophyll and carotenoid levels in color classes of citrus fruits sorted on the Model G machine, 1966–67

<table>
<thead>
<tr>
<th>Sorting and date</th>
<th>Sorting basis</th>
<th>Sorting basis</th>
<th>Number of fruit per class</th>
<th>Measuring system</th>
<th>Color class 1</th>
<th>Color class 2</th>
<th>Color class 3</th>
<th>Color class 4</th>
<th>C.V.</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  —— Persian limes</td>
<td>Chlorophyll</td>
<td>20</td>
<td>Chlorophyll</td>
<td>0.921 a</td>
<td>0.817 b</td>
<td>0.723 c</td>
<td>0.464 d</td>
<td>9.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2  —— Valencia oranges</td>
<td>Chlorophyll</td>
<td>40</td>
<td>Chlorophyll</td>
<td>.529 a</td>
<td>.444 b</td>
<td>.389 c</td>
<td>.344 d</td>
<td>8.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3  —— Hamlin oranges</td>
<td>Carotenoids</td>
<td>40</td>
<td>Carotenoids</td>
<td>.630 a</td>
<td>.693 b</td>
<td>.444 c</td>
<td>.344 d</td>
<td>4.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4  —— Hamlin oranges</td>
<td>Chlorophyll and</td>
<td>40</td>
<td>Chlorophyll</td>
<td>.213 a</td>
<td>.173 b</td>
<td>.174 b</td>
<td>.165 b</td>
<td>12.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5  —— Temple oranges</td>
<td>Chlorophyll and</td>
<td>20</td>
<td>Chlorophyll</td>
<td>.336 a</td>
<td>.207 b</td>
<td>.188 c</td>
<td>.187 c</td>
<td>14.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6  —— Temple oranges</td>
<td>Chlorophyll and</td>
<td>25</td>
<td>Chlorophyll</td>
<td>.276 a</td>
<td>.240 b</td>
<td>.229 bc</td>
<td>.219 c</td>
<td>14.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 Difference meter measurements recorded as ΔOD 695–740 for chlorophyll and as relative reflectance 540–650 nm for carotenoids.

2 Values in the same row followed by any letter in common are not significantly different at the 5-percent level.
ing would give more benefits through improved efficiency in degreening and reduced decay than the sorting of degreened fruit. Also sorting on chlorophyll may result in some differences between classes in carotenoids as shown in figure 5. However, a similar type of separation may be made on mature fruit, where all chlorophyll has disappeared from most of the fruit.

On December 15, 1966, a test on nondegreened Hamlin oranges was run in which sorting on the basis of chlorophyll was combined with sorting on level of carotenoids. In this test, color class 1 was sorted on the basis of chlorophyll, but color classes 2, 3, and 4 were sorted on the basis of both chlorophyll and level of carotenoid pigments. Samples of 40 fruit each were selected from each color class, and chlorophyll and carotenoid measurements were made with the difference meter.

The results of this sorting are shown in figure 23, B, and in table 4, sorting 4. No significant difference in chlorophyll level was found between classes 2, 3, and 4. The chlorophyll level in class 1 may be high enough to require a brief degreening treatment, but no degreening of fruit in classes 2, 3, and 4 would be needed. Also included in class 1 were a few lightly russeted fruits (fig. 23, B, left edge). Carotenoid levels increased from class 1 to 4, which indicates improved orange color. Even before color reaches the level shown in figure 23, B, a sorting of this type would be preferable to the regular chlorophyll sorting used for degreening.

**Temple Oranges**

On January 26, 1967, samples of Temple oranges were sorted with the Model G machine on the basis of both chlorophyll and carotenoids. Again the greenest fruit were sorted into class 1, and increasing carotenoid levels were sorted into classes 2, 3, and 4. Samples of 20 fruit from each class were retained for chlorophyll and carotenoid measurements with the difference meter. Juice from five-fruit samples from each color class was composited for analysis of solids and acid in each color class. Three replications, representing single adjacent trees in the grove, were included.

On February 2, 1967, a second test on Temple oranges was run. This fruit, from a different grove, was more highly colored; hence, the sorting procedure was modified to base the sorting primarily on carotenoid levels. Four color classes were obtained, and samples of 25 fruit from each class were used for chlorophyll and carotenoid measurements with the difference meter. Three replications were included as in the previous test.
The results of the February sorting are shown in figure 24. The incidence of scab was greater in the fruit in the January test than in the fruit in the February test. Scabby fruit tended to be sorted by the Model G sorter into class 1 with the normal green fruit. Results of difference meter measurements for the two tests show little variation in chlorophyll levels among the classes except for class 1 (table 4, sortings 5 and 6). Carotenoid data, however, show consistent and significant differences from class 1 to class 4 in the February test. These carotenoid measurements also show the presence of deeper orange color of the oranges in the February test than of those in the January test and the relatively high color of the fruit as compared with Hamlin oranges.

Results of the analyses of samples of Temple oranges from the January 26 sorting are shown in table 5. Despite the wide color differences, little variation in the internal quality was found. These results, like those on Hamlin oranges, indicate that the main benefit from color sorting is color uniformity and not in increased uniformity of internal quality.
TABLE 5.—Analysis of Temple oranges color sorted on the Model G sorter, January 26, 1967

[Averages of three replications of 5-fruit composited samples]

<table>
<thead>
<tr>
<th>Color class</th>
<th>Soluble solids</th>
<th>Acid</th>
<th>Solids-to-acid ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percent</td>
<td>Percent</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>13.53</td>
<td>1.51</td>
<td>9.04</td>
</tr>
<tr>
<td>2</td>
<td>13.75</td>
<td>1.59</td>
<td>8.65</td>
</tr>
<tr>
<td>3</td>
<td>14.01</td>
<td>1.54</td>
<td>9.10</td>
</tr>
<tr>
<td>4</td>
<td>13.98</td>
<td>1.47</td>
<td>9.53</td>
</tr>
</tbody>
</table>

DEFECT SORTING

Procedure

As indicated earlier, fruits with surface defects often tended to be sorted into certain color classes. These defects gave a response similar to chlorophyll on the Model G sorter. Surface defects on fruit are generally erratic, in both severity and frequency. Because of this variability and the limitations in machine design, only one test was run to sort defects. This test was made on a sample of seedling oranges that had extensive rust-mite injury. This fruit was not mature when tested on January 26, 1967, but was fairly well-colored. Fruit representing a maximum range in amount of injury was harvested and sorted by the use of the chlorophyll filter. No measurements with the difference meter were made.

Results and Discussion

Results of the test on rust-mite injured fruit are shown in figure 25. Although four classes were obtained and some range in appearance was evident, there would be no practical value in obtaining more than two classes of such fruit. Commercially a defective fruit is graded out whether the defect just exceeds the prescribed standard or is much larger.

Many surface defects appear on citrus with varying frequency. These vary in color and area on the fruit; hence, they present a complex problem for sorting. Many of the requirements for defect sorting appear to be more specific or different from those for color sorting. Defect sorting generally would be improved by reducing the size and increasing the number of areas measured and by contrasting, rather than averaging, the measurements on a fruit. Defects may vary in light absorption characteristics; therefore, sev-
eral different measurement wavelengths might be required for optimum sorting. The number of types of possible defects in a lot of fruit creates a major problem in sorting, but the removal of certain more common defects would appear to be possible with further study. If practical procedures could be developed, defect sorting would have great potential for labor savings in packinghouse operations.

MACHINE OPERATION

The results of the tests reported here indicate that color sorting with light reflectance may be applied to citrus for various purposes, including improved degreening, color uniformity, and removal of some defective fruit. Under Florida conditions, all of these applications could be made in the average packinghouse. A color sorter must, therefore, have flexibility to meet varying requirements. Changes in the color of fruit with maturity, as shown in figures 3 and 5, require changes in the sorter operation. Changes in voltage of the three classifiers needed to adjust for changes in chlorophyll levels in the degreening tests are shown in figure 26, A. The small differences in voltages in tests 1, 2, and 7 illustrate the narrow range of chlorophyll in these tests. Such results may indicate either that fewer classes should be sorted or that a more effective sorting

![Figure 25.—Chlorophyll sorting on rust-mite injured seedling oranges, January 26, 1967.](image-url)
procedure should be used that would make use of the color range existing.

In these studies the objective was to obtain four color classes with enough fruit in each class to provide the test needs. As shown in figure 26, B, the distribution of fruit in the four classes frequently varied considerably from an average of 25 percent per class, regardless of the color range of fruit tested. In practice, equal distribution in classes is not needed so long as the number and size of classes are effective in providing good separations. However, there is a lower limit to the volume of fruit that could be justified as a separate color class in the packinghouse. Narrow chlorophyll ranges as in tests 1 and 2 would not be a problem with oranges, since such fruit should not be picked. On limes, this problem might be best handled by using fewer color classes. The narrow chlorophyll range found in test 7 indicates that probably only two color classes should be made on green color, but additional classes could be obtained by sorting such fruit on carotenoids as well as chlorophyll. Since some variation in fruit color may be found from grove to grove, some adjustment of the machine between fruit lots may be necessary to maintain the optimum number of color classes.

In any color separation, some marginal fruit will be found. For example, the frequency distribution in test 4 (fig. 27) shows that there was a considerable overlap between the four classes, based on difference meter data. This overlap occurred even though the mean chlorophyll levels for each class differed significantly from each other. Such marginal fruit probably constitutes most of the fruit that is not consistently sorted. In repeated tests on the Model G sorter, with the same adjustments, as much as 20 to 30 percent of the fruit in a class was resorted into each adjacent color class. These tests were on a sample of fruit with a narrow color range. Where there is a wide color range or the number of color classes is reduced as needed, the number of marginal fruit should average around 10 percent of the class. Since much of this variation in sorter classification is due to the variation in color on an individual fruit, increasing the percentage of surface measured would also improve the results. The overall distribution of the measured fruit in test 4 is shown in figure 28. This shows a nearly normal distribution of fruit color, which presents a good range for sorting. Where the distribution tends to shift toward one end of the range, as at the beginning and end of the degreening season, it is much more difficult to color sort on the basis of a single pigment system such as chlorophyll.
Sorting on carotenoid levels presents problems similar to those for sorting on basis of chlorophyll. For the machine to be used for both purposes, the design must also allow for changes in the light-measuring system and electronic circuits. Requirements for other problems such as defect sorting may not be compatible with those for color sorting, as was suggested earlier.
Figure 27.—Frequency distribution of color-sorted Hamlin oranges within the four individual color classes in test 4 as measured by the difference meter.
Figure 28.—Frequency distribution of the four color classes (0.020 ΔOD classes) in test 4 combined.
The acceptance of any new procedure in industry should be based on the evaluation and comparison of potential benefits against expected costs of installation and operation. The present study was limited to exploring possible benefits of color sorting citrus. Further information will be needed before specific costs can be evaluated. At present a commercial light reflectance sorter similar to that used in these tests would probably cost $15,000 to $30,000. Lower immediate costs could be obtained by leasing machines on a per-box basis. The actual cost would depend on the make and model selected, and this would be modified by other factors. For instance, the cost would be increased if design changes were needed for specific applications or to improve efficiency or capacity and would be decreased if the number of machines in production permitted assembly-line construction. The probable need for several sorting machines in a packinghouse represents a sizable investment. In addition, most packinghouses would require major reorganization of the layout for efficient use of the sorters. Other factors, such as the ability to identify and handle specific lots of fruit, also need to be considered. Many of the problems are not peculiar to color sorting but are true of any new packinghouse procedure.

The economic value of some of the benefits can be estimated in some instances. Where the cost of degreening and the average packout are known, the combined effect of grading and color sorting fruit before degreening can be determined. In some instances, the value of color sorting would depend on how effectively it is used as in color uniformity. In any evaluation of color sorting, the cost-benefit relation must be based on the unit of output and not on the initial investment. Color sorting has been successfully used on lemons in California for many years to improve the uniformity of color. There the industry has a long season of operation, but this is not essential. Color sorting has been accepted more recently by the cherry industry (29, 40) as a means of removing certain defects. Cherries are a short-season crop in comparison with citrus.

Color sorting for degreening of oranges alone represents a relatively short season. Extension of its use to other purposes and other types of citrus would extend the season and improve the economic benefits of the sorter. The effectiveness of color sorting in these areas, in addition to degreening, may make color sorting of citrus a practical consideration. Although results in these tests were generally good, these should not be considered as the best obtainable.
It is felt that, with other optical viewing system designs and a wider choice of wavelength combinations, photoelectric sorting equipment could be expected to provide better results in some of the sorting problems on citrus than were obtained in this study.

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## APPENDIX

### TABLE 6.—Analysis of variance of the degreening test data

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<th>Source</th>
<th>d.f.</th>
<th>Test 1</th>
<th>Test 2</th>
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<th>Test 4</th>
<th>Test 5</th>
<th>Test 6</th>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Color class</td>
<td>3</td>
<td>0.6835*</td>
<td>0.6851**</td>
<td>0.9993**</td>
<td>0.9867**</td>
<td>0.4683**</td>
<td>0.3528**</td>
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<td>0.0161</td>
<td>0.0236</td>
<td>0.0186</td>
<td>0.0061</td>
<td>0.0087</td>
</tr>
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<td>Days degreening</td>
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<td>21.2041**</td>
<td>20.3329**</td>
<td>19.5037**</td>
<td>11.7895**</td>
<td>3.9622**</td>
<td>1.3220**</td>
</tr>
<tr>
<td>Color x days</td>
<td>12</td>
<td>0.0044*</td>
<td>0.0056**</td>
<td>0.0322**</td>
<td>0.1104**</td>
<td>0.1398**</td>
<td>0.1085**</td>
</tr>
<tr>
<td>Error b</td>
<td>32</td>
<td>0.0020</td>
<td>0.0016</td>
<td>0.0024</td>
<td>0.0023</td>
<td>0.0010</td>
<td>0.0029</td>
</tr>
<tr>
<td>Total</td>
<td>2,399</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>C.V. color, percent</td>
<td></td>
<td>48</td>
<td>27</td>
<td>34</td>
<td>44</td>
<td>35</td>
<td>50</td>
</tr>
<tr>
<td>C.V. color x days, percent</td>
<td></td>
<td>8</td>
<td>8</td>
<td>12</td>
<td>16</td>
<td>14</td>
<td>29</td>
</tr>
<tr>
<td>Color plaque:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Color class</td>
<td>3</td>
<td>497**</td>
<td>1,208**</td>
<td>6,085**</td>
<td>5,089**</td>
<td>10,542**</td>
<td>5,870**</td>
</tr>
<tr>
<td>Error a</td>
<td>6</td>
<td>46</td>
<td>87</td>
<td>131</td>
<td>109</td>
<td>132</td>
<td>27</td>
</tr>
<tr>
<td>Days degreening</td>
<td>4</td>
<td>85,609**</td>
<td>95,052**</td>
<td>115,411**</td>
<td>125,822**</td>
<td>44,878**</td>
<td>11,894**</td>
</tr>
<tr>
<td>Color x days</td>
<td>12</td>
<td>17 NS</td>
<td>48 NS</td>
<td>368**</td>
<td>491**</td>
<td>2,895**</td>
<td>2,365**</td>
</tr>
<tr>
<td>Error b</td>
<td>32</td>
<td>22</td>
<td>92</td>
<td>58</td>
<td>46</td>
<td>81</td>
<td>22</td>
</tr>
<tr>
<td>Total</td>
<td>2,399</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>C.V. color, percent</td>
<td></td>
<td>16</td>
<td>19</td>
<td>23</td>
<td>19</td>
<td>18</td>
<td>8</td>
</tr>
<tr>
<td>C.V. color x days, percent</td>
<td></td>
<td>11</td>
<td>20</td>
<td>15</td>
<td>13</td>
<td>14</td>
<td>7</td>
</tr>
</tbody>
</table>

1  Error a, interaction of replicates x color.
2  Error b, combined interactions of replicates x days and replicates x color x days.
*Significant at 5-percent level.
**Significant at 1-percent level.
### Table 7.—Combined analysis of means for 6 degreening tests

<table>
<thead>
<tr>
<th>Source</th>
<th>d.f.</th>
<th>Difference meter</th>
<th>Color plaque</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tests</td>
<td>5</td>
<td>1.2672**</td>
<td>4,984**</td>
</tr>
<tr>
<td>Error a (^1)</td>
<td>10</td>
<td>.0033</td>
<td>4</td>
</tr>
<tr>
<td>Color class</td>
<td>3</td>
<td>.0997**</td>
<td>619**</td>
</tr>
<tr>
<td>Tests x color</td>
<td>15</td>
<td>.0009 NS</td>
<td>28**</td>
</tr>
<tr>
<td>Error b (^2)</td>
<td>36</td>
<td>.0006</td>
<td>2</td>
</tr>
<tr>
<td>Days degreening</td>
<td>4</td>
<td>1.6799**</td>
<td>10,581**</td>
</tr>
<tr>
<td>Tests x days</td>
<td>20</td>
<td>.0560**</td>
<td>289**</td>
</tr>
<tr>
<td>Color x days</td>
<td>12</td>
<td>.0081**</td>
<td>44**</td>
</tr>
<tr>
<td>Tests x color x days</td>
<td>60</td>
<td>.00078**</td>
<td>21**</td>
</tr>
<tr>
<td>Error c (^3)</td>
<td>192</td>
<td>.00005</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>359</td>
<td>----</td>
<td>----</td>
</tr>
</tbody>
</table>

\(^1\) Error a, interaction of replicates x tests.
\(^2\) Error b, combined interactions of replicates x color and replicates x tests x color.
\(^3\) Error c, residual.
**Significant at 1-percent level.
TABLE 8.—Combined analysis of variance of data for each of 8 fruit-quality measurements

<table>
<thead>
<tr>
<th>Source</th>
<th>d.f.</th>
<th>Chlorophyll</th>
<th>Fruit weight</th>
<th>Juice Weight</th>
<th>Juice Percent</th>
<th>Soluble solids Percent</th>
<th>Soluble solids Weight</th>
<th>Percent acid</th>
<th>Ratio solids/acid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tests</td>
<td>5</td>
<td>2.792**</td>
<td>6,969**</td>
<td>2,944**</td>
<td>120.61**</td>
<td>31.563**</td>
<td>76.48**</td>
<td>2.150**</td>
<td>274.86**</td>
</tr>
<tr>
<td>Error a</td>
<td>10</td>
<td>.007</td>
<td>354</td>
<td>145</td>
<td>8.95</td>
<td>.175</td>
<td>1.24</td>
<td>.028</td>
<td>3.49</td>
</tr>
<tr>
<td>Color class</td>
<td>3</td>
<td>.2710**</td>
<td>656 NS</td>
<td>168 NS</td>
<td>31.92**</td>
<td>4.383**</td>
<td>3.53*</td>
<td>.014 NS</td>
<td>8.25*</td>
</tr>
<tr>
<td>Tests x color</td>
<td>15</td>
<td>.0094**</td>
<td>461 NS</td>
<td>122 NS</td>
<td>3.77 NS</td>
<td>1.172*</td>
<td>1.82 NS</td>
<td>.023 NS</td>
<td>2.73 NS</td>
</tr>
<tr>
<td>Error b</td>
<td>36</td>
<td>.0029</td>
<td>347</td>
<td>94</td>
<td>4.24</td>
<td>.455</td>
<td>.90</td>
<td>.019</td>
<td>1.94</td>
</tr>
<tr>
<td>Total</td>
<td>359</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>

1 Error a, interaction of replicates x tests.
2 Error b, combined interactions of replicates x color and replicates x color x tests.
*Significant at 5-percent level.
**Significant at 1-percent level.
### Table 9. Analysis of variance of percentage decay data

<table>
<thead>
<tr>
<th>Source</th>
<th>d.f.</th>
<th>Test 2</th>
<th>Test 4</th>
<th>Test 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color class</td>
<td>3</td>
<td>47.27 NS</td>
<td>613.09 NS</td>
<td>676.21 NS</td>
</tr>
<tr>
<td>Error a</td>
<td>6</td>
<td>99.07</td>
<td>698.32</td>
<td>328.41</td>
</tr>
<tr>
<td>Days</td>
<td>4</td>
<td>824.95**</td>
<td>3,370.22**</td>
<td>2,817.98**</td>
</tr>
<tr>
<td>Color x days</td>
<td>12</td>
<td>154.08 NS</td>
<td>111.16 NS</td>
<td>63.80 NS</td>
</tr>
<tr>
<td>Error b</td>
<td>32</td>
<td>147.33</td>
<td>215.83</td>
<td>145.57</td>
</tr>
<tr>
<td>Weeks</td>
<td>3</td>
<td>4,995.16**</td>
<td>5,062.40**</td>
<td>9,652.41**</td>
</tr>
<tr>
<td>Color x weeks</td>
<td>9</td>
<td>17.69 NS</td>
<td>17.97 NS</td>
<td>50.73*</td>
</tr>
<tr>
<td>Days x weeks</td>
<td>12</td>
<td>83.37**</td>
<td>79.21**</td>
<td>73.97**</td>
</tr>
<tr>
<td>Color x days x weeks</td>
<td>36</td>
<td>12.64 NS</td>
<td>10.43 NS</td>
<td>22.25 NS</td>
</tr>
<tr>
<td>Error c</td>
<td>120</td>
<td>16.13</td>
<td>14.04</td>
<td>19.70</td>
</tr>
<tr>
<td>Total</td>
<td>239</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
</tbody>
</table>

1 Error a, interaction of replicates x color.
2 Error b, combined interactions of replicates x days and replicates x color x days.
3 Error c, residual.

*Significant at 5-percent level.
**Significant at 1-percent level.
<table>
<thead>
<tr>
<th>Source</th>
<th>d.f.</th>
<th>Mean square and significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tests</td>
<td>2</td>
<td>3,353.39*</td>
</tr>
<tr>
<td>Error a (^1)</td>
<td>4</td>
<td>331.38</td>
</tr>
<tr>
<td>Color class</td>
<td>3</td>
<td>719.97 NS</td>
</tr>
<tr>
<td>Tests x color</td>
<td>6</td>
<td>308.30 NS</td>
</tr>
<tr>
<td>Error b (^2)</td>
<td>18</td>
<td>375.27</td>
</tr>
<tr>
<td>Days</td>
<td>4</td>
<td>6,206.37**</td>
</tr>
<tr>
<td>Tests x days</td>
<td>8</td>
<td>403.38*</td>
</tr>
<tr>
<td>Color x days</td>
<td>12</td>
<td>113.97 NS</td>
</tr>
<tr>
<td>Tests x color x days</td>
<td>24</td>
<td>107.54 NS</td>
</tr>
<tr>
<td>Error c (^3)</td>
<td>96</td>
<td>169.51</td>
</tr>
<tr>
<td>Weeks</td>
<td>3</td>
<td>19,089.57**</td>
</tr>
<tr>
<td>Tests x weeks</td>
<td>6</td>
<td>310.20**</td>
</tr>
<tr>
<td>Color x weeks</td>
<td>9</td>
<td>42.37**</td>
</tr>
<tr>
<td>Days x weeks</td>
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<td>135.58**</td>
</tr>
<tr>
<td>Tests x color x weeks</td>
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<td>22.01 NS</td>
</tr>
<tr>
<td>Tests x days x weeks</td>
<td>24</td>
<td>50.49**</td>
</tr>
<tr>
<td>Color x days x weeks</td>
<td>36</td>
<td>20.07 NS</td>
</tr>
<tr>
<td>Tests x color x days x weeks</td>
<td>72</td>
<td>12.78 NS</td>
</tr>
<tr>
<td>Error d (^4)</td>
<td>360</td>
<td>16.62</td>
</tr>
<tr>
<td>Total</td>
<td>719</td>
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</tr>
</tbody>
</table>

\(^1\) Error a, interaction of replicates x tests.

\(^2\) Error b, combined interactions of replicates x color and replicates x color x tests.

\(^3\) Error c, combined interactions of replicates x days, replicates x tests x days, replicates x color x days, and replicates x tests x color x days.

\(^4\) Error d, residual.

*Significant at 5-percent level.

**Significant at 1-percent level.
END