TO: Tomato Processing Industry

FROM: Teri Wolcott
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RE: Objective Tomato Color Measurement

July 23, 1980

Since March, 1979, when "Color Scoring Tomato Products Objectively" was released, procedures and equations for USDA color scores have been updated. As a result of the changes, a revision of that report is being issued.

The major purpose for this report is to provide a uniform set of procedures for colorimeter users and potential users in the tomato industry. To obtain reliable, consistent results within and between laboratories, sample preparation, instrument calibration and standardization and other procedures must be uniform.

The March 1, 1979 report was prepared so that page-by-page updates could be issued as changes occurred in the procedures. However, since this update includes a large number of procedural additions as well as revisions in the color equations for most instruments, we have decided to issue a complete revised report. Please be sure to discard all copies of the March, 1979 report.

The 1979 tentative tomato sauce and catsup equations have been revised. Based on additional data, a term has been added to the Gardner, Hunter and Agtron M500 sauce equations. These equations should provide more accurate scores. Evaluation of diluted catsup samples has been abandoned, and incorporation of additional data has resulted in a change in the terms of the catsup color score equations. These equations will remain tentative through the 1980 season.

Until now, colorimetric values for the standard puree have been assigned using colorimeters at U.C. Davis. With this report, the basis for assigning these values has been shifted to an absolute system. From now on, the National Bureau of Standards will evaluate standard puree samples and assign values to them based on spectral data using a barium sulfate reference.
As a result of this shift in standardization, it was necessary to revise the equations to calculate USDA scores for those instruments using puree standardization (Hunter and Gardner). The revised equations are included in this report. **DISPOSE OF OLD EQUATIONS AND GRAPHS - THEY WILL NOT GIVE VALID SCORES WITH THE NEW STANDARDIZATION SYSTEM.**

Graphs to determine score points are not included in this revision. Graphs have been prepared and are available on request for specific colorimeters and specific products. Programmable calculators which yield precise scores are now available at reasonable prices and we recommend their use.

The revised procedures include:
- Introduction and background information concerning development of methods and results of round robin instrument reliability testing. (1976-1979)
- Sample preparation.
- Standardization and operation of colorimeters.
- Conversion to USDA color scores by approved and tentative equations.
- Appendix
  : Procedure for production of tomato puree color standard.
  : Procedure for calibration of sample cups.
  : Explanation of the conversion to absolute (NBS) standardization.

The procedures for cup calibration provide guidelines which enable processors to check their own sample cups at regular intervals if they so desire.

We have prepared the Introduction and each page of the Procedures so updates can be made as they become available. We will maintain a mailing list and issue updated procedures page by page as the need arises. It is important that we have a complete list of interested people. If we have missed important people, please let us know.

We are anxious to obtain feedback from you, the users of these procedures. Your comments and suggestions will be appreciated.
COLOR SCORING TOMATO PRODUCTS OBJECTIVELY

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Revised, July 15, 1980

This report replaces the March 1, 1979 report. Please discard previous copies.
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1. Introduction

Color is a major quality attribute of processed tomato products. A system of color scoring these products introduced as early as 1938 not only evaluated lot quality grades, but also made possible the differentiation of lots within grades. Lots receiving high scores became economically more valuable.

The color scoring system adopted for use by USDA in 1938 was based upon the pioneering work of MacGillivray (1931). He demonstrated that scores could be assigned to tomato products by comparing their color to colors produced by spinning discs prepared from colored papers suitable for the purpose. The method was highly subjective and required close control over light quality, viewing angle, and the operator's color sense, but at that time it provided the industry with a much needed tool. Color measuring devices capable of performing this function on an industrial basis had not as yet been developed.

Until 1977 the MacGillivray system using papers prepared by the Munsell Company was still the only official method in the USDA Standards for Grades. Although colorimeters were available during the time from 1942 to 1977, color scores were still assigned subjectively because a cooperative project initiated by the Agricultural Marketing Service in 1956 (Agricultural Marketing Service, 1957) indicated that the colorimeters available were not sufficiently uniform in their responses to permit the development of a system of color measurement serving the entire industry. However, the results of this study did support the conclusions of many investigators (Younkin, 1950; Robinson et al., 1951; Davis, 1949; Kramer, 1951) reporting prior to this date that photoelectric systems of color measurement could be developed for objective color score assignment in a single location.

Data acquired during the development of the State of California method of color grading tomato deliveries for processing emphasized the need for an objective method of color scoring tomato products, and the necessity for a study that would bring together the technical groups within industry, the USDA, and the research capabilities at U.C. Davis. Funding to support a project leading to the development of instrument systems for color scoring tomato paste was provided by the Canners League of California. Work by personnel at U.C. Davis and at USDA (USDA, 1977) indicated that in the measurement of translucent materials, lack of reproducibility between reflectance colorimeters (other than Agron and Gardner) was related to factors not commonly controlled by the instrument manufacturer. Two tristimulus colorimeters of the same make and model were set up in the same laboratory, and standardized using the same red tile. Readings on ten samples were taken under ideal conditions, using both instruments. The first three graphs in Figure A illustrate reproducibility of the two colorimeters with the tile standard ("o" on graphs) in terms of differences in L, a*, and b* values between the two colorimeters. Measurements on the ten samples are listed in order of increasing L values. As shown in Figure A, the differences between instruments using the tile standard were much too great to allow the use of instruments for optical color scoring of tomato products.
Early in 1974, the reproducibility problem was discussed with Richard S. Hunter, developer of the L, a, b color measurement system and President of Hunter Associates Laboratory. It was agreed that the approach most likely to bring about agreement between instruments was to use a standardized tomato puree to periodically re-calibrate the red tile "hitching post" standard on each instrument. The Canners League of California Technical Committee subsequently authorized trials utilizing the puree standard. This tomato product standard was assigned colorimetric values obtained using instruments at U.C. Davis as standardizing mechanisms.

The side-by-side instrument reproducibility test described previously was repeated with a duplicate set of 10 samples, using the puree standard. Results are shown in the first three graphs of Figure A, again in terms of differences in L, a, and b values between the two colorimeters ("X" on graphs). Adoption of the puree standard brought about better agreement between the two instruments in terms of L and a. Once instrument reproducibility was controlled the program could proceed to studies which would produce USDA color score equations.

Three series of tests on tomato paste were conducted in which samples covering a wide range of color were subjectively scored by expert USDA and Canners League panelists using the MacBeth Munsell Disc Colorimeter. Colorimetric data using Hunter, Agtron E5M, Agtron M500A and Neotec Trucolor units were also obtained.

Extensive statistical analyses of the data by USDA personnel in Washington, D.C. led to the development of tentative mathematical relationships which took into account the three-dimensional properties of color and fit the data for these instruments with a very high degree of correlation. Members of the Canners League Technical Committee approved the use of instruments and their appropriate equations for scoring purposes for the 1975 season.

Based on the equations developed, the bottom graph of Figure A shows differences in USDA color scores computed using the raw data from the three preceding graphs. Use of the puree standard resulted in much better agreement between the two instruments. The computed USDA color scores from the two colorimeters differed by an average of 1.29 score points using the tile standard, and only 0.45 score points with the puree standard. A supply of the tomato puree standard was distributed to all participating laboratories, which permitted periodic assignment of new calibration values to their tiles.

A greater degree of uniformity was achieved through adopting the puree-based procedure than existed beforehand. Collaborative testing of unknown duplicate samples was conducted by 16 participating laboratories shortly after the new procedure was adopted. One set of samples was received and tested by each participant at the beginning of the 1975 processing season. A duplicate set of samples was received and tested at the end of that season. Results of this collaborative study (shown in Figure B) indicated that approximately 95% of the laboratory results were within a one score point range for pastes scoring higher than 45 points.

On July 12, 1976, the USDA, at the request of the Canners League of California, published in the Federal Register, Vol. 41, number 134, a proposed amendment to the USDA United States Standards for Grades of Tomato Paste which would permit instrumental evaluation of the color of tomato paste. This amendment was subsequently adopted on September 19, 1977.
Early in 1976, Canners League, acting on a request from the Technical Committee, suggested that the colorimetric system of color scoring be extended to tomato juice and purees. A nation-wide collection of samples was undertaken with the USDA soliciting samples from Midwest and East Coast packers. Canners League of California supervised the collection of samples from packers within its jurisdiction.

Scores by panel members and colorimetric data using Hunter, Agtron, Neotec and Gardner instruments were collected on a selected portion of these samples in April, 1976, at the USDA Laboratory in Stockton, California. These data were subjected to extensive statistical analyses, and mathematical relationships were developed which fit the data for each instrument with a high degree of correlation.

It was found that both panelists and instruments responded to the color of tomato puree in a way identical to that of tomato paste. Consequently, the paste equations were also used for puree. A proposal to incorporate instrumental methods for color measurement into the USDA United States Standards for Grades of Tomato Puree was published in the Federal Register of April 14, 1978 (43 FR 15610). This became effective May 1, 1978.

In September, 1976, the Technical Committee tentatively authorized the use of equations for the Hunter, Agtron ESM, and Agtron 500 Colorimeters for scoring tomato juice on a trial basis for the rest of the season. Later, equations for scoring paste, puree and juice using the Gardner instrument were approved. The Technical Committee also proposed that colorimetric scoring be extended to catsup and sauce and that the scoring tests on juice be duplicated. Samples of these materials were collected during the 1976 and 1977 processing seasons and were used in score point panels and instrument studies in April, 1977, and in April, 1978. Based on statistical analyses of the data obtained in these studies, the USDA United States Standards for Grades of Tomato Juice were amended on June 15, 1978, to include instrumental methods for color measurement.

Tentative equations are presently available for use with tomato sauce and catsup, although they have not become part of the official USDA Standards for Grades of those products.

The 1978 studies included the Macbeth MS-2045 Spectrophotometer and a Photovolt Reflectance Colorimeter, and resulted in tentative tomato juice equations for both of these instruments. However, the Macbeth instrument has not been submitted for subsequent studies, so it has not been possible to finalize the tentative juice equation and develop equations for other products.

A Photovolt was used also in 1979 studies, and duplicate instruments were submitted for 1980 studies.
Samples in the 1980 studies were also evaluated using a single Neotec Digi-color and two IBM 7409 spectrophotometers. Analysis of data from those instruments has not been completed. A separate report will be issued when results are available.

The following section of this report includes detailed procedures for colorimetric analysis of tomato juice, paste, puree, sauce and catsup, using the Agtron E5M, the Agtron M500, the Gardner XL-20 and XL23, and the Hunter D25 colorimeter with A head.

The use of colorimeters in this study does not constitute or imply endorsement of or preference for these instruments by the University of California, Davis. Other colorimeters which will provide the information necessary for accurate and objective tomato color evaluation can be used after passing qualification tests.
FIGURE A
DIFFERENCE BETWEEN TWO TRISTIMULUS COLORIMETERS EVALUATING TOMATO PASTE

\( \Delta L \)

\( \Delta a \)

\( \Delta b \)

\( \Delta \text{USDA} \text{ Score} \)

SAMPLE NUMBER

\( \bigcirc \) Tile standard

\( \times \) Puree standard
References


Kramer, Amihud. 1951. This meter gives better color evaluations. Food Ind. 22, 1897-1900.

Mac Gillivray, J. H. 1931. Tomato color as related to quality in the tomato cannig industry. Bulletin No. 350, Purdue University Agricultural Experiment Station, Lafayette, Indiana.


USDA. 1977. Status report on joint USDA, Canners League of California and University of California processed tomato product color project.


Reliability of instruments in participating laboratories has been monitored since the beginning of the tomato product color program. This was first accomplished by submitting replicate tomato paste samples to all laboratories during the 1975 tomato processing season. Results were reported in Status Report on Joint USDA, Canners League of California, and University of California Processed Tomato Product Color Project, distributed in the spring of 1977. These "Round Robin" studies were expanded during the 1976 and 1977 processing seasons by including tomato juice in addition to paste. Tables 1-5 show average USDA color scores and standard deviations for instruments in participating laboratories.

Table 1

<table>
<thead>
<tr>
<th>Product</th>
<th>Average Score</th>
<th>Standard Deviation</th>
<th>Number of Laboratories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Juice 1</td>
<td>23.0</td>
<td>0.365</td>
<td>12</td>
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<tr>
<td>Juice 2</td>
<td>29.2</td>
<td>0.269</td>
<td>13</td>
</tr>
<tr>
<td>Juice 3</td>
<td>26.2</td>
<td>0.369</td>
<td>13</td>
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<tr>
<td>Paste A</td>
<td>47.7</td>
<td>0.264</td>
<td>13</td>
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<td>Paste C</td>
<td>48.4</td>
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<tr>
<td>Paste D</td>
<td>46.2</td>
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1.1 Instrument Reliability Studies (continued)

Table 2

1977 Round Robin Study, Tomato Paste

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<th>Average Score</th>
<th>Standard Deviation</th>
<th>Number of Measurements</th>
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<tr>
<td>Paste E</td>
<td>47.37</td>
<td>0.636</td>
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<tr>
<td>Paste F</td>
<td>46.35</td>
<td>0.743</td>
<td>48</td>
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<tr>
<td>Paste G</td>
<td>47.25</td>
<td>0.610</td>
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Table 3

1977 Round Robin Study, Tomato Paste

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<tr>
<td>Paste E</td>
<td>47.31</td>
<td>0.305</td>
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<tr>
<td>Paste F</td>
<td>46.34</td>
<td>0.371</td>
<td>38</td>
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<tr>
<td>Paste G</td>
<td>47.21</td>
<td>0.313</td>
<td>42</td>
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Table 4

1977 Round Robin Study, Tomato Juice

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<tr>
<td>Juice 4</td>
<td>25.67</td>
<td>0.671</td>
<td>50</td>
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<tr>
<td>Juice 5</td>
<td>26.90</td>
<td>0.624</td>
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</tr>
<tr>
<td>Juice 6</td>
<td>27.70</td>
<td>0.532</td>
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1.1. Instrument Reliability Studies (continued)

Table 5

<table>
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<th>Product</th>
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<th>Standard Deviation</th>
<th>Number of Measurements</th>
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<tr>
<td>Juice 4</td>
<td>25.74</td>
<td>0.357</td>
<td>41</td>
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<tr>
<td>Juice 5</td>
<td>26.86</td>
<td>0.430</td>
<td>43</td>
</tr>
<tr>
<td>Juice 6</td>
<td>27.72</td>
<td>0.379</td>
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Standard deviations for the 1976 data ranged from 0.26 to 0.47 which was similar to the range from 0.24 to 0.58 for the 1975 study. Standard deviations for tomato juice were very nearly the same as those for tomato paste.

The 1977 round robin study was much larger (32 laboratories) than the 1976 study (14 laboratories). Many of the participants were untrained and were following the written instructions for sample preparation and instrument standardization for the first time. All instruments in the 1976 study had been "tuned up" prior to the processing season; however, data were gathered for the 1977 round robin study using instruments that were in "as is" condition. Some were tested by the owners, others were not. The data bear out the suspected condition of instruments and lack of training of operators. Standard deviations jumped to the range of .53 to .74. Removal of extreme values as shown in Tables 3 and 5 returned standard deviations to their normal ranges (1977 paste $S_x = .31$ to .37, 1977 juice $S_x = .36$ to .43). It appeared that acceptable color scoring could be achieved if instruments were properly maintained, and personnel were properly trained.

Figures 1-6 and 7-12 show color scores determined laboratory-by-laboratory on round robin samples for 1976 and 1977 respectively. Average score for all laboratories is indicated by the horizontal line. The scores generated by each
1.1. Instrument Reliability Studies (continued)

laboratory can be easily compared with the average of the scores from all laboratories. Your laboratory identification number is given in the cover letter for this section of the report so that you may evaluate your own color measurement systems (both 1976 and 1977 use the same laboratory identification numbers).

If your scores do not agree well with the mean values, and if you have carefully checked your instrument and operating procedures please contact U.C. Davis for help (see section 2.3.1.).
1.2. INSTRUMENT RELIABILITY TESTING (Round Robin Study - 1979)

Reliability of instruments in participating tomato processors' laboratories was monitored twice during the 1979 tomato processing season, once early and once later in the season. Two samples each of paste, sauce, juice and catsup, accompanied by standard puree, were distributed to the laboratories for colorimetric evaluation. Previous studies included only paste and juice samples. Users were instructed to dilute paste samples to 8.5% NTSS prior to evaluation and to evaluate catsup both at full strength and diluted to 20% NTSS. Juice and sauce samples were evaluated at single strength. Results were returned to U.C. Davis for tabulation.

Table 1 shows average USDA color scores and standard deviation for data returned by participating laboratories.

Standard deviations for paste and juice samples ranged from 0.69 to 0.81 in the 1979 study. These deviations are somewhat higher than those for 1976 and 1977. Removal of the extreme values reduced the range of deviations to 0.42 - 0.57 for paste, juice and sauce. (Table 2)

Catsup samples, both diluted and full strength, exhibited the largest variation between laboratories. It should be noted that the equations used to calculate catsup scores are tentative ones, subject to revision as more information is collected. Improved equations are expected to reduce the variation between scores obtained from different types of colorimeters. The increased variation in catsup scores may also be due in part to the fact that catsup colors are farther from the color of the standard puree than are juice, sauce and paste colors. Instruments are expected to agree better on samples with colors closer to the standard. This theory is substantiated by the fact that standard deviations for diluted catsup, which is closer in color to the standard puree, are less than those for undiluted catsup. For both catsup samples, the full-strength evaluations gave higher scores than their diluted counterparts. The discrepancy between full strength and diluted scores for the same sample has not yet been explained. Average scores were lowered by the presence of several extremely low scores, particularly in the full strength catsups.

The disagreement between instruments used for catsup color evaluation emphasizes the need for studies such as this to verify that equations obtained in USDA Stockton color studies using duplicate or triplicate instruments of each type give realistic results in widespread, less rigidly controlled laboratory use.

Figures 1-10 show color scores determined in individual laboratories. The horizontal line on each figure indicates the average score for all laboratories. If your laboratory participated in the 1979 Round Robin study, your identification number is given in the cover letter accompanying this report, so you may evaluate your own color measurement systems. The identification numbers used in the 1979 study are the same as those used in 1976 and 1977 studies.
<table>
<thead>
<tr>
<th>Product</th>
<th>Average Score</th>
<th>Standard Deviation</th>
<th>Number of Measurements</th>
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<tbody>
<tr>
<td>Paste 1</td>
<td>47.86</td>
<td>0.814</td>
<td>72</td>
</tr>
<tr>
<td>Paste 2</td>
<td>48.29</td>
<td>0.780</td>
<td>71</td>
</tr>
<tr>
<td>Juice 1</td>
<td>26.56</td>
<td>0.873</td>
<td>71</td>
</tr>
<tr>
<td>Juice 2</td>
<td>27.43</td>
<td>0.691</td>
<td>72</td>
</tr>
<tr>
<td>Sauce 1</td>
<td>20.88</td>
<td>0.868</td>
<td>72</td>
</tr>
<tr>
<td>Sauce 2</td>
<td>21.41</td>
<td>0.874</td>
<td>72</td>
</tr>
<tr>
<td>Catsup 1</td>
<td>23.11</td>
<td>2.442</td>
<td>71</td>
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<tr>
<td>Catsup 2</td>
<td>22.80</td>
<td>2.365</td>
<td>71</td>
</tr>
<tr>
<td>Catsup (20°B) 1</td>
<td>22.46</td>
<td>1.287</td>
<td>64</td>
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<td>Catsup (20°B) 2</td>
<td>22.17</td>
<td>1.260</td>
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Table 2

1979 Round Robin Study

Extreme Values Removed

<table>
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<tr>
<td>Paste 1</td>
<td>47.73</td>
<td>0.48</td>
<td>61</td>
</tr>
<tr>
<td>Paste 2</td>
<td>48.18</td>
<td>0.42</td>
<td>60</td>
</tr>
<tr>
<td>Juice 1</td>
<td>26.44</td>
<td>0.57</td>
<td>60</td>
</tr>
<tr>
<td>Juice 2</td>
<td>27.33</td>
<td>0.44</td>
<td>61</td>
</tr>
<tr>
<td>Sauce 1</td>
<td>20.80</td>
<td>0.45</td>
<td>60</td>
</tr>
<tr>
<td>Sauce 2</td>
<td>21.32</td>
<td>0.52</td>
<td>60</td>
</tr>
<tr>
<td>Catsup 1</td>
<td>23.93</td>
<td>1.02</td>
<td>56</td>
</tr>
<tr>
<td>Catsup 2</td>
<td>23.64</td>
<td>0.89</td>
<td>56</td>
</tr>
<tr>
<td>Catsup (20°B) 1</td>
<td>22.44</td>
<td>0.66</td>
<td>53</td>
</tr>
<tr>
<td>Catsup (20°B) 2</td>
<td>22.19</td>
<td>0.81</td>
<td>53</td>
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FIGURE 1
1979 ROUND ROBIN STUDY - TOMATO PASTE, SAMPLE P1

USDA SCORE

PROCESSOR I.D. NUMBER

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**PROCESSOR I.D. NUMBER**

- **Early Season**: ⬤
- **Late Season**: ▲
2.4.3. CONVERSION TO ABSOLUTE STANDARDIZATION OF TOMATO PUREE

Introduction

As discussed previously in this report, the use of standardized tomato puree as a "hitching post" began in 1974 in an attempt to bring about agreement between colorimeters. Standardized tomato puree at 8.5°B was formulated from tomato paste at U.C. Davis and assigned colorimetric values using U.C. Davis instruments as standardizing mechanisms. Samples of the puree were distributed to colorimeter users who evaluate tomato product color. Using this puree to standardize instruments or check calibration, it became possible to obtain reproducible color readings from different instruments.

As a result of several annual studies at the USDA Processed Products laboratory in Stockton, CA, equations were developed relating panelists' visual USDA color scores to instrumental color measurements for tomato paste, puree and juice. Based on the data obtained, colorimeters have been approved by USDA for color evaluation of these products. Instrumental evaluation of tomato sauce and catsup color is still under investigation; tentative equations are presently available for these products.

With USDA approval of colorimeters for grading tomato products, it became desirable to convert from U.C. Davis colorimeters as a basis for puree calibration to an absolute system. The National Bureau of Standards, which provides official standards for a number of commodities, seemed the logical choice and they agreed to cooperate.

PROCEDURE

Since the first batch of standardized puree was formulated in 1974, several additional batches were prepared, as dictated by demand. Each of these subsequent lots was assigned colorimetric values at U.C. Davis, based on instrument standardization using the preceeding standardized purees. In this way, continuity was maintained from batch to batch. All samples were refrigerated to minimize color change, and samples of each batch were saved for future comparison.

Samples of each standard puree batch were taken to the National Bureau of Standards in Washington, D.C. Using their spectrophotometer with a BaSO₄ calibration tile, absolute Y, X, Z values were obtained on duplicate samples of each batch. Based on the difference between these absolute values and those assigned using U.C. Davis colorimeters, the colorimetric data from previous Stockton color studies on tomato products were 'corrected' to absolute values. These absolute values were correlated with the panelists' visual scores for each sample to obtain revised color score equations based on instrument calibration using the NBS absolute standard. In all cases, the correlation between visual scores and instrument readings was at least as high using the NBS Standardization as using the U.C. Davis standardization.
Standardized tomato puree samples have been assigned new color values using NBS absolute standardization. As new batches of standard puree are formulated, samples will be sent to NBS for assignment of color values.

The change from U.C. Davis colorimeter standardization to NBS absolute standardization will not change the color score of samples. The change in puree standardization values is compensated for by a corresponding change in the color equations. A sample scoring 47 under the old system will also score 47 with the new system, although the instrumental L, a, b values for the two systems will differ.
1979 ROUND ROBIN STUDY - TOMATO CATSUP, SAMPLE C2

FIGURE 8 (p.2)

PROCESSOR I.D. NUMBER

USDA SCORE

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LATE SEASON ▲
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*Early Season • Late Season ▲*
2.2.2. Agtron Colorimeters

2.2.2.1. Standardization

2.2.2.1.1. Agtron E5-M. Directly reads green to red ratio times the factor 48, and has a built-in standard. To standardize, open drawer to position standard disc beneath sensor, then adjust "standardize" knob so colorimeter reads 48. Check standardization before evaluating each sample.

2.2.2.1.2. Agtron M500. Using black disc (cat. #21747-0), adjust green, red and blue modes to read zero on scale. Then, using red disc (cat. #22868) adjust green, red and blue modes to read 100 on scale. Recheck black disc to be sure the three modes read zero. If re-calibration is necessary with black disc, recheck red disc. Repeat until no further adjustment is necessary. If sample reading is off scale, re-standardize to zero and 50 on scale with black and red, respectively, then multiply sample reading by 2.

2.2.2.1.3. Agtron M400. Use black (cat #21747-0) and red (cat #22868) discs to set zero and full scale values respectively for red mode. Place sample in instrument and take red reading. Change to green mode and repeat standardization, then take green reading on sample. Repeat for blue mode. If sample reading is off scale, re-standardize to zero and 50 on scale, then multiply sample reading by 2.

2.2.2.2. Selection and Use of Sample Cups (Agtron M400 and M500 Models). Use only pre-selected cups. Participating laboratories should calibrate sample cups according to 2.4.1. or submit sample cups to the UCD Food Processing Laboratory (see 2.3.1. for address) for checking before the start of the season. Do not mix sample cups of different calibration values as they may introduce significant error.

Clean cups with mild detergent, rinse thoroughly and blot dry with soft tissue. Do not rub with coarse toweling or paper towels; these materials will scratch the optical glass windows. Do not place cups on any hard objects, as traces of dirt or grit will scratch the windows. Fill the cup with tomato product to the line scribed at the time of selection. Examine each cup from time to time to confirm the absence of scratches or water spots. Cups with blemished windows should be destroyed. Cups should be recalibrated according to 2.4.1. or be returned to UCD for re-checking at 2-year intervals.

2.2.2.3. Calibration Checks. Check calibration at weekly intervals using standard purée described in section 2.2.1.5. The standard purée has been assigned an Agtron E5M value and G, R, B values for other Agtron models when standardized with black and red discs. If the model E5M instrument reading deviates more than 1 unit from the standard purée value remove drawer and clean standard, drawer, and floor of instrument beneath drawer. If readings continue to exceed the tolerance, obtain qualified service assistance (see 2.3.2.1.). Values for G, R, and B must also lie within ± 1 unit of the values stated on the purée standard can. If the tolerance is exceeded, check the standards, well cup, and window of the optical assembly for cleanliness.
2.2.2.4. Sample Measurement

2.2.2.4.1. Agtron E5M. Fill sample dish to scribed line (170 ml), rotate dish quickly several times to smooth surface, then tap gently on bench top to level sample. Remove air bubbles from surface of sample, check instrument standardization, place sample in drawer, close and read meter to nearest half unit.

2.2.2.4.2. Agtron M400 and M500 Models. Standardize according to method in previous section. Fill sample cup with properly diluted product to fill line. Check window for adhering air bubbles; remove bubbles carefully so as not to scratch inner surface of window. Place cup on colorimeter, close lid and record red, green and blue readings.

2.2.2.5. Color Score Point Conversions - Agtron Colorimeters

2.2.2.5.1. Tomato Paste and Puree. The following equations are used for calculation of paste and puree color score:

2.2.2.5.1.1. Agtron M400 and M500 Colorimeters.
Score = 20.850 + 0.828(R) - 0.004335(R^2) - 0.283(G) + 0.312(B)

2.2.2.5.1.2. Agtron E5M Colorimeters
Score = 54.250 - 0.005265 (E5M reading)^2

For tomato paste and tomato puree having a "brown" or "burnt" visual appearance the Agtron E5M meter reading yields accurate "substandard" scores.

2.2.2.5.2. Tomato Juice. The following equations are used for calculation of tomato juice color score:

2.2.2.5.2.1. Agtron M400 and M500 Colorimeters
Score = 28.629 + 0.14286R - 0.24197G + 0.14176B

2.2.2.5.2.2. Agtron E5M Colorimeters
Score = 40.898 - 0.35759 (E5M reading)
Agtron Colorimeters (continued)

2.2.2.5.3. Tomato Sauce. The following tentative equations are used for calculation of tomato sauce color scores:

2.2.2.5.3.1. Agtron M400 and M500 Colorimeters
Score = -25.002 + 1.5234(R) - 0.0092174(R<sup>2</sup>) - 0.25817(G)

2.2.2.5.3.2. Agtron E5M Colorimeters
Score = 38.936 - 0.45231(E5M Reading)

2.2.2.5.4. Tomato Catsup. The following tentative equation is used for calculation of tomato catsup color scores:

2.2.2.5.4.1. Agtron M400 and M500 Colorimeters
Score = -5.3411 + 1.0309(R) - 0.00745(R<sup>2</sup>) - 0.15663(G)

2.2.2.5.4.2. Agtron E5M Colorimeter
Correlation between panelists and instrument readings was not sufficiently high to develop an accurate color score equation.
2.2.3. Gardner Colorimeters

2.2.3.1. Instrument. Use Gardner models XL20 or XL23 with aperture having a 1½" diameter opening. No windows or glass plates are to be used over the aperture. An opaque black cover for the sample cup must be provided to prevent room light from entering the system through the sample. A #303 can painted flat black on the inside works well for this purpose.

2.2.3.2. Cleaning Standard Tiles. Keep all tiles clean. Do not touch reflecting surfaces or allow them to contact any hard objects. Every tile should be cleaned routinely at four week intervals and at any other time that it appears to have foreign material on the reflecting surface.

Clean the tile surface in mild detergent solution (Haemo-sol, available from most scientific supply houses, 1 Tablespoon per gallon of water), brushing gently with a soft nylon-bristled paint brush. Do not use soap as it leaves a film. Do not submerge the tiles as this will damage the labels. Rinse thoroughly in flowing hot water and blot dry with tissue or a soft towel. Do not rub the reflecting surface since some tissues or towels may be sufficiently abrasive to scratch the tile.

2.2.3.3. Selection and Use of Sample Cups. Sample cups must be pre-selected for this study. Participating field stations and industry laboratories should calibrate sample cups according to 2.4.1. or submit their sample cups to the UCD Food Processing Laboratory (see 2.3.1. for address) for checking prior to the start of the season. Do not mix sample cups of different calibration values as they may introduce significant error.

Clean cups with mild detergent, rinse thoroughly and blot dry with soft tissue. Do not rub with coarse toweling or paper towels; these materials will scratch the optical glass windows. Do not place cups on any hard objects, as traces of dirt or grit will scratch the windows. Fill the cup with tomato product to the line scribed at the time of selection by UCD. Examine each cup from time to time to confirm the absence of scratches or water spots. Cups with blemished windows should be destroyed. Cups should be recalibrated according to 2.4.1. or be resubmitted to UCD for rechecking at 2-year intervals.

2.2.3.4. Calibration and Adjustment of Instrument. Follow manufacturer's instructions. Since different apertures may be used for other products, zeroing of the Y, X, Z scales will be done with an open sample port (no aperture in place). Error due to zero offset with the 1-1/2" aperture is compensated by the standardization procedure.
Gardner Colorimeters (continued)

2.2.3.5. Calibration of Red Tile. The red tile normally used to standardize the Gardner colorimeter is routinely re-calibrated at weekly intervals by means of a tomato puree color standard.

Several 6 oz cans of the standard will be supplied by UCD upon request (see 2.3.1. for address). The assigned $L$, $a_L$, and $b_L$ values are printed on the label. This material was sterilized to prevent spoilage but must be stored in a refrigerator at about 35-40°F to minimize minor changes in color (do not freeze). Open a can of standard puree, stir gently to re-distribute solids, and allow it to stand for 20 minutes. No dilution is necessary as this material was adjusted to 8.5% NTSS prior to canning. Adjust standard puree to room temperature before use.

Stir sample, fill sample cup with standard puree, place on colorimeter, and cover. Adjust controls so that instrument displays $L$, $a_L$, and $b_L$ values printed on can. Adjust $L$ knob before adjusting $a_L$ and $b_L$ knobs since they are influenced by $L$ setting. Place red tile on instrument and read $L$, $a_L$, $b_L$ values. Assign these newly determined values to the tile, replacing the factory calibration. Use red tile with these newly established values for routine standardization of the instrument. It may be convenient to record these new tile values with the calibration date on an adhesive label to be placed on the colorimeter case or on the back of the tile. Re-calibrate tile at weekly intervals by the foregoing procedure. This calibration system must be used to compensate for differences in optical alignment, lamp age, filter differences, dust in optics, etc.

Maintain a permanent record of weekly tile calibrations. If the $L$, $a_L$, or $b_L$ values change by more than 0.2 units open a second can of standard puree and re-check tile calibration.

2.2.3.6. Standardization. Standardize instrument using red tile with new calibration values. Adjust standardization before reading each set of one or more samples. While measuring a set of samples, time interval between standardization must be no longer than four minutes.

2.2.3.7. Sample Measurement. Fill samples cup with juice or properly diluted product to fill line, or from 1/4 to 3/8 inch of the top. Check the window for adhering air bubbles; if present take steps to remove them, but be careful not to scratch the inner surface of the window. Center cup over aperture of colorimeter, cover with opaque light shield, and record $L$, $a_L$, and $b_L$ readings.
2.2.3.8. Color Score Point Conversions – Gardner Colorimeters

2.2.3.8.1. Tomato Paste and Puree: The following equation is used for calculation of tomato paste and puree color score:
Score = -46.383 + 1.0211(a_L) + 10.607(b_L) - 0.42198(b_L)²

2.2.3.8.2. Tomato Juice. The following equation is used for calculation of tomato juice color score:
Score = 34.094 + 0.71464(a_L) - 1.7883(b_L)

2.2.3.8.3. Tomato Sauce. The following tentative equation is used for calculation of tomato sauce color score:
Score = -193.20 + 1.0211(a_L) + 27.649(b_L) - 1.0175(b_L)²

2.2.3.8.4. Tomato Catsup. The following tentative equation is used for calculation of tomato catsup color score:
Score = -40.511 + 4.7767(a_L) - 0.07791(a_L²) - 0.56986(b_L)
2.3. Information and Assistance

2.3.1. Assistance in colorimeter standardization and operation may be obtained by contacting:

Professor George L. Marsh, Jim Buhlert or Teri Wolcott
Department of Food Science and Technology
Cruess Hall
University of California
Davis, CA 95616
(916) 752-3685
752-7162
752-1484

2.3.2. Repairs to instruments may be obtained as follows:

2.3.2.1. Agtron

2.3.2.1.1. Honeywell Service Centers (check telephone listings)

2.3.2.1.2. Magnuson Engineers, Inc.
1010 Timothy Drive
San Jose, CA 95150
(408) 287-1260

2.3.2.2. Hunter

2.3.2.2.1. Albright Associates
425 First Street
Los Altos, CA 94022
(415) 941-5928

2.3.2.2.2. Hunter Associates Laboratory
9529 Lee Highway
Fairfax, Virginia 22031
(703) 591-5310

2.3.2.3. Gardner

2.3.2.3.1. Pacific Scientific
541 Taylor Way, Unit 4
Belmont, CA 94002
(415) 592-6300

2.3.2.3.2. Gardner Laboratory, Inc.
5521 Landy Lane
Bethesda, MD 20014
(301) 656-3600
2.3.3. Development of Equations for New Colorimeters

The USDA Food Safety and Quality Service Products Branch has developed a procedure for certifying new colorimeters for official use by that Branch. Copies of the procedure are available from:

Joe Fly, Chief  
Processed Products Branch  
Fruit and Vegetable Quality Division  
Food Safety and Quality Service  
United States Department of Agriculture  
South Agriculture Building  
Washington, D.C. 20250


2.3.4. ACKNOWLEDGEMENT

The efforts of all people who have been involved are sincerely appreciated. The Canners League of California provided funding and guidance; USDA Food Safety and Quality Service in Washington, D.C. provided funding and guidance; USDA Food Safety and Quality Service in San Jose and Stockton, California provided facilities and technical personnel; USDA Statistical Service Group in Washington, D.C. provided guidance and data analysis services; members of the tomato processing industry have cooperated in supplying samples and personnel to help conduct the Stockton color studies from which the colorimeter equations were generated; colorimeter manufacturers have provided instruments and technical assistance; and our secretary, Karen Hunter, has been most helpful in preparing this report for distribution.
2.4 APPENDIX

2.4.1. CALIBRATION OF SAMPLE CUPS FOR TOMATO PRODUCT COLOR EVALUATION

Introduction

The following procedure is used to check sample cups for use with colorimeters which view samples through the glass cup bottoms. The purposes of sample cup calibration are (1) to ensure uniformity of a series of sample cups which will be used interchangeably within a processing laboratory and (2) to verify that the cups are free from defects which could result in inaccurate colorimeter readings. Each batch of sample cups so checked should be kept as a unit. Cups from different populations should not be used interchangeably unless it has been verified that they do, in fact, yield the same readings on product samples.

PROCEDURE

One calibrated cup is used as a reference to check other cups. Wash each cup in Haemosol or Sparkleen (1 tablespoon per gallon of warm water). Rinse thoroughly with distilled water. Dry thoroughly with facial tissue or soft towel. Do not use harsh toweling or other substances which might scratch the optical glass bottoms of the cups. Be certain to keep cups from different sources in identifiable groups.

Number or code cups with an engraver or permanent marker. The number should not be over 1/2" from the top of the cup. It is important that each cup receives a distinct code.

Open six cans of USDA tomato puree color standard. Mix the contents together by hand taking care to avoid incorporation of any bubbles into the product, and let the mixture stand thirty minutes.

Using the calibrated cup, standardize the colorimeter and calibrate the red tile with the standard puree according to instructions in paragraph 2.2 of "Color Scoring Tomato Products Objectively" (Marsh, Buhlert and Leonard, July, 1980). (Stir the puree mixture just prior to filling the sample cup). Pour additional mixed standard puree into the cups to be checked, filling within 1/4" of the top. Record L, a\textsubscript{L}, b\textsubscript{L} or Y, X, Z values for each cup. If several cups are calibrated at the same time, it is important to check colorimeter standardization frequently with the red tile. L, a\textsubscript{L}, b\textsubscript{L} values for the various sample cups should agree within 0.1 unit (Y, X, Z values should agree to within 0.05 unit). Agtron readings should agree within 1 unit. Calculate USDA color scores from the resulting values to verify that scores agree within a range of 0.5 score points for the cups within each group.

Scribe a line around the outside of the approved cups corresponding to a sample fill depth of 1-3/16". Cups should be re-checked for uniformity at least every two years.
2.4.2. PROCEDURE FOR PRODUCTION OF TOMATO PUREE COLOR STANDARD

Introduction

Standard tomato puree was developed several years ago for use as a "hitching post" standard to bring about improved agreement between colorimeters. This puree has been produced in small batches (~2,000 six-ounce cans) every year or two at UC Davis as the demand dictates. Cans of the newly-produced puree are assigned color values for various colorimeters based on values assigned to previously-produced standard puree samples. The samples are then distributed to various tomato colorimeter users to standardize their instruments and calibration tiles or to check instrument standardization.

Color readings obtained on instruments standardized using this puree can be converted to USDA color scores using appropriate equations which were developed by correlating instrument readings with panelists' grades.

Commercially manufactured 26% tomato paste with .033 finish in #10 cans from a single production run was used as the feedstock for production of the standard puree. Attempts were made to obtain a feedstock paste for dilution which would produce a standard puree with a score near 47 and L, aL, bL readings as close as possible to the preceding standard puree color.

PROCEDURE

Dilution

Centrifuge a sample of the selected commercial paste and determine NTSS on the centrifugate. Based on the weight of standard puree desired, calculate the necessary weights of tomato paste (Wp) and water (Ww) using the following formulas:

\[
W_p = \frac{8.5W}{B}
\]

where \( W \) is desired weight of diluted puree

\( B \) is initial NTSS (0 Brix) of paste used

\[
W_w = W - W_p
\]

Add water and mix thoroughly, using a commercial mixer. Gradual addition of water minimizes paste lumps during dilution. After mixing is complete, centrifuge a sample of the puree for NTSS determination. The diluted sample should be between 8.4 and 8.60 B. If the NTSS exceeds 8.6, add water according to the formula:

\[
\text{Water needed} = P \left( B_p - 8.5 \right)/8.5
\]

where

\( P \) is the weight of diluted puree

\( B_p \) is the NTSS of the diluted puree

Mix well, resample, centrifuge and check the NTSS reading. If the value is still too high, repeat the process.
If the NTSS of the diluted sample is less than 8.4, re-mix, checking for paste lumps in the bottom of the container. Centrifuge and evaluate another sample. If the NTSS is still low, add paste according to the formula:

\[ \text{Paste needed} = \frac{P(8.5 - 0B)}{\frac{WB \cdot P}{W_p}} - 8.5 \]

To facilitate mixing, weigh the paste to be added into a separate container, and then add a small amount of the thin puree. After thorough mixing, add more puree and mix. Continue adding puree and mixing until the mixture becomes pourable. Add this thicker puree to the remainder of the batch and mix well. Recheck the NTSS. When a suitable NTSS is reached, the puree is ready for canning.

**Processing**

Puree produced at U.C. Davis was canned using a hot fill-hold-cool procedure. The puree was heated to 195-205°F using a single pass through a Cherry-Burrell heat exchanger. Flow was balanced (no recirculation or bypass) with a feed pump, and the hot puree was fed into a filler. The puree was filled into 202 X 308 tomato enamel cans and sealed. Cans were inverted and held 3 minutes then cooled in ice water.

After cooling, cans were check weighed and those weighing less than 195g were discarded. Cans were stored at 40°F to minimize color changes.

**Assigning Color Scores to the Puree**

Open ten cans of the previous standard puree, mix together and allow mixture to sit 30 minutes. Open ten cans of the new standard puree and allow them to stand 30 minutes. Assign color scores to the new puree as follows:

**Gardner and Hunter Colorimeters** - Standardize the colorimeter using the old standard to assign values to the red tile, then record color readings for the individual cans of new standard, checking instrument standardization frequently. Determine mean and standard deviation for L, a, b or Y, X, Z and USDA score (from USDA tomato paste and puree equation). Standard deviations should be less than ± 0.05 for Y, X and Z, less than ± 0.10 for L and b and less than ± 0.15 for a and USDA score.

**Agtron Colorimeters** - Standardize the colorimeters using the internal calibration (red disk at 4B) for the Agtron E5M and the red and black disks for Agtron M400 and M500. Verify that the instrument reads the correct values (those on the can labels) for the previous puree standard batch. Record color readings for the ten individual cans of puree standard, checking instrument standardization frequently.

Determine means and standard deviations for the E5M reading, R, G, B values, and corresponding USDA scores (from USDA tomato paste and puree equation). Standard deviations should be less than 1 unit for R, G, B values and less than 0.15 score points for USDA scores calculated for the E5M, M400 or M500.

If standard deviation requirements are met, label cans with mean values. Store at 40°F to minimize color change with time (do not freeze).
Color Scoring Tomato Products Objectively

2. Methods

2.1. Sample Preparation

2.1.1 Paste and Puree. Samples for color measurement must be diluted from their original natural tomato soluble solids (NTSS) level to 8.5 ± 0.1 % NTSS using distilled water which has been de-aerated just prior to use.

Water is to be de-aerated as follows: Fill a 2 liter vacuum flask half-full with distilled water. Close opening with rubber stopper, then connect side arm using heavy wall tubing to a pump or water aspirator which will maintain a vacuum of 28 inches mercury. If water aspirator is used, turn on water before connecting flask to aspirator. Shake flask vigorously when clouds of small carbonation-type bubbles begin to appear. Maintain vacuum on flask and continue to shake until these small bubbles no longer form. Do not prepare water more than three hours in advance or transfer to another container before use. When adding water to the samples during dilution, care should be taken to avoid incorporation of air bubbles into the product.

Ordinary distilled water which has not been de-aerated may be substituted if diluted tomato product samples are mixed continuously by magnetic stirrer for 30 minutes. Stirrer must be operated so that no vortex forms to draw air into sample. Beaker containing sample must be examined from time to time to ensure that no lumps of tomato paste adhere to bottom or walls.

The procedure in Table I, "Tomato Product Dilution to 8.5 % NTSS", provides a convenient system for dilution of product.
TABLE 1. TOMATO PRODUCT DILUTION TO 8.5% NTSS

Weigh tomato product into 400 ml beaker according to the following table:

Nominal NTSS: 40 38 36 34 32 31 30 29 26 25 24 13 12 11
Product, grams: 75 79 83 88 93 96 99 103 115 119 124 230 249 271

Add de-aerated water* to reach a net weight of 310 grams. Problems with paste lumps are minimized if the water is added in small amounts and stirred in after each addition. Stir thoroughly with spoon or spatula, taking care not to mix in air. Check to be certain that there are no paste lumps on sides or bottom of beaker, then withdraw exactly 10 c.c. (using syringe), centrifuge and determine the refractive index or sugar scale of the clear serum.

If the sugar scale value is above 8.5, adjust to 8.5% by adding to the remaining 300 grams of mixture the amount of water corresponding to the R.I. or sugar scale reading obtained:

<table>
<thead>
<tr>
<th>R.I. (20°C)</th>
<th>Sugar Scale</th>
<th>Add Water</th>
<th>R.I. (20°C)</th>
<th>Sugar Scale</th>
<th>Add Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.3455</td>
<td>8.5</td>
<td>None</td>
<td>1.3467</td>
<td>9.3</td>
<td>28</td>
</tr>
<tr>
<td>57</td>
<td>8.6</td>
<td>4</td>
<td>69</td>
<td>9.4</td>
<td>32</td>
</tr>
<tr>
<td>58</td>
<td>8.7</td>
<td>7</td>
<td>70</td>
<td>9.5</td>
<td>35</td>
</tr>
<tr>
<td>60</td>
<td>8.8</td>
<td>11</td>
<td>72</td>
<td>9.6</td>
<td>39</td>
</tr>
<tr>
<td>61</td>
<td>8.9</td>
<td>14</td>
<td>73</td>
<td>9.7</td>
<td>42</td>
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<td>63</td>
<td>9.0</td>
<td>18</td>
<td>75</td>
<td>9.8</td>
<td>46</td>
</tr>
<tr>
<td>64</td>
<td>9.1</td>
<td>21</td>
<td>76</td>
<td>9.9</td>
<td>49</td>
</tr>
<tr>
<td>66</td>
<td>9.2</td>
<td>24</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mix thoroughly and re-check R.I. or sugar scale. This should be 1.3454 to 1.3457 or 8.4 to 8.6°B. If not, mix further and re-check. If reading is still too high, weigh out 300 grams of mixture, add water as above and re-mix.

If the sugar scale value is below 8.4, check beaker for lumps of paste. If lumps are present, stir then centrifuge a second sample. If no lumps are present, add tomato paste to 300 grams of mixture in the amount expressed by the following equation:

\[
\text{grams paste} = \frac{300 \times (8.5 - \text{sugar scale of mix})}{310 \times \text{sugar scale of mix}} - 8.5
\]

Mix thoroughly, taking care to blend in all lumps of undiluted paste. Withdraw a 10 c.c. sample, centrifuge, and determine R.I. or sugar scale of serum.

*Water must be freshly de-aerated (within 3 hrs of use) by placing in a stoppered vacuum flask, evacuating to 28 inches Hg, and shaking vigorously until small carbonation-type bubbles no longer form. Water which has not been de-aerated may be substituted if samples are mixed continuously by magnetic stirrer for 30 minutes. Stirrer must be operated so that no vortex forms to draw air into sample. Beaker containing sample must be checked from time to time to ensure that no lumps of paste adhere to bottom or walls.
2.1.2. Juice. Color of tomato juice is measured as it comes from the can. No dilution is necessary. Juice has a much greater tendency to separate than the concentrated product, therefore it must be stirred just prior to measurement. The time interval during measurement must be no longer than five minutes to limit the effect of settling. Stirring should be very thorough but not so vigorous as to form air bubbles in the product.

Mix tomato juice in the can before opening by gently rotating the can end over end. Open the can, empty it into a plastic or glass container, stir with a spoon, taking care to avoid incorporation of air bubbles, then transfer into the appropriate colorimeter sample cup for measurement. The cup must be filled exactly to the fill marking line, otherwise erroneous readings may occur in juice samples which lack solids or pigment.

2.1.3. Tomato Sauce. Color of tomato sauce is measured as the product comes from the can. No dilution is necessary; however, the sample should be stirred prior to measurement. During stirring, care should be taken to avoid incorporation of air bubbles into the product. Transfer sample to the appropriate colorimeter sample cup for measurement.

2.1.4. Tomato Catsup. Color of tomato catsup is measured as the product comes from the container. No dilution is necessary. (Initial studies included evaluation of samples diluted to 20°B but that procedure did not provide improved results and has been abandoned.) If the sample is in a bottle, the entire contents of the bottle must be emptied into a beaker so the sample can be thoroughly mixed prior to sampling or color measuring. During stirring, care should be taken to avoid incorporation of air bubbles into the product.
2.2 Colorimeters - Operation, Standardization and Color Score Calculation

2.2.1. Hunter Colorimeters

2.2.1.1 Instrument - Use Hunterlab D25-D2 series with type A optical head containing small elliptical baffles between aperture and mirrors. Openings in baffles measure 1-1/16" x 1-1/2". Aperture is 2" dia open type with scribed line for positioning sample cup. No windows or glass plates are to be used at the aperture. An opaque black cover for the sample cup must be provided to prevent room light from entering the system through the sample. A #303 can painted flat black on the inside works well for this purpose.

2.2.1.2 Cleaning Standard Tiles. Keep all tiles clean. Do not touch reflecting surfaces or allow them to contact any hard objects. Every tile should be cleaned routinely at four week intervals and at any other time that it appears to have foreign material on the reflecting surface.

Clean the tile surface in mild detergent solution (Sparkleen, Fisher Cat. No. 4320, or Haemo-sol, 1 Tablespoon per gallon of water), brushing gently with a soft nylon-bristled paint brush. Do not use soap as it leaves a film. Do not submerge the tiles, as this will damage the label. Rinse thoroughly in flowing hot water and blot dry with tissue or a soft towel. Do not rub the reflecting surface since some tissues or towels may be sufficiently abrasive to scratch the tile. Do not use Hunter GTC 59 glass treatment compound; this material leaves a film which affects the instrument readings.

2.2.1.3. Selection and Use of Sample Cups. Sample cups manufactured by Gardner Laboratory and Magnuson Engineers have been approved for this work. However, calibration of the red tile by means of the standard puree and sample measurement must always be done in the same brand of sample cup. Don't mix cups from different manufacturers. All sample cups must be pre-selected for this study. Participating field stations and industry laboratories should calibrate sample cups according to 2.4.1. or submit their sample cups to the UCD Food Processing Laboratory (see 2.3.1 for address) for checking prior to the start of the season. Do not mix sample cups of different calibration values as they may introduce significant error.

Clean cups with mild detergent, rinse thoroughly and blot dry with soft tissue. Do not rub with coarse toweling or paper towels; these materials will scratch the optical glass windows. Do not place cups on any hard objects, as traces of dirt or grit will scratch the windows. Fill the cup with tomato product to the line scribed at the time of selection. Examine each cup from time to time to confirm the absence of scratches or water spots. Cups with blemished windows should be destroyed. Cups should be recalibrated according to 2.4.1. or be returned to UCD for re-checking at 2-year intervals.
2.2.1.8. Color Score Point Conversions - Hunter Colorimeter

2.2.1.8.1. Tomato Paste and Puree. The following equation is used for calculation of paste and puree color score:
Score = -46.383 + 1.0211(a_L) + 10.607(b_L) - 0.42198(b_L)^2

2.2.1.8.2. Tomato Juice. The following equation is used for calculation of tomato juice color score:
Score = 29.600 + 0.88354(a_L) - 1.8553(b_L)

2.2.1.8.3. Tomato Sauce. The following tentative equation is used for calculation of tomato sauce color score:
Score = -154.39 + 1.1142(a_L) + 22.596(b_L) - 0.86736(b_L)^2

2.2.1.8.4. Tomato Catsup. The following tentative equation is used for calculation of tomato catsup color score:
Score = -74.937 + 7.5172(a_L) - 0.1278(a_L)^2 - 0.8051(b_L)
2.2.1.4. Calibration of Instrument - Hunter Colorimeter

2.2.1.4.1. Checks to be made twice daily

2.2.1.4.1.1. After 15 minute warmup lamp voltage (S button) must indicate value printed on sticker on optical head. Adjust by screwdriver through hole at right of buttons.

2.2.1.4.1.2. Place white tile over aperture and adjust Y, X and Z scales to values on white tile turning respective knobs, then place black glass tile on instrument. Use screwdriver to adjust Y, X, and Z scales to +0.0, (small holes beside each knob), approaching 0.0 from the minus direction.

2.2.1.4.2. Monthly checks. Place white tile over aperture and adjust L, aL, and bL scales to values on tile. Take L, aL and bL readings on pastel pink, blue, green, yellow and gray standard tiles. Readings for each tile should agree within ±0.3 of factory values reported in Hunter lab manual. If readings exceed tolerance obtain qualified service assistance to make necessary internal adjustments to instrument (see 2.3.2.2.). Maintain a permanent record of all calibrations.

2.2.1.5. Calibration of Red Tile. Re-calibrate the red tile normally used to standardize the Hunter colorimeter at weekly intervals using tomato puree color standard. Re-calibration must also be done after any change in instrument optics, i.e. re-lamping, mirror adjustments or cleaning. On request, UCD will supply several 6 oz cans of the standard (see 2.3.1. for address). Assigned L, aL, and bL values are printed on the label. This material was sterilized to prevent spoilage but must be refrigerated (35-40°F) to minimize minor color changes (do not freeze).

Adjust standard puree to room temperature. Open can, stir gently to re-distribute solids, and allow it to stand for 20 min. No dilution is necessary as this material was adjusted to 8.5% NTSS before canning.

Stir sample, fill sample cup to scribed line with standard puree, place cup on colorimeter and cover. Adjust controls so instrument displays L, aL and bL values on can label. Adjust L before adjusting aL and bL, since they are influenced by L setting. Place red tile on instrument and read L, aL, bL values. Assign these new values to tile, replacing factory calibration. Use red tile with these newly established values for routine instrument standardization. For convenience, record these new tile values with calibration date on an adhesive label on the colorimeter case or on the back of the tile. Re-calibrate tile at weekly intervals by the preceding procedure. This calibration system must be used to compensate for lamp age differences in optical alignment and filters, dust in optics, etc.

Keep a permanent record of weekly tile calibrations. If L, aL, or bL values change more than 0.2 units, re-check tile calibration with second standard can.

2.2.1.6. Standardization. Standardize using red tile with new calibration values. Standardize before reading each set of samples. During measurements time interval between standardizations must not exceed four minutes.

2.2.1.7. Sample Measurement. Fill product to sample cup fill line. Check window for adhering air bubbles; remove bubbles carefully so as not to scratch inner surface of window. Place cup over colorimeter aperture within scribed line, cover with opaque light shield, and record L, aL, and bL readings.