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GENERAL PURPOSE TRISTIMULUS COLORIMETERS FOR COLOR GRADING ORANGE JUICE

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Abstract. **Four general purpose tristimulus colorimeters were tested in comparison with the industry accepted standard HunterLab Citrus Colorimeter to determine their suitability for color grading orange juice. The instruments, when possible, were adapted to accept the presently used standard 1-inch diameter tubes for sample presentation to minimize variation due to geometry. The colorimeters were calibrated as recommended to a standard ceramic white tile and when feasible, to the OJ4 plastic standard tube, commonly used by the citrus industry. Multiple regression equations were generated for each instrument/calibration combination with the values obtained with the citrus colorimeter used as the dependent variable. Correlation coefficients (R) above 0.98 were obtained with all instruments calibrated to the OJ4 standard, indicating that all are adaptable for the accurate estimation of orange juice color numbers.**

The measurement of color plays an important part in the sensory evaluation of orange juice. The present USDA Standards (11) allot 40% of the total grade points to color. Initially, color of orange juice was evaluated by visual comparisons to plastic color standards. This subjective color grading system was superceded by the current method, utilizing the citrus colorimeter, required for color determination in Florida (10) and the only instrument accepted by the USDA Inspection Service (11). This instrument was the result of extensive studies by Huggart, Wenzel and coworkers (3, 4, 5, 6, 13), as well as Hunter (7, 8). The present HunterLab Model D45D2 performs in accordance with the 1931 CIE specifications, with data output provided as X, Y and Z tristimulus values, as well as the citrus industry-wide accepted CR, CY and CN scales (6, 7).

Dramatic improvements in electronics resulted in considerable advances in color measuring instrumentation since the development of the citrus colorimeter. Availability of inexpensive computers also added to ease of data manipulation. In view of these developments, the Florida Citrus Processors Association and the Research Council of the Florida Department of Citrus recommended a study of the applicability of state-of-the-art colorimeters for measurement of orange juice color (1).

Previous experiments established that various types of color measuring instruments could be used for the measurement of orange juice color (1, 2, 12). This work shows results of trials with four tristimulus reflectance colorimeters.

Materials and Methods

The HunterLab Model D45D2 Citrus Colorimeter, presently the only instrument accepted by the USDA Inspection Service and the State of Florida, Department of Citrus, for measurement of orange juice color, was used to determine reference values. This instrument conforms to CIE 1931 specifications, employs illuminant C, 4 broadband filters corresponding to tristimulus response functions, with 0/45 degree observer-illuminant arrangement to examine orange juice presented in 1-inch diameter selected and matched glass test tubes. Color value readings can be obtained in terms of CIE X, Y and Z or CR, CY and CN.

With the introduction of modern digital electronics, a new generation of tristimulus reflectance type color instruments have emerged. Four of these, employing similar geometry to the citrus colorimeter, were selected for testing. Each of these either provides results in terms of X, Y and Z, or chromaticity coordinates x and y, with the Y tristimulus value. An adapter was constructed to enable use of the 1-inch test tube normally employed with the citrus colorimeter to maintain uniform sample presentation throughout the experiments. The following instruments, each employing 0/45° observer-illuminant arrangement, similar to the citrus colorimeter, were examined:

1) HunterLab LabScan (Hunter Associates Laboratory, Inc., Reston, Virginia), a scanning reflectance spectrocolorimeter. This instrument was adapted for the 1-inch tubes by use of the standard test tube adapter used with the citrus colorimeter.

2) Minolta Chroma Meter II (Minolta Camera Company, Ltd., Osaka, Japan), a general purpose handheld tristimulus color analyzer, with a pulsed xenon arc source, providing results in terms of Y and chromaticity coordinates x and y. These values were converted to tristimulus values rearranged from the relations:

$$x = X/(X+Y+Z) \text{ and } y = Y/(X+Y+Z)$$

An adapter was constructed from a 1-inch inside diameter steel tube to accommodate the glass tubes, with a ½-inch opening drilled into it to permit the color head tip to come in direct contact with the test tube. The adapter and the color head were aligned, immobilized and placed into a box. The entire assembly was painted internally with a flat black paint.

3) Colorgard Model XL-1000/25 (Pacific Scientific Company, Gardner/Neotec Instrument Division, Silver Spring, Maryland), is also a general purpose colorimeter with a remote color head. It is equipped with an Epson computer. It was adapted in the same manner as the Minolta Chroma Meter II, however the opening in the steel tube was 0.65 inch.

[1]South Atlantic Area, U. S. Department of Agriculture, Agricultural Research Service. Mention of a trademark or proprietary product is for identification only and does not imply an endorsement or warranty of the product by the U. S. Department of Agriculture over other products which may also be suitable.

4) Macbeth Model 1500 Color-Eye (Kollmorgen Corporation, Newburgh, New York), a spectrocolorimeter with a pulsed xenon light source. Due to the short time available for testing, it was calibrated to a white tile only, with a 0.4 inch deep flat glass cell as the sample holder.

All instruments tested are equipped with some form of computer interface connection, but in our study this feature was not used.

Color values of selected orange juice samples (12 reconstituted from commercial frozen orange concentrate and 9 experimental pasteurized, single-strength juices prepared from Hamlin, Pineapple and Valencia oranges) were determined with each instrument and the citrus colorimeter, utilizing the same 1-inch diameter glass test tube or the 0.4 inch flat glass cell as indicated in Tables 2-7.

The data were analyzed with the Advanced Statistical Analysis system (9), adapted to work on a Digital Equipment Rainbow 100 computer.

All instruments were calibrated to a standard white ceramic tile according to the manufacturer's instructions. In addition, each instrument, with the exception of the Macbeth Color-Eye, was also calibrated to the OJ4 plastic standard to more closely match sample presentation conditions existing with the citrus colorimeter.

Results and Discussion

All tristimulus values obtained from these instruments were converted to CR, CY and CN values according to the relationships developed by Hunter (7). The equations are shown in Table 1. The values calculated with these equations apply to measurements obtained with the citrus colorimeter, calibrated to a USDA OJ4 standard. However, the same equations were applied to data acquired with all instruments tested. To distinguish measurements obtained with the citrus colorimeter, calibrated to the OJ4 standard tube and used as the reference values, from those calculated with data from the instruments under test, these values were designated as CR(CC), CY(CC) and CN(CC) in the tables.

Table 1. Color scale conversions.

$$CR = 200[(1.277X - .213Z)/Y - 1]$$
$$CY = 100(1 - .847Z/Y)$$
$$CN = 22.51 + .165CR + .111CY$$

As all instruments were calibrated to a flat white tile, the citrus colorimeter was also examined with such a calibration to test possible effects of differing geometry of the flat tile surface from the curved surface of the OJ4 standard color tube and the glass sample tubes normally used. Table 2 shows the regression equations, correlation coefficients (R) and the standard error of the estimate (S.E.). The results indicate excellent correlation between the flat white tile and the 1-inch diameter OJ4 tube calibration, although there was a slight shift in the regression coefficients, probably due to geometric differences.

Each instrument differed in the area of the sample surface illuminated. In addition, there was considerable variation in the intensities of the light sources employed. These factors, as well as light losses caused by scattering due to the curved surface of the test tube used for sample presentation whenever it was employed, resulted in data sets different for each instrument, although expressed in terms of the same color scales. Quantitatively, however, all data sets correlated well with the master set obtained with the citrus colorimeter. Some improvement was gained by calibration to the OJ4 standard, shown in reduced standard errors.

Table 2. Regression equations for HunterLab Citrus Colorimeter—White tile calibration—1-inch tube.

Equation	R	S.E.
CR(CC) = 0.975CR + 9.148	0.999	0.185
CY(CC) = 0.913CY + 8.924	0.999	0.238
CN(CC) = 0.156CR + 0.104CY + 24.97	0.999	0.052

Table 3 shows regression data obtained with the HunterLab LabScan system. The modification of this unit involved attachment of the sample holder of the citrus colorimeter to the top of the instrument, and tilting the color head to permit the sample tube to be vertical.

Table 3. Regression equations for HunterLab LabScan—1-inch tube.

Equation	R	S.E.
White tile calibration		
CR(CC) = 1.003CR + 9.458	0.977	1.354
CY(CC) = 0.952CY + 13.267	0.988	0.999
CN(CC) = 0.243CR + 0.031CY + 28.91	0.985	0.306
OJ4 calibration		
CR(CC) = 1.103CR + 0.421	0.971	1.522
CY(CC) = 1.135CY − 10.695	0.988	0.995
CN(CC) = 0.282CR + 0.022CY + 26.69	0.981	0.344

The regression equations generated from the data acquired with the Minolta Chroma Meter II showed improvement in correlation coefficients and standard errors (Table 4) when calibration was performed with the OJ4 standard. This instrument, apparently due to a relatively small surface illuminated and sensed, showed the greatest change in response to calibration with a surface similar to the sample presentation.

Table 4. Regression equations for Minolta Chroma Meter II—1-inch tube.

Equation	R	S.E.
White tile calibration		
CR(CC) = 2.308CR + 25.537	0.966	1.737
CY(CC) = 0.861CY + 45.486	0.900	3.013
CN(CC) = 0.507CR + 0.061CY + 32.73	0.967	0.485
OJ4 calibration		
CR(CC) = 1.710CR − 19.336	0.970	1.554
CY(CC) = 1.959CY − 70.097	0.904	2.885
CN(CC) = 0.573CR − 0.116CY + 27.95	0.983	0.330

The Colorgard colorimeter (Table 5) produced data also well correlated with the citrus colorimeter. The steel tube adapter somewhat restricted the area illuminated and sensed. The difference between the two sets of correlation coefficients was the least of all the instruments evaluated.

Table 5. Regression equations for Pacific Scientific Colorgard—1-inch tube.

Equation	R	S.E.
White tile calibration		
CR(CC) = 1.180CR + 17.746	0.990	0.828
CY(CC) = 0.769CY + 26.713	0.996	0.581
CN(CC) = 0.253CR + 0.050CY + 29.82	0.994	0.188
OJ4 calibration		
CR(CC) = 1.113CR − 0.066	0.990	0.821
CY(CC) = 1.062CY − 2.684	0.997	0.475
CN(CC) = 0.212CR + 0.092CY + 23.25	0.994	0.192

However, the regression coefficients and constants for the lines indicated that the use of similar geometry in standardization was an advantage.

An alternate sample presentation, employing a 0.4 inch pathlength, optically flat, glass cuvette was also examined with the Macbeth Color-Eye and Minolta Chroma Meter II, in addition to the 1-inch test tubes. In conjunction with this mode of sample presentation, the effect of white and black background on the results was studied.

Tables 6 and 7 show results of correlations obtained when flat surfaced sample cells were used. In these instances standardization was restricted to the white tile. All measurements were made with the juices placed at the sensing aperture, in a 0.4 inch deep glass cuvette. Since at this juice depth the surface behind the cell was visible to the sensors, the effect of brightness of the background material had some influence on the results. A flat black painted surface and a white calibration tile was used to examine their effects on measured reflectance. Table 7 shows results of these experiments. The Color-Eye (Table 6) was not tested with other methods of sample presentation.

Table 6. Regression equations for Macbeth Color-Eye—White tile calibration—0.4-inch cell, black background.

Equation	R	S.E.
CR(CC) = 1.030CR + 11.839	0.981	1.241
CY(CC) = 0.913CY + 24.008	0.958	1.929
CN(CC) = 0.321CR − 0.028CY + 31.84	0.990	0.260

These results indicate all of the instruments tested are suitable for the color evaluation of orange juice. While individual results obtained with each of these colorimeters differ from those with the citrus colorimeter, it is relatively simple, with computers, to calculate regression equations to enable the operator to convert results obtained with any of these instruments to those comparable with the citrus colorimeter. The newer instruments offer more modern electronics, greater flexibility and programming capability. Although the results indicate the possibility of immediate use, more extensive testing is necessary to establish highly reliable regression equations for the expression of color parameters. Such a program is planned for the approaching citrus processing season.

Table 7. Regression equations for Minolta Chroma Meter II—White tile calibration—0.4-inch cell.

Equation	R	S.E.
White background		
CR(CC) = 1.780CR + 15.110	0.974	1.526
CY(CC) = 1.063CY + 27.437	0.982	1.320
CN(CC) = 0.262CR + 0.150CY + 26.90	0.996	0.176
Black background		
CR(CC) = 1.947CR + 25.975	0.982	1.272
CY(CC) = 0.798CY + 43.940	0.946	2.242
CN(CC) = 0.538CR + 0.001CY + 34.63	0.987	0.306

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