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A GENERAL PURPOSE TRISTIMULUS COLORIMETER FOR THE MEASUREMENT OF ORANGE JUICE COLOR

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Abstract. **The Minolta Chroma Meter II/CR-100 portable, hand-held colorimeter was adapted to enable it to accept 1-inch diameter test tubes and was tested in comparison with the industry standard HunterLab Citrus Colorimeter. The results were statistically analyzed. Regression equations were developed for the expression of color numbers. This instrument, employing the prescribed adapter and equations, was accepted by U. S. and Florida regulatory agencies as one alternative to the Citrus Colorimeter.**

As an indication of the importance of color in sensory evaluation of orange juice, the present USDA standards (14) allow up to 40% of the total grade points to represent color. During early history of quality grading, the color of orange juice was evaluated by visual comparisons to plastic color standards. This subjective color grading system was superseded by an instrumental method, utilizing the HunterLab Citrus Colorimeter (CC). For a long time the HunterLab Model D45 and the Model D45D2, its successor, were the only instruments accepted by the USDA Inspection Service for color grading (14) and required for color determination in Florida (13). The development of the CC was the result of extensive studies by Huggart, Wenzel and coworkers (4, 5, 6, 7, 16), as well as Hunter (8, 9). The HunterLab Model D45D2, the current model, provides readings in the citrus industry specific CR, CY and CN scales and as X, Y and Z tristimulus values, in accordance with the 1931 Commission Internationale de l'Eclairage (CIE) specifications.

The recent advances in electronics and computer technology brought new improvements in color measuring instrumentation. Availability of miniaturized, sensitive detectors resulted in portability and inexpensive computers eased data manipulation. As a result, the CC, however important historically for the measurement of orange juice color, became obsolete and was only produced by special group order arrangement. In view of these developments, the Florida Citrus Processors Association and the Research Council of the Florida Department of Citrus requested a study of the applicability of state-of-the-art colorimeters for measurement of orange juice color.

In response to this request, as evidenced by earlier publications, we established that several of the newer color measuring instruments were suitable for orange juice color measurement (1, 2, 3, 15). This work shows the results obtained with the Minolta Chroma Meter II/CR-100 (CM) portable colorimeter.

Materials and Methods

The HunterLab Model D45D2 CC was used as the experimental reference device. This instrument, evolved from a HunterLab color difference meter (4, 5, 16), employs illuminant C, four broad-band filters corresponding to tristimulus response functions, with 45° source and 0° observer position to examine orange juice presented in 1-inch diameter selected and matched glass test tubes. Color value readings can be obtained in terms of CR, CY and CN or CIE X, Y and Z. The appropriate relationships are shown in Table 1.

The Minolta CM II/CR-100 (Minolta Camera Company, Ltd., Osaka, Japan) is a general purpose hand-held tristimulus color reflectance analyzer (12). This instrument uses a pulsed xenon arc source, produces diffuse illumination, has 0° observer position and 8 mm diameter measuring area. We used illuminant C setting throughout the experiments. Gloss is not totally excluded from the measurements with this instrument, therefore surface variations in the test tubes may interfere with readings.

An adapter was constructed from a nominally 1-inch I.D. steel tube to accommodate the glass tubes, with a 12.5-mm opening drilled into it to permit the color head tip to come in direct contact with the test tube. The adapter was lined with thin black felt. The color head was aligned perpendicularly to the test tube and was immobilized.

The CMs were employed in two configurations:

(a) The basic instrument, consisting of a color head, meter electronics and tube adapter, completely manual operation. Three consecutive readings were averaged with each sample.

(b) The basic instrument attached to a microprocessor (Minolta DP-100) with a ribbon cable, set to average three readings taken at 10sec intervals.

Both Minolta systems are operated by rechargeable batteries. During our measurements the accompanying power supply/charger was used as the power source with all units requiring power. The results were expressed in terms of Y (luminance) and the chromaticity coordinates, x and y. These values are related to tristimulus values through the relationships shown in Table 2. The instruments were calibrated to the OJ4 plastic standard used with the reference CC. Values for x and y were calculated from the equations above. Calibration with the OJ4 tube was performed

Table 1. Citrus Colorimeter scales.

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

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

Table 2. Chromaticity scale conversion.

CIE XYZ to chromaticity
$x = X/(X + Y + Z) \quad y = Y/(X + Y + Z)$
Chromaticity to XZ
$X = Y(x/y) \quad Z = Y(1/y - x/y - 1)$

after each group of 24 readings. A total of 419 juice samples were measured with the CC and each of two CMs, utilizing the same 1-inch diameter glass test tube to remove variation due to glass imperfections, resulting in 838 paired data points.

The data analysis and calculations were performed with the MINITAB Statistical Analysis System (11) on a DEC VAX. minicomputer or the MSTAT: Microcomputer Statistical Program (10) on a DEC Rainbow 100 microcomputer.

Results and Discussion

With the dramatic improvements in modern digital electronics, a new generation of reflectance type tristimulus color instruments have emerged. The Minolta CM II, later renamed the CR-100, was originally designed to measure color characteristics of coated and painted surfaces, printing ink density, textiles, soil, fruits, grains, ceramic and glass products, skin and tissues. In contrast with the CC, the CM readings are displayed in either Yxy or L*a*b* color space. The Yxy system was selected, since conversion to the more familiar XYZ coordinates is easily accomplished (Table 2). As the CM does not provide direct CR and CY values, nor are the values calculated from its display easily converted into CR and CY, we decided to generate the expression to yield the color number (CN), either from the measured Y and calculated X and Z values, or from the Yxy values directly. The equations in Table 3 represent the results of the regressions performed from the data obtained. These equations, obtained with limited instrumentation in a single season, may need to be altered as additional data is gathered.

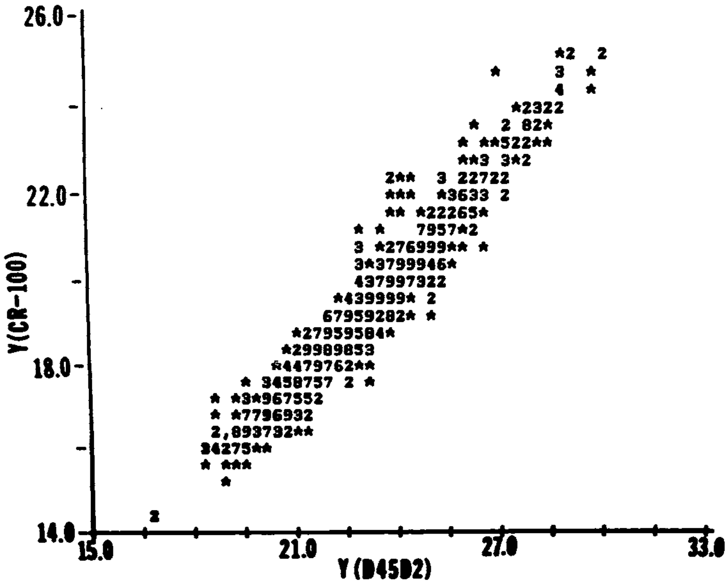

Fig. 1. Luminance (Y) values, CM *vs* CC. Numerals represent number of values at that point. Asterisks are either 1 or greater than 9 values.

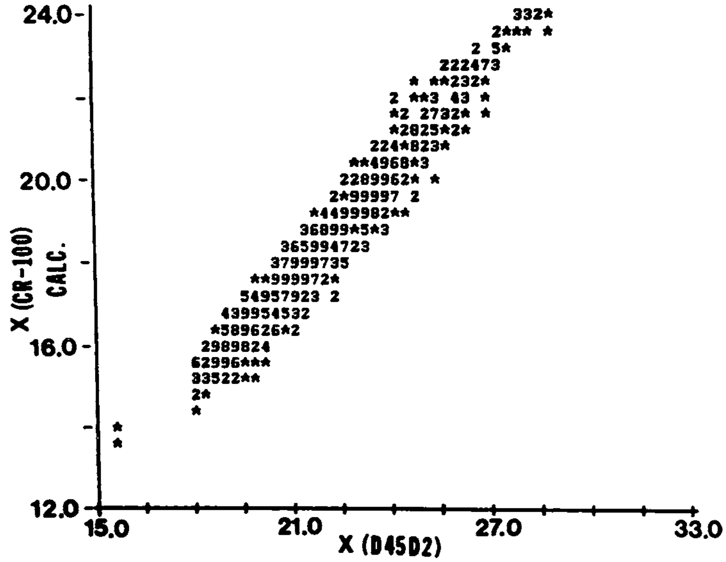

Fig. 2. X(CM-calculated *vs* X(CC-measured).

The luminance values (Y), measured with the CM, were correlated with the same parameter obtained with the CC. The resulting coefficient, r = .965, indicated a high level of correlation. Plotting these values (Fig. 1) indicated some random scatter which may be the result of geometric differences in the two measurement systems, with addition of the gloss component from the glass test tubes by the CM. The chromaticity coordinates, x and y, which were read from the CM, cannot be compared directly with the X, Y or Z values. However, conversion to the appropriate values can be easily accomplished by the equations shown in Table 2. Upon conversion of these to X and Z values, the correlation coefficients were calculated *versus* the analogous CC values. These were r = .970 for X and r = .950 for Z. Figs. 2 and 3 are the plots obtained with these parameters. Both the Y and the calculated X values from the measurements were consistently lower than the related values from the CC, although the CM was calibrated with the same OJ4 tube to give identical values. This implies that there are

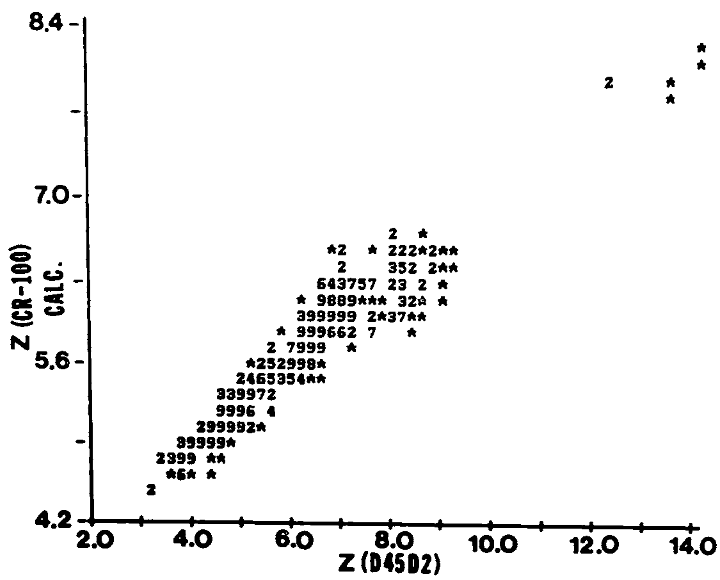

Fig. 3. Z(CM-calculated) *vs* Z(CC-measured).

Table 3. Regression equations.

CN = 1.07X − .61Y − 2.74Z + 43.85
R = .963 S.E. = .385
CN = 170.12x + 100.97y − .35Y − 73.98
R = .964 S.E. = .380

significant qualitative differences between juices and the plastic tubes used for calibration. Regardless of this observation, the correlation coefficients were sufficiently high to permit adequate estimation of these values based on one another. Similarly, the calculated Z values, compared to the values from the CC, were lower in the majority of instances. It was particularly notable that the great majority of these values covered a much narrower range than the related Z values from the CC. At this point we do not know the reason for this observation.

Multiple linear regression equations were calculated by using the CC color values (CN) as the dependent variable and CM Y, calculated X and Z values or the directly read Y, x and y values as independent variables. Table 3 shows the equations generated. Both of these equations are based on the same numerical values. The first equation requires calculation of X and Z values prior to calculating the CN value. The main advantage provided by this method lies in greater familiarity of the citrus industry personnel with the XYZ scales, as well as the similar magnitude of the numbers in this system. In contrast, the second equation uses the less familiar chromaticity values in addition to Y. However, the calculation is easier, since all values are read directly from the instrument. The results are shown in Fig. 4, plotting CN calculated according to the second equation from Y, x and y read from the CM, against CN read from the CC. The diagram indicates a slight deviation of the results obtained with the CM from the measurements with the CC, particularly noticeable at the extremes of the measured range. The correlation is sufficiently high to show that the CM adequately estimates color values in comparison with the CC.

In late 1985, following approval received from the U. S. Department of Agriculture Inspection Service to use some new colorimeters, the Florida Citrus Commission revised Chapter 20-65 of the Florida Citrus Fruit Laws (13), concerning the use of colorimeters for official color score determination. The Minolta CM II/CR100, along with two others were permitted in addition to the HunterLab CC.

Since the approval of these additional colorimeters, several CMs were purchased by various processors. The performance of some of these was examined by measuring the same 24 juices with each instrument, all calibrated with its own standard OJ4 tube. The juice color values ranged from about 32 to above 40. The results indicated good instrument to instrument reproducibility of the CMs and also confirmed the existencce of the previously observed deviation at the color extremes. Variation between parallel measurements greatly underscored the importance of careful adapter and accurate color head alignment and calibration.

The equations developed for the CM II/CR-100 colorimeter were based on the results of a single season, therefore some improvement can be expected when additional data can be collected. In addition, a newer version of this instrument, the CM CR-200 was recently intro-

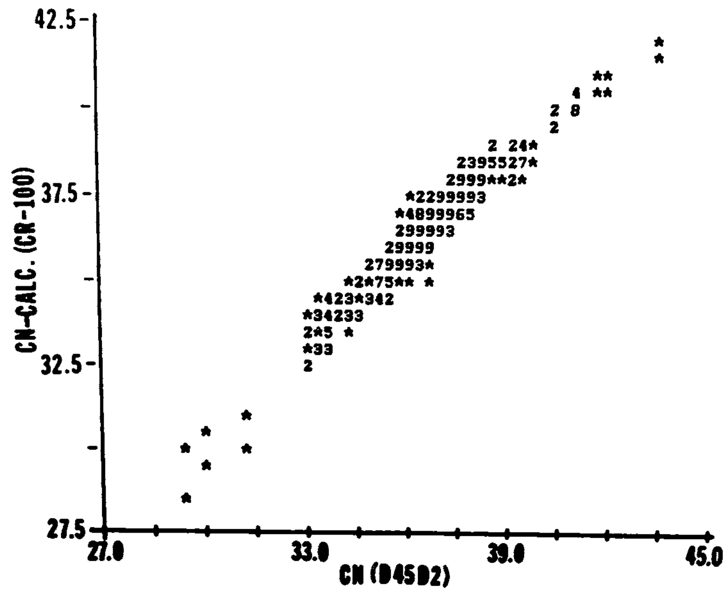

Fig. 4. CN(CM-calculated) *vs* CN(CC-measured).

duced. Preliminary data indicated that it performs as well as the CM II/CR-100 and is easier to operate. Currently we are examining the available data to reduce variation in the related parameters and to introduce possible improvements in the equations. Nevertheless, with careful calibration and instrument maintenance, the present equations will successfully estimate color values of orange juices from measurements with these instruments.

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