Chapter 10

Color Quality of Tomato Products

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The vibrant red color of tomatoes is due to the presence of the carotenoid, lycopene. Beta-carotene may also contribute to the color profile, particularly in the case of immature or orange pigmented tomatoes. Tomato color may be determined instrumentally using simple instruments employing filters or light-emitting devices or more complex tri-stimulus colorimeters and spectrophotometers. In California, processing tomato cultivars are evaluated using all of these instruments, and values may prove difficult to correlate. Raw color measurements may be used to predict the color of finished tomato products. The University of California – Davis has for years generated a "soft tomato standard" that is used to calibrate instruments and allows for incorporation of the parameter of translucency. We have attempted to use color measurements to estimate lycopene content and will discuss this and other color-related research.

Why Measure Tomato Color?

The color and appearance of products are the first quality attributes to stimulate us to purchase, consume and enjoy them. Tomatoes are known for their vibrant red color, which indicates not only maturity and therefore level of desired flavor, but also relative content of the beneficial antioxidant lycopene. Tomatoes that are deep red in color, as compared to those that are lighter red or pink, are usually more mature fruit with desirably sweet flavor and a high content of lycopene.

The USDA Processed Products Standards and Quality Certification program has developed color standards showing minimum color for grades "A" and "C" in tomato juice, puree, paste and catsup. Canned tomato color may be judged in accordance with grade "C" or better. Color is such an important quality attribute in tomato products that 30 points of the total 100 in the grade are specifically allocated to the color quality of the fruit.

In this chapter we discuss changes in the measurement of tomato color over time, instrumental measurements of tomato color, industry practices for determining tomato color in California, the chemical components responsible for tomato color and efforts to correlate color measurements to lycopene content in tomatoes.

Changes in Tomato Color Measurement over Time

Prior to 1972, the color acceptability of raw tomatoes for processing was determined visually, and state inspectors at receiving stations compared fruit of questionable minimum color to standardized U.S. Department of Agriculture color discs (*1*). The United States Department of Agriculture recently designed bi-color vinyl tiles to be used in place of the original color discs for visual determination of the minimum color allowed for different grades of products.

While sensory evaluation is the optimal means of determining color, individuals differ in their assessment of color, and for that reason sensory evaluation may be both time-consuming and challenging to quantify. In many cases instrumental measurements of color may be used to approximate sensory color determination. In 1972, the California tomato industry decided that a system of color determination was needed in which human judgment was at an absolute minimum. A research project carried out by the University of California and the California Department of Food and Agriculture developed a method for evaluating tomato color using an Agtron E-5M instrument.

Instrumental Measurements of Tomato Color

Instrumental tomato color measurements were originally made using a spinning disk in a light booth. Maxwell's spinning disk was one of the first devices used for a semi-quantitative determination of the color of various foods.

Evaluation of Color Measuring Instrumentation for USDA Processed Tomato Scores

In the late 1970's, the USDA and the University of California – Davis worked with the California tomato industry and instrument suppliers to correlate visual scoring of tomato product quality to instrumental color measurements. A report published in 1980 (*2*) established equations for correlation of color measured on Gardner, Agtron and Hunter (HunterLab, Reston, VA) instruments, as compared to the D25 A™ from HunterLab, which was housed at UC Davis. The D25 A™ was considered by the US Department of Agriculture to be the 'gold standard' or standard instrument for measuring tomato color. All other instruments were referenced to this one. A "C" illuminant was used with a 2° observer and directional 45/0 conditions. All samples were measured through the bottom of a glass sample cup in reflectance mode (Figure 3).

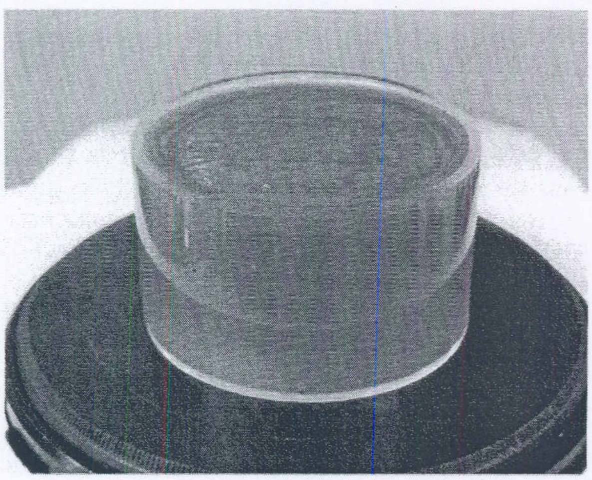

Figure 1. Tomato puree in a glass sample cup, placed on the port of a HunterLab LabScan X™ instrument. (Photo courtesy of Gordon Leggett, Hunter Lab.)
(See page 10 of color inserts.)

The following equations were generated for tomato paste and puree score (TPS), sauce (TSS), catsup (TCS) and juice (TJS) products using the HunterLab D25 A™:

Tomato Paste and Puree = TPS = $-46.383 + 1.0211(a) + 10.607(b) - 0.42198(b^2)$
Tomato Sauce = TSS = $-154.39 + 1.1142(a) + 22.596(b) - 0.86736(b^2)$
Tomato Catsup = TCS = $-74.937 + 7.5172(a) - 0.1278(a^2) - 0.8051(b)$
Tomato Juice = TJS = $29.6000 + 0.88354(a) - 1.8553(b)$

Since this study was published in 1980, most of the instruments used for measuring color have been replaced by models that are more sensitive, accurate and robust. In addition, the HunterLab D-25 A™ instrument originally used as the 'gold standard' for establishing tomato scores was replaced at the University of California – Davis by a Hunter Lab Scan 5100™. Therefore, the original study was repeated for Hunter Lab and BYK Gardner instruments and approved by the USDA in 2003 (*3*). Equations to correlate the Minolta CR-410 to the Hunter LabScan 5100 are currently being developed.

A two-part study was conducted to compare color measuring capabilities of five different color measuring devices (ColorFlex™, LabScan XE ™ and D25 A™ from HunterLab; and Color Guide and Color View from BYK Gardner) to the UC Davis Reference LabScan 5100™. The goals of Part I were (1) to establish sample cup variability, (2) to establish measurement variability for a single instrument and (3) to generate data to determine USDA Processed Tomato Scores using the different color measuring instruments and 30 different samples each of tomato juice, sauce/puree, catsup and paste diluted to 8.5° Brix.

Part II of the study was a more comprehensive evaluation based on Part I, using more samples and replicate instruments. The goals of Part II were (1) to establish measurement variability, (2) to generate data to validate tomato scores using ten different color measuring instruments and fifty different samples each of tomato juice, sauce/puree, catsup and paste diluted to 8.5° Brix and (3) to establish instrument variability. For this part of the study, two ColorFlex™, two LabScan XE™, two Color Guide and two Color View color measuring devices were used in addition to the D25™ and LabScan 5100™.

All color measuring instruments except the Color Guides and D25 A™, which were used independently of computer, were interfaced to IBM-compatible computers. These consisted of an optical sensor and used a directional orientation of 45°/0°, except for the D25 A™, which was not interfaced to a computer and uses a directional orientation of 0°/45. The illuminant used for the color study was CIE illuminant C. The standard observer was 1931 2° Standard Observer and the color scale was Hunter L, a, b (Hunter) or L*a*b* (BYK Gardner).

Equations for TPS, TSS, TCS and TJS were determined statistically to correlate the LabScan XE™, ColorFlex 4500L™, re-qualified D25A-9000™, Color View and Color Guide back to the USDA/UC – Davis Reference LabScan 5100 ™ (serial number 12379) in the measurement of Processed Tomato Scores. As an example, the new equations to be used for tomato paste scores by the various instruments are as follows:

UC Davis Reference LabScan 5100 $TPS = -46.383 + 1.0211(a) + 10.607(b) - 0.42198(b^2)$

HunterLab LabScan XE $TPS = -40.926 + 1.061(a) + 9.473(b) - 0.376(b^2)$

HunterLab ColorFlex $TPS = -81.582 + 1.069(a) + 15.390(b) - 0.591(b^2)$

Hunter D25A-9000 $= -58.296 + 1.093(a) + 12.120(b) - 0.480(b^2)$

BYK Color Guide $= -304.741 + 1.134(a) + 46.595(b) - 1.687(b^2)$

BYK Color View $= -2.63270 + 13.822(\log b) - 7.442(\log L) + 0.0234(a) - 1.002(b) + 0.295(L)$

Similar equations were generated and validated for tomato sauce, catsup and juice. Following completion of the study, data and statistical analysis was submitted to the USDA for review. The HunterLab LabScan XE™ and Color Flex™ were approved, and the D25A-9000 was accepted by USDA for use in the measurement of processed tomato paste, sauce, catsup and juice color. The BYK Color View was also approved for all of the tomato products, while the Color Guide was only approved for measurement of tomato juice and sauce.

California Processing Industry Practices

Processing tomatoes comprise the largest volume of vegetable harvested in the state, typically 10 to 11 million tons annually. Color is an important quality attribute and is therefore determined both in the raw fruit and in the processed product.

Raw tomato inspection

Raw tomato color is determined by the Processing Tomato Advisory Board (PTAB), a neutral third party inspection agency, on every load of tomatoes harvested. Growers receive a financial incentive for producing tomatoes that are of good character, color and flavor, and defect free. California is the only state in the U.S. that does not rely on U.S.D.A. inspectors to carry out grade inspection. Two fifty pound samples of tomatoes are randomly taken from each 25,000 pound truckload of tomatoes.

In the late 1970's, the Agtron E-5M instrument, which used green and red filters, was used to evaluate color on a homogenized sample. In 1996, PTAB started using an instrument that utilized light emitting devices or LEDs, developed by Dr. David Slaughter, Dept. of Biological and Agricultural Engineering at UC Davis. The LED instrument employs an array of green and red LEDs to illuminate tomato juice and the ratio of green to red reflected light is measured. Although this instrument is rugged and has functioned well in raw tomato color measurement for the industry for 10 years, processed product color is most often measured by Quality Control departments using L, a and b values and PTAB is considering moving to this scale. This would allow growers, processors and inspection agencies to use the same color scale for measurement of both the raw material and finished tomato product.

Finished tomato product color

The California tomato processing industry uses USDA 'approved' instruments (see discussion above) for measurement of processed tomato paste, sauce, catsup and juice color. Instruments are standardized against white and black tiles, and a green tile supplied by the factory is used as a further check, using illuminant D65, 10° observer and either the XYZ (Hunter) or CIELAB (BYK Gardner) scale. The illuminant used for the color study was CIE illuminant C. Color measurement is made using the 1931 2° Standard Observer and the color scale used is Hunter L, a, b (Hunter) or L*a*b* (BYK Gardner).

During the tomato processing season, sample bags or containers are pulled from the processing line at least hourly and read in duplicate. Processors have their own particular specifications which define whether color is out of the acceptable range or not. Color quality may be inadequate due to either poor raw material color or excessive thermal exposure. The raw fruit color may suffer if immature tomatoes are utilized, or if tomatoes have been sunburned. During the tomato paste process, there is opportunity for non-enzymatic browning to occur during the hot break or concentration steps. Likewise, tomato juice may have undergone browning reactions if it is exposed to high heat.

Use of the University of California - Davis Soft Tomato Standard

Reflectance color measurements, while useful, are not able to measure all of the properties of translucent samples such as tomato sauce, juice and paste. Light emitted by an instrument not only reflects back, but also penetrates into the product to a certain degree, bounces around and then is reflected back into the instrument. In order to standardize instruments for use with translucent samples, the University of California – Davis developed a 'soft tomato standard' to address the issue of translucency. These standards are produced on an annual basis under standard processing conditions. A sub-sample is evaluated using the 'gold standard' instrument. It is necessary to produce the standard each year because the color degrades with storage time in the can. Each year, the industry need for soft standard is determined, that amount of tomato sauce is canned and a statistically valid sub-set of the canned soft is measured using the 'gold standard' instrument. Cans of soft standard are labeled with the L, a and b values obtained with that instrument and distributed to the California tomato processing industry.

Tomato Industry Interest in Measuring Lycopene

Processing tomato industry interest in the measurement of lycopene, in addition to color, began in the early to mid 1990's. At that time scientific research indicated the benefits of lycopene consumption in preventing both cardiovascular disease and cancer. Tomatoes are the primary source of lycopene in the American diet, so the fresh and processing tomato industries took note.

During the period from 1999 to 2005, the California tomato processing industry funded research to begin determining lycopene content of new tomato varieties, to evaluate the range of lycopene content in these varieties grown in different counties throughout California (*4*), and to develop a standard rapid method for determining lycopene.

Chemical Components Responsible for Tomato Color

In mature red tomatoes, lycopene comprises ninety percent of the pigment responsible for the red color. Small amounts (<5%) of ß-carotene exist as well. Lycopene is a 40 carbon molecule with alternating single and double bonds (Figure 1). Structurally similar to lycopene, ß-carotene also contains 40 carbons, but has a 6 carbon ring structure at each end of the molecule, with a 28 carbon straight chain between them.

The concentration of lycopene in a solvent extract from tomatoes can be determined either spectrophotometrically or by high performance liquid chromatography (HPLC). Figure 2 illustrates the absorbance spectrum for *cis*- and *trans*-lycopene, as well as β-carotene, as adapted from Ishida et al., 2001 (*5*). Lycopene has three peaks of absorbance at 444, 471 and 503 nm. This third peak is at a wavelength where the absorbance of β-carotene (and other minor carotenoids) have relatively low absorbance and thus cause very little interference. Spectrophotometric measurements of absorbance at 503 nm are thus very good estimates of the lycopene content.

We have developed a standard method for lycopene determination in mature red processing tomatoes for the California processing tomato industry (*6,7*). This method, based on the solvent extraction procedure developed by Sadler et al. (*8*), involves adding a mixture of hexane:ethanol:acetone at 2:1:1 to an aliquot of homogenized tomato juice, mixing and waiting for 10 min to several hours, then adding water, mixing and letting the sample stand to separate the polar and non-polar phases. The carotenoids remain in the upper hexane layer, while the cellular debris is separated into the ethanol:water:acetone layer below.

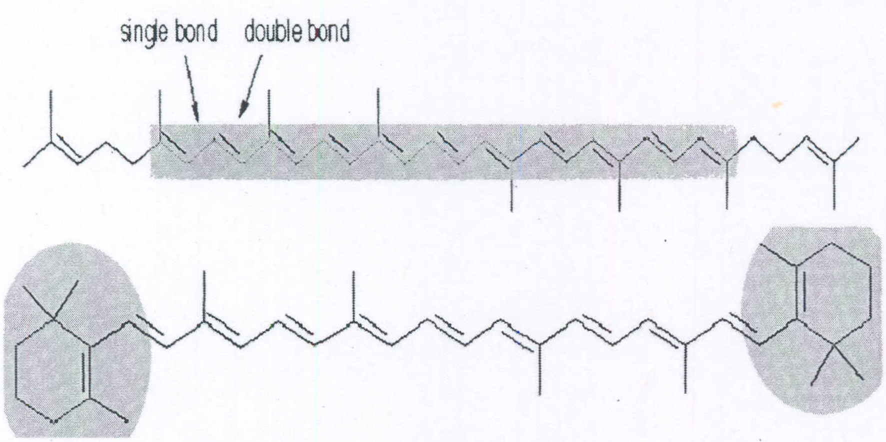

Figure 2. Chemical components responsible for tomato color. Lycopene (top) and β-carotene (bottom). (See page 11 of color inserts.)

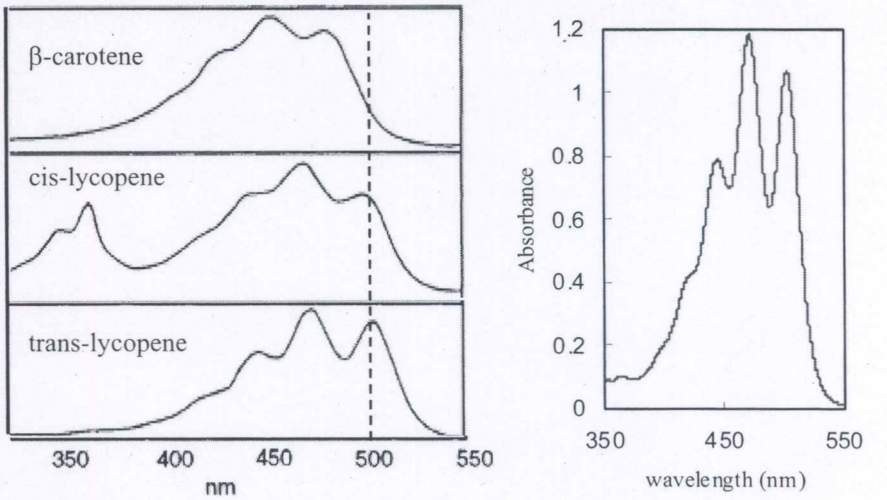

Figure 3. The absorbance spectra of β-carotene and cis- and trans- lycopene (left). The dashed line indicates 503 nm. The absorbance spectrum of a hexane extract of tomato (right). (See page 11 of color inserts.)

The hexane layer is removed and absorbance at 503 nm is read as a measurement of lycopene content.

Correlation of Color Measurements to Lycopene Content in Tomatoes

Determination of lycopene using a wet chemistry approach, e.g. by extraction and measurement using a spectrophotometer, is often not possible for tomato breeders, growers, processors and other parties. The spectrophotometric method standardized in our laboratory, while time-saving in comparison to HPLC procedures, still requires capital investment in an instrument, and a skilled analyst to carry out the measurement. For this reason, we have attempted for a number of years to develop a correlation between L, a and b values measured by a colorimeter and chemical measurements of lycopene.

Our early efforts to correlate lycopene content to L, a, b, hue, chroma, value, ΔE and other common colorimetric measurements were unsuccessful. More recently, we have undertaken evaluations of the Hunter LabScan™ and the Hunter UltraScan XE™ for their ability to predict lycopene levels in tomatoes (*6, 7*). Using the Hunter LabScan™ with a tomato juice sample diluted 1:10 with water, we obtained a roughly linear correlation between the a/b value and the lycopene content of the juice samples, determined by spectrophotometric measurements of a hexane extract (Figure 4).

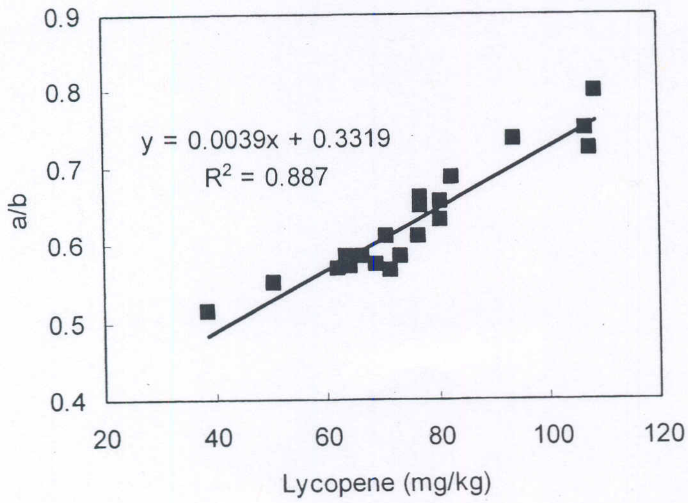

Figure 4. Relationship between the a/b ratio of a 10-fold diluted juice sample and the lycopene content of the tomato juice. The lycopene values given are for the undiluted juice.

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