Tomato Analyzer Color Test User Manual Version 3 August, 2010

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Part 1: Overview of color and Tomato Analyzer – Color Test (TACT)

The Tomato Analyzer module called Color Test (TACT) is designed to collect objective color measurement from JPEG and TIFF images (**Figure 1**), which are collected from scanning fruits on the flatbed surface of a scanner.



Figure 1. Tomato Analyzer – Color Test

Digital color and the RGB color space. Computer color measurements are based on the RGB color space. This system is additive, at it measures the strength of each R (red), G (green), B (blue) color in each pixel to reproduce other colors. The additive RGB color space is a cube with each axis representing variance in one of the primary colors and a white reference point. This color space is nonlinear and does not mimic the nature of color perception. It is not generally standardized. While there is a standardized version (sRGB) for which conversion formulas exist, measurements may differ among hardware and software. These differences can be corrected by calibrating the devices involved in the process of collecting and analyzing color images.

Tomato Analyzer and the CIELab color space. TACT takes the average RGB values for each pixel and translates the color measurements to L*, a*, b* values of the CIELab color space. Unlike the RGB color space, the CIELab color space is able to approximate human visual perception. It is a spherical color space with the vertical axis

representing lightness (+L*) to darkness (-L*). The chromaticity coordinates are a* and b* and their axis indicates color directions: $+a^*$ is the red direction, $-a^*$ is the green direction, $+b^*$ is the yellow direction and $-b^*$ is the blue direction (**Figure 2**).



Figure 2. Representation of the CIELab color space.

Hue and chroma are descriptors of color based on a* and b* values (**Figure 3**). Hue represents the basic color. It is an angular measurement in the quadrant between the a* and b* axes. Chroma is the saturation or vividness of color. It is measured radially from the center of each quadrant with the a* and b* axes.





Standard illuminant and observer angle. Different light sources will make colors appear different. A standard illuminant has a specific spectral distribution. Standard illuminant D65 represents natural daylight. It should be used for specimens that will be illuminated by daylight, include ultraviolet radiation. Illuminant C was also constructed to represent natural daylight, but its spectral distribution excludes ultraviolet radiation. In addition to the light source, the angle of view will also affect color sensitivity of the eye. Colors are perceived most precisely if they strike the area of the fovea in the eye, which is most sensitive to color. The 2° Standard Observer angle is used for viewing

angles between 1° and 4°, whereas the 10° Standard Observer is used for angles larger than 4°.

TACT application

TACT collects RGB values for each pixel of an object. It then translates them to L*, a*, b* values of the CIELab color space, as well as luminosity. Algorithms were written for TACT to compute hue and chroma based on L*, a*, b* values. The output of each image analyzed with the TACT consists of the averaged values of RGB, luminosity, L*, a*, b*. In addition, six parameters based on specific ranges of hue, chroma and/or L values can be defined by the user (see Part 4: Defining parameters).

Part 2: Basic Features

Details about the use of the Tomato Analyzer application (TA) can be found in the TA morphology user manual, Version 3. It can be downloaded from the following URL: <u>http://www.oardc.ohio-state.edu/vanderknaap/</u>. The basic features of TA will be briefly described in this part of the TA-Color Test manual.

Collecting and formatting images for TACT. For the most accurate color measurements, the user is advised to scan a color checker to calibrate the scanner prior to scanning objects such as fruit and leaves (described in Part 3). Set the output image size of the scanner at the highest number of colors available in the scanner software. Scan the objects with a black background by placing a box over the scanner. A label with descriptive information for the objects (year, plot number, etc) and a ruler can be included on the scan. Save the image as TIFF (100 dpi) or JPEG (200 dpi). Because TIFF files preserve the image as it was originally scanned, these file types are recommended. JPEG images alter some of the colors in the image, reducing the accuracy of object boundary detection and color analysis.

Generating the boundaries. After opening an image, click the "Color test" button on the toolbar. The color test dialog box appears (see below, **Figure 5**). Select "Analyze" to

allow TA to find the boundaries. Objects that are highlighted in yellow will be analyzed. Objects highlighted in blue will not be analyzed. Objects that are not highlighted in blue or yellow are not recognized by TA. By right-clicking the highlighted objects, the user can toggle between analyzed and not analyzed objects.

Adjusting boundaries. If needed, the boundaries of the object can be adjusted. Select the object by left-clicking on it. The selected object will be displayed in the upper-right panel. Click on the "Revise" button on the toolbar, selecting "Boundary" (shift+B). On the object in the right window, click on the boundary at the start and the end of the area to adjust. The delimited boundary between the selected points will disappear. Left-click at multiple points on the boundary to delimit the desired contour. Any action can be undone by right-clicking. Press the Enter key to accept the changes or Escape key to cancel. Click the "Save Fruit" to save any changes on the image. A TMT file with the same name as the image and containing all information and adjustments will be saved along with the image in the same file. Both files should be kept in the same folder to avoid reanalyzing the image.

Part 3: Calibration

Obtaining color standards. Color standards should be chosen based on the broad range of colors observed in the object of interest. For the best results, choose a color checker with a black or very dark background. L*,a*b* values for each tile will need to be available for either Illuminant C2 at Observer Angle 2° or Illuminant D65 at Observer Angle 10°, from either the manufacturer or a colorimeter. Color checkers can be purchased custom made or standard.



Figure 4. Custom-made 28-patch color checker from X-rite (Grand Rapids, MI).

Collecting colorimeter L, a*, b* values.* If the manufacturer does not provide L*, a*,b* values, they must be determined by a colorimeter. Verify the settings of the colorimeter for its source of illuminant and observer angle which should be consistent with the scanner. Calibrate a colorimeter with a white tile, following the manufacturer's protocol. Collect L*, a*, b* values for each patch of the color checker. Make sure to report the tile number with its corresponding color values.

Analyzing the color checker and entering the correct L*, a*, b* values. Scan the color checker as described above and open the image in TA. Click the Color Test button in the toolbar to open the Color Test dialog. Choose the combination of illuminant and observer angle provided with the manufacturer's listing of L*,a*,b* values for the color checker. TACT accepts either Illuminant C2 at Observer Angle 2° or Illuminant D65 at Observer Angle 10°. Click the Calibrate button to open the Input L*a*b* dialog. **Figure 5-A** shows the Color Test dialog box. After clicking Calibrate, the Input L*a*b* dialog is displayed (**Figure 5-B**)

Figure 5. Color Test dialog box (A) and Input L*a*b* dialog box (B)

A	В
Color Test	
Select Color Attributes	Input L*a*b* Values for Color Checker
Verage color values	CSV data entry Choose File
Set custom color parameters	Manual data entry
Select Calibration Settings Warning: Calibration has not been performed.	input the L*a*b* values for each tile on the color checker. These values should be provided with the color checker.
	Tile 01
$L = 1 \times L' + 0$	L* 🚺
a = 1 × a' + 0	a* 0
$\mathbf{b} = \begin{bmatrix} 1 & \mathbf{x} \mathbf{b}' + \end{bmatrix} 0$	Ъ* <u>ј</u> 0
Restore Defaults	Next Finish
Analyze color Calibrate Save settings Cancel	Cancel

The user now needs to enter the actual L*,a*,b* values for each tile in the color checker, as provided by the manufacturer or determined by a colorimeter. There are two ways to do this.

If this is the first time the color checker is used in the calibration, type or paste the • L*,a*,b* values for the first tile and click Next. Repeat for each tile. When all L*,a*,b* values have been entered, click Finish. In the Save as dialog that appears, the actual data you entered can be saved to a CSV file with the name of the color checker image followed by the word calibration. TA uses the actual and observed L*, a*, and b* values in a linear regression to find linear equations to convert observed values to actual values. The calibration information is displayed in the Color Test window under the section "Equations" (Figure 5-A). This means that the calibration of the scanner is done. The slopes should be close to 1 and the intercepts close to 0; if not, check that the L*,a*,b* values were entered correctly.

NOTE: It is important to ensure that the values entered for each tile correspond to the correct tile in the manufacturer's specification. TA may number the tiles differently than the manufacturer, and TA may not recognize some dark-colored tiles. Tiles that are not recognized are not bordered by a yellow or blue line. To help ensure that the correct values are entered, TA displays the current tile in the right window panel when entering the actual L*, a*, b* values (**Figure 5-B**).

• If the color checker was used before and the CSV file with the actual L*, a*, b* values was saved during the calibration, the correct L*, a*, b* values can be imported from the CSV file. Click Choose File, and open the CSV file with the actual color checker values. In the Save dialog that appears, either choose another CSV file or click Cancel. Make sure that you import the values for the same color checker scanned in the same orientation. Also, make sure TA recognizes the same color patches as it did for a previous calibration.

When reopening TA, the calibration equation values from the previous analysis will be used. If multiple sets of equations are to be used on the same computer, the equations can be saved and loaded by going to the Settings menu on the toolbar, select Load/Save Settings, select Save Settings to save the calibration equation values and Load Settings to use previously calculated calibration equation values. Alternatively, the equations can be copied and pasted from the CSV file saved during calibration.

Part 4: Color test

The application is now ready to analyze color on the objects such as fruit and leaves. The user can analyze the color of the objects by either selecting from the Settings menu on the toolbar, select Select Attributes, click on Average Color Values, L* Distribution, etc (see **Figure 6**). Alternatively, the user can select Color test on the toolbar, Select Color Attributes, click Analyze color.





NOTE: The calibration step with a color checker can be skipped if color accuracy is less important. For example, a user might want to know the percentage green and brown in an object but the exact L^* , a^* , b^* values are not relevant. In that case, the scanner is assumed to be perfect and the equations can be reset to default values (click Restore default, **Figure 5-A**).

There are three methods to analyze color (Figure 5-A):

Average color values. The values displayed are: Average Red, Average Green, Average Blue, Average Luminosity, Average L* Value, Average a* Value, Average b* Value, Average Hue, Average Chroma. These average values are calculated taking into account all pixels within the object.

 L^* , *hue, chroma distributions*. These measurements provide histogram data for L*, hue, and chroma. The data appear in the tabs called L* Distributions, Hue Distributions, and Chroma Distributions, respectively. Each column shows the fraction of the object whose color falls within a certain range. For example, if the L[40..50) column in L* Distributions has the value 0.3, then 30% of the fruit has L* between 40 (inclusive) and 50 (exclusive).

Set custom color parameters. Based on the L*, hue, chroma distributions, the user can define custom ranges of L*, hue, chroma, or a combination of the three. Click the Color

Test button in the toolbar to open the Color Test dialog. Check the box for User-Defined Color Ranges. Click the Analyze Color button. The User-Defined Color Ranges dialog appears as shown in **Figure 7**.

Custom Color Parameters		X
Parameter 1		
<= L* <	30 <= Hue < 45	<= Chroma <
Parameter 2		
0 <= L* < 30	0 <= Hue < 90	<= Chroma <
Parameter 3		
<=L* <	<= Hue <	<= Chroma <
Parameter 4		
<= L* <	<= Hue <	<= Chroma <
Parameter 5		
<= L* <	<= Hue <	<= Chroma <
Parameter 6		
<= L* <	<= Hue <	<= Chroma <
	OK Clear Cancel	1

Figure 7. Set Custom Color parameters dialog box

The user can define up to 6 combinations of color ranges. In the example in **Figure 7**, Parameter 1 includes all colors where the hue is between 30 (inclusive) and 45 (exclusive); L* and chroma may be anything. Parameter 2 includes all colors where the L* is between 0 and 30 and the hue is between 0 and 90; the chroma may be anything. When finished entering color ranges, click OK. The data appears in the data window tab called Custom Color Parameters.

Part 5: Color standard specifications

Table 1. L*, a*, b* values for each patch of the color checker (see **Figure 4**). The source of illuminant was D50 and the observer angle was 2°.

	L*	a*	b*
1	37.986	13.555	14.059
2	65.711	18.13	17.81
3	49.927	-4.88	- 21.925
4	43.139	-13.095	21.905
5	55.112	8.844	-25.399
6	70.719	-33.397	-0.199
7	62.661	36.067	57.096
8	40.02	10.41	-45.964
9	51.124	48.239	16.248
10	30.325	22.976	-21.587
11	72.532	-23.709	57.255
12	71.941	19.363	67.857
13	28.778	14.179	-50.297
14	55.261	-38.342	31.37
15	42.101	53.378	28.19
16	81.733	4.039	79.819
17	51.935	49.986	-14.574
18	51.038	-28.631	-28.638
19	96.539	-0.425	1.186
20	81.257	-0.638	-0.335
21	66.766	-0.734	-0.504
22	50.867	-0.153	-0.27
23	35.656	-0.421	-1.231
24	20.461	-0.079	-0.973

Part 6: Mathematical formulas

The algorithm implemented in TACT to convert RGB values to L*, a*, b* values of the CIELab color space can be adjusted to account for the illuminant (D65 or C) and observer angle (2° or 10°). Converting RGB to L*, a*, b* is accomplished in three steps. First, RGB values are scaled to a perceptually uniform color space (equation 1):

$$Var_R = ((((R/255)+0.055)/1.055)^2.4)*100$$
$$Var_G = ((((G/255)+0.055)/1.055)^2.4)*100$$
(1)
$$Var_B = ((((B/255)+0.055)/1.055)^2.4)*100$$

Scaled RGB values are then converted to XYZ trismulus values using the following relationships (equation 2):

$$X = (Var_R*0.4124) + (Var_G*0.3576) + (Var_B*0.1805)$$
$$Y = (Var_R*0.2126) + (Var_G*0.7152) + (Var_B*0.0722)$$
(2)
$$Z = (Var_R*0.0193) + (Var_G*0.1192) + (Var_B*0.9505)$$

The XYZ values are converted to L*, a*, b* values using the following relationships (equation 3):

$$L^{*} = 116 f (Y/Yn) - 16$$

$$a^{*} = 500 [f (X/Xn) - f (Y/Yn)]$$

$$b^{*} = 200 [f (Y/Yn) - f (Z/Zn)]$$
(3)

where

f
$$(q) = (q)^{1/3}$$
 $q > 0.008856$
f $(q) = 7.787q + (16/116)$ $q \le 0.008856$.

Yn, Xn and Zn are the trismulus values of the illuminant and observer angle. For illuminant C, observer angle 2°, Xn=98.04, Yn=100.0 and Zn=118.11. For illuminant D65, observer angle 10°, Xn=94.83, Yn=100.0 and Zn=107.38.

The L*, a*, b* values were then used to calculate chroma as $\sqrt{a^2+b^2}$. Hue is calculated as 180/pi*acos(a/ $\sqrt{a^2+b^2}$)) for a*>0 and as 360-((180/pi)*acos(a/ $\sqrt{a^2+b^2}$))) for a*<0.

In addition, luminosity is computed from the following relationship (equation 4):

Luminosity =
$$(maxCol + minCol) * 240.0 / (2.0 * 255.0)$$
 (4)

where maxCol is the highest of the R, G, B values of a pixel analyzed, and minCol is the lowest value.

Part 7: Definitions of measurements

Basic Color Analysis

- Average Red The average R value (0-255) in the RGB color system across all pixels in the object.
- Average Green The average G value (0-255) in the RGB color system across all pixels in the object.
- Average Blue The average B value (0-255) in the RGB color system across all pixels in the object.
- Average Luminosity The average luminosity (0-240) across all pixels, calculated from the RGB value of each pixel as:

 $[(\max(R, G, B) + \min(R, G, B)) * 240] / (2 * 255)$

- Average L Value The average L* value (0-100) in the L*a*b* color system across all pixels in the object
- Average a Value The average a* value (0-100) in the L*a*b* color system across all pixels in the object
- Average b Value The average b* value (0-100) in the L*a*b* color system across all pixels in the object
- Average Hue The hue (0°-360°) represented by the Average a Value and the Average b Value.
- Average Chroma The chroma represented by the Average a Value and the Average b Value.

The RGB and luminosity of a pixel can be viewed in Microsoft Paint. The approximate L*a*b* of a pixel can be viewed in Adobe Photoshop.

L*, hue, chroma distributions and set custom color parameters

- L* Ranges For the range L[m..n), the value is the fraction (between 0 and 1) of the object having L* between m (inclusive) and n (exclusive).
- Hue Ranges For the range H[m..n), the value is the fraction (between 0 and 1) of the object having hue between m (inclusive) and n (exclusive).
- Chroma Ranges For the range C[m..n), the value is the fraction (between 0 and 1) of the object having chroma between m (inclusive) and n (exclusive).
- Set Custom Color Parameters -For the range L[m..n) H[p..q) C[r..s), the value is the fraction (between 0 and 1) of the object having L* between m (inclusive) and n (exclusive) AND hue between p (inc.) and q (exc.) AND chroma between r (inc.) and s (exc.). If L[m..n) is absent, then the value is the fraction of the object having hue and chroma within the given ranges, regardless of L*; similarly for H[p..q) and C[r..s).