A Brief History of Color Measurement in Tomato

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Electromagnetic Radiation

- We use a ruler to measure length, and a scale to measure mass.
- Isn’t there a way to measure color?
A Tale of Two Cities

Richard Hunter & USDA

PTAB & Magnuson Engineers, Inc.
Karl Ewald Hering (1834-1918) German Physiologist

- When viewing a mixture of psychologically pure red and pure green lights,
- a person will see: red, green, or white,
- never yellow.

- Hering created a theory of color vision based on three opposing pairs:
  - Red – Green
  - Yellow – Blue, and
  - Black - White
Afterimage Example

• Stare for ~30s at center, then switch to white slide.
Richard S. Hunter
Optical Engineer

• In 1948, he developed the Hunter L, a, b color space
  – Based upon the Hering’s red-green, yellow-blue opponent color axes
• Hunter’s Objective:
  – Create a “Uniform” color space
    • A one-unit change in a or b is consistent with human perception of the amount of color change.
Hunter L, a, b color space

- Since color is the principal attribute that consumers use in purchasing decisions, the Hunter a & b color scores were adopted by the industry as a measure of quality.

- USDA Processed Tomato Juice Color Score
  - USDA Color = 25.715 +K₁ * [a –K₂*b]
  - K₁ = 0.956, K₂ = 1.828
S. R. Whipple, 1955. COLOR INSPECTION—FRESH FRUITS AND VEGETABLES

• First electronic instrument to measure tomato ripeness was developed in the early 1950’s.
• Designed to measure the color of the surface of two halves of a tomato.
• Color score was the G/R ratio of green reflectance (546nm) to red reflectance (640 nm).
• Initially used to train inspectors and to determine the grade of “doubtful” tomatoes.
• Modified in the 1970’s to measure the color of de-aerated juice.
Measuring Tomato Ripeness

- Kader & Morris, 1978
  - Used an Agtron E5-W

- Agtron score was well correlated with ripeness stage.

Fig. 1. Agtron E5-W reflectance readings vs ripeness classes of ‘Ace 55’ fruits. Each point represents a mean for 50 fruits and vertical lines indicate standard deviation.
Agtron E5-M
Color in Processing Tomato Inspection

Red Neon &
Green Mercury
Lamps
Tomato Juice Reflectance

PTAB Color

Wavelength (nm)

Reflectance (%)

Lycopene Absorbance (502 nm)

Chlorophyll Absorbance (670 nm)
INTER-INSTRUMENT AGREEMENT OF AGTRON & LED MACHINES READING A SINGLE TOMATO JUICE SAMPLE

Percentage of machines giving the same color score for LED and AGTRON.
UC Davis LED Tomato Color Meter

LED LAMP ARRAY

TEMPERATURE CONTROLLED CHAMBER (110 °F)

REFLECTED LIGHT DETECTOR

TOMATO JUICE
CIE L*, a*, b* color system

- “Uniform” color system
  - Developed in 1976 by the International Commission on Illumination
  - “Improved” version of Hunter L, a, b color space
Hunter L, a, b vs. CIE L*, a*, b*

**HUNTER**

\[
L = 10\sqrt{Y}
\]

\[
a = \frac{17.5 \times (1.02X - Y)}{\sqrt{Y}}
\]

\[
b = \frac{7 \times (Y - 0.85Z)}{\sqrt{Y}}
\]

**CIE**

\[
L^* = 116 \times \left(\frac{Y}{Y_n}\right)^{\frac{1}{3}} - 16
\]

\[
a^* = 500 \times \left[\left(\frac{X}{X_n}\right)^{\frac{1}{3}} - \left(\frac{Y}{Y_n}\right)^{\frac{1}{3}}\right]
\]

\[
b^* = 200 \times \left[\left(\frac{Y}{Y_n}\right)^{\frac{1}{3}} - \left(\frac{Z}{Z_n}\right)^{\frac{1}{3}}\right]
\]
Comparison of Color Space Uniformity

Hunter Lab

CIE L*a* b*

$L = 54$

$L^* = 82$
The original Munsell system is almost perfectly uniform.

- **Hue** = name of color
  - (e.g., purple, green, yellow)
- **Value**, (or lightness)
  - Divided into 11 equal steps
    - (black=0, white = 10)
  - Value ~ $\sqrt{\text{ave. reflectance}}$
- **Chroma**, purity, or saturation
Konica Minolta CR-10 CIE L* C* H* Color Meter

- Over 13,000 peaches evaluated for maturity with the CR-10 in 2006.
- Operated by SPI inspectors in 2006.
Hue Color Wheel

Standard Illuminant: D65
10 Degree Observer

UC Davis
PTAB Color Situation

• The current LED technology is beginning to require increased maintenance and will require replacement.

• The opportunity exists to make a significant change in how maturity/color is determined at harvest.
PTAB Color Proposal for 2012

- PTAB would start using the Minolta CR-410 Colorimeter for color inspection in 2012.
- CIE H* (Hue Angle) would become the official grade.
- Hunter L, a, b, and CIE L*, a*, b* could be provided at no
PTAB Color vs. USDA Color

UC Davis 2006 Color Study Results

Hunter / USDA Processed K1*(a - K2*b) Color Score
PTAB Color vs. Hue Angle

UC Davis 2006 Color Study Results

PTAB Screeneed Juice Color Score vs. CIE H* (Hue Angle) Unscreened Juice
PTAB Color vs. L*/a* Ratio

UC Davis 2006 Color Study Results

L* ≈ Green
a* ≈ Red
L*/a* ≈ G/R = Agtron
2011 Prototype Flow-Through Color Grading System

- Blends juice sample,
- Measures Color, pH, and Soluble Solids,
- Self-cleaning.