Measuring Desirable and Undesirable Color in White and Yellow Food Corn

C. D. FLOYD,[1] L. W. ROONEY,[1,2] and A. J. BOCKHOLT[1]

ABSTRACT

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Subjective field and objective nondestructive laboratory measurements of color in white and yellow corn were compared. *L, a, b*, and *E* color values were correlated to subjective field color grades by a trained observer. Physical factors that affect the variability of *L, a, b* and *E* color values such as position of the germ and adhering colored cob material were examined. Variability of objective measurements decreased when colored cob material was removed or the kernels were positioned with the germ facing away from the light source during color measurements. Pearson correlation coefficients between field color grades and *L, a, b*, and *E* color values were <0.54. Differences in endosperm hardness, pericarp thickness, and pericarp gloss between cultivars with the same subjective field ratings contributed to the low correlation values. The *L, a, b*, and *E* color values provide a general index of color especially for yellow corn. Important subtle differences in color, particularly in white corn, were not accurately determined by these indices. Subjective evaluation of corn on the cob viewed in the field is the most effective method for selecting appropriate color corn.

The color of foods greatly influences consumer acceptance. Processors want clean, brightly colored corn for food products. Methods of color measurement of raw commodities are therefore important to food manufacturers and breeders developing new food corn hybrids.

The color of corn kernels can differ considerably from white to yellow, orange, red, purple, and brown (Watson 1987). Pigments responsible for the coloration have been reported in the pericarp, aleurone layer, endosperm, and scutellum (Wolf et al 1952).

Carotenes and xanthophylls are primarily responsible for the yellow color of corn. Genetically, the color of the endosperm is controlled by genes *yyy* for a completely white endosperm, *Yyy* for a light yellow endosperm, *YYy* for a lemon-yellow endosperm, and *YYY* for an intense yellow endosperm (Zuber and Darrah 1987). Obviously, the genetic color and thickness of the pericarp and the aleurone layer further influence the final color of the kernel. Also, the cob color can change the perception of corn color.

White food corn hybrids vary from a pale, dull white to a gray off-white appearance, while yellow hybrids can range from a light yellow to a dark reddish-yellow color. Bright, clean white and yellow kernels are desirable for food corn. The hybrids with unacceptable color are usually culled by breeders. Most of the methods used by breeders are subjective measurements used in the field. Accurate objective methods to evaluate yellow and white corn color would help breeders select appropriately colored corn for processing. Nondestructive methods for evaluating color are important in breeding programs because of small sample sizes available for analysis.

Color measurement machines have been developed to duplicate the response of the human eye. Color solids, like the *Lab* color system, represent color on an objective basis. The *Lab* system is based on a tristimulus system with the *L* value representing black (100) to white (0), the *a* value representing blue (–) to yellow (+), and the *b* value representing green (–) to red (+). *Lab* values and their derivatives have been used to evaluate a variety of cereal products objectively (Hahn 1984, Paredes-Lopez and Mora-Escobedo 1989, Cole et al 1991, Oliver et al 1992, Mireles 1995). Visual subjective color ratings and objective *Lab* measurements have been correlated in a variety of food products including lima beans, tomato juice, applesauce, and orange juice (Francis 1991).

The objectives of this research were to examine the effectiveness of objective measurements of corn color and to relate objective color measurements of typical yellow and white corn samples to subjective field ratings.

[1]Graduate student, professor, and associate professor, respectively, Cereal Quality Laboratory, Dept. Soil & Crop Sciences, Texas A&M University, College Station, TX 77843-2474.
[2]Corresponding author. E-mail: lrooney@tamvm.tamu.edu

MATERIALS AND METHODS

Subjective and Objective Color Measurements

Samples were rated subjectively in the field while on the cob by A. J. Bockholt, an experienced corn breeder, on a scale of 1–5 with 0.5 increments. Color ratings of 3.0 represented optimum color for both white and yellow corn (Table I).

Objective color measurements were taken with the HunterLab Tristimulus Colorimeter (model D25M-9, Hunter Associates Lab, Inc., Fairfax, VA) The colorimeter was calibrated with a standard white tile (L = 91.69, a = –0.90, b = –0.90), and the calibration was verified with a standard yellow tile (L = 78.2, a = –2.3, b = 22.4). Samples were placed in a 5.5-cm diameter plastic cell with an optically clear glass bottom, and *L, a,* and *b* readings were taken. An *E* value (Hahn 1984) was calculated as:

$$E = (L^2 + a^2 + b^2)^{1/2}$$

Trial Samples

Replicate samples of six corn cultivars were used to examine the influence of kernel placement on objective color analysis. Two yellow cultivars (Asgrow 404 and Pioneer 3192), two white

TABLE I
Subjective Field Rating System for Yellow and White Food Corn[a]

Rating	Description
Yellow corn	
1.0	Very pale yellow
2.0	Light yellow
3.0	Bright, clean yellow
4.0	Orange-yellow
5.0	Reddish-yellow
White corn	
1.0	Very pale, dull white
2.0	Pale, dull white
3.0	Bright, clean white
4.0	Cream-colored white
5.0	Off-colored white

[a] Corn rated from 1.0 to 5.0 in 0.5 increments.

TABLE II
Effect of Corn Placement on Color Parameters[a] and Coefficients of Variation (CV)[b,c]

		L		*a*		*b*		*E*	
Cultivar	Color	Mean	CV	Mean	CV	Mean	CV	Mean	CV
Random placement									
Asgrow 404	Yellow	58.2d	1.4	9.3b	8.5	26.3c	1.9	64.6d	1.0
Pioneer 3192	Yellow	55.7c	1.7	10.2b	7.1	26.0c	1.3	62.3c	1.6
Asgrow 405w	White	66.7e	0.7	1.3a	11.3	23.2b	2.8	70.4e	0.8
Conlee 117w	White	66.7e	0.9	1.1a	20.1	21.1a	3.0	70.0e	0.9
Flint Colorado	Orange-red	51.3b	1.1	12.6c	7.5	22.3b	4.9	57.3b	2.4
Flint Amarillo	Orange-red	48.9a	1.0	13.7d	7.4	22.3b	5.3	55.5a	1.6
LSD (0.05)[d]		1.0		1.0		1.1		1.1	
Germ-up placement									
Asgrow 404	Yellow	57.6d	0.6	11.3b	4.3	28.0e	1.0	65.0d	0.5
Pioneer 3192	Yellow	55.7c	0.6	11.7b	2.1	26.9d	0.8	62.5c	0.3
Asgrow 405w	White	66.7e	0.6	0.9a	8.5	23.7c	1.3	71.4e	0.6
Conlee 117w	White	66.7e	0.6	1.0a	13.9	21.8a	0.9	70.8e	0.6
Flint Colorado	Orange-red	51.3b	0.9	15.3c	2.1	23.3b	1.0	57.6b	0.7
Flint Amarillo	Orange-red	48.9a	0.6	15.1c	3.3	23.8c	1.4	56.9a	1.0
LSD (0.05)		0.5		0.5		0.4		0.5	

[a] *L* = black (0) to white (100); *a* = blue (–) to yellow (+); *b* = green (–) to red (+). $E = (L^2 + a^2 + b^2)^{1/2}$.
[b] Average and coefficient of variation of replicate samples of each cultivar.
[c] Means with the same letter in the same column are not significantly different.
[d] Least significant difference.

TABLE III
Effect of Adhering Red or White Cob Material in Color Parameters[a] of Yellow Corn Kernels (3.0 field rating)[b,c]

Cob Material	*L*	*a*	*b*	*E*
Not removed				
White	60.0b	10.2a	28.9a	67.4a
Red	58.8a	12.0b	30.8b	67.4a
LSD (0.05)[d]	1.1	0.7	1.2	NS
Removed				
White	59.6a	10.5a	29.4b	67.3a
Red	59.3a	10.1a	28.7a	66.6a
LSD (0.05)	NS	NS	0.6	NS

[a] *L* = black (0) to white (100); *a* = blue (–) to yellow (+); *b* = green (–) to red (+). $E = (L^2 + a^2 + b^2)^{1/2}$. NS = not significant.
[b] Average of duplicate analysis of three hybrids in each cob category.
[c] Means with the same letter in the same column are not significantly different.
[d] Least significant difference.

cultivars (Asgrow 405W and Conlee 117W), and two orange-red cultivars (Flint Colorado and Flint Amarillo) were analyzed for *L*, *a*, *b*, and *E* color values by random introduction and by placing kernels with the germ side away from the light source (germ up placement) in the sample container.

To examine the influence of cob material on color measurements, three red cob yellow corn hybrids and three white cob yellow corn hybrids with a field rating of 3.0 were randomly selected from the 1992 National Yellow Food Corn Test. Samples were analyzed with germ up placement with and without removing the adhering cob material to determine whether cob color affected objective color readings.

Subjective vs. Objective Color Measurements

Yellow and white corn samples were grown and harvested under standard conditions during the 1992 National Yellow and White Food Corn Tests by the Texas Agricultural Experiment Station, College Station, TX. Five hybrids were randomly selected from 2.0, 2.5, 3.0, and 3.5 subjective field color rating categories for objective color analysis.

Statistical Analysis

Data was analyzed with analysis of variance, and means were separated with least significant difference. *L*, *a*, *b*, and *E* values were correlated with subjective field ratings with Pearson Correlation Coefficients. All statistical analysis was performed with PC-SAS (SAS 1985).

RESULTS AND DISCUSSION

L, *a*, and *E* color values were affected by kernel color of white, yellow, and orange-red cultivars (Table II). Kernels that were randomly introduced had a higher coefficient of variation than kernels with germ-up placement. Hence, to reduce variability, all subsequent samples evaluated from the National Yellow and White Food Corn Test were evaluated in this position.

When yellow corn samples (3.0 field color rating) with white and red cobs were compared, *L*, *a*, and *b* color values were significantly different, while *E* values were not different (Table III). When the cob material was removed by hand, *L*, *a*, and *E* color values were not significantly different between cob types. All adhering cob material from the National Yellow and White Food Corn Test samples was removed by hand before color evaluation.

Yellow corn *b* values with different field color ratings were not significantly different (Table IV). Yellow corn samples with a rating of 3.0 had significantly lower *L* values than samples with a rating of 2.0 or 3.5. Yellow corn samples with a field rating of 3.0 and 3.5 had the lowest *E* values and the highest *a* values.

E values of white corn samples with different field color ratings were not significantly different (Table IV). White corn samples with a field rating of 2.0 had significantly higher *L* and lower *b* values than white corn samples with a field rating of 3.5. White corn samples with a field rating of 2.0 had significantly lower *a* values than the other field color rating categories.

Correlation coefficients between colorimeter parameters and field ratings were <0.54 ($P < 0.02$) (Table V). For yellow corn, the highest correlation coefficient was between *a* and field rating ($r = 0.53$). For white corn, the highest correlation coefficients were found between field rating and *a* ($r = 0.53$) and field rating and *b* ($r = 0.53$).

To measure color in food corn tests, the best method appears to be subjectively rating the corn with the kernels attached to the cob. Breaking the cob and evaluating the non-germ side of the kernels compared to standards representing color ratings from 1 to 5 is an effective and inexpensive way to evaluate color. Standard corn kernels can be established and stored in plastic bags in the freezer

TABLE IV
Subjective Color Ratings for *L, a, b,* and *E* Color Values[a] of 1992 National Yellow and White Food Corn Tests[b,c]

Field rating[d]	*L*	*a*	*b*	*E*
Yellow food corn				
2.0	59.7b	11.0a,b	28.3a	68.8a,b
2.5	59.4a,b	10.7a	28.5a	69.3b
3.0	57.7a	12.0b	28.3a	67.0a
3.5	60.2b	12.1b	28.5a	67.0a
LSD (0.05)[e]	1.7	1.1	NS	2.0
White food corn				
2.0	67.7b	0.7a	21.7a	71.1a
2.5	66.9a,b	1.0b	22.5b,c	70.5a
3.0	66.4a	1.1b	22.3a,b	70.1a
3.5	66.8a,b	1.0b	23.1c	70.8a
LSD (0.05)	1.2	0.2	0.7	NS

[a] *L* = black (0) to white (100); *a* = blue (–) to yellow (+); *b* = green (–) to red (+). $E = (L^2 + a^2 + b^2)^{1/2}$.
[b] Average of duplicate analysis of five hybrids in each field rating category. Adhering cob material removed by hand and kernels placed with germ side away from machine.
[c] Means with the same letter in the same column are not significantly different.
[d] Field rating on a scale of 1–5 lightest to darkest in 0.5 increments. Field rating of 3.0 indicates optimum color.
[e] Least significant difference.

TABLE V
Pearson Correlation Coefficients for Field Rating vs. *L, a, b,* and *E* Values[a] for White and Yellow Corn[b]

	Rating *vs.* [c]			
	L	*a*	*b*	*E*
Yellow	–0.10 ($P = 0.96$)	0.53 ($P = 0.02$)	0.07 ($P = 0.78$)	–0.49 ($P = 0.03$)
White	–0.38 ($P = 0.10$)	0.53 ($P = 0.02$)	0.53 ($P = 0.02$)	–0.21 ($P = 0.38$)

[a] *L* = black (0) to white (100); *a* = blue (–) to yellow (+); *b* = green (–) to red (+). $E = (L^2 + a^2 + b^2)^{1/2}$.
[b] Yellow corn $n = 20$; white corn $n = 20$. $P \geq 0.05$ not significant.
[c] Field rating from 1 to 5 lightest to darkest in 0.5 increments. Field rating of 3.0 indicates optimum color.

so evaluations are consistent from year to year.

Many factors can affect objective color measurements. Cob color and orientation of kernels in the light can be controlled with hand-picking and placement of kernels, but these methods are time consuming when compared to subjective methods. With field trials, only small samples of kernels are available for analysis. Destructive preparation, such as grinding, is not an option.

We conclude that objective measurements of corn color are useful to distinguish among corns with large differences in color, provided that orientation of kernels is uniform and adhering cob material is removed. However, for critical evaluation of food corns in breeding programs, subjective evaluations are most efficient and effective.

CONCLUSIONS

This colorimetric method was able to distinguish between very different samples of corn (white vs. yellow vs. orange-red). Position of the germ and adherence of colored cob material affected color ratings. The low correlation values (<0.54) between field ratings and the nondestructive objective method indicate that objective color measurements cannot distinguish the subtle color differences that can affect food quality. This can be attributed to many characteristics of corn including hardness differences, variation in thickness of the pericarp, and variation in glossiness of the pericarp. Subjective field ratings by a trained panelist are more applicable to corn breeding programs.

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