DIFFERENCES IN THE RATE OF COLORATION IN TOMATO FRUIT

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ABSTRACT

The evolution of fruit color of twelve tomato (Lycopersicon esculentum Mill.) *cultivars during ripening was evaluated. Final color of each of the cultivars was determined by calculating its fresh tomato color index (TCI_f). Luminosity (L^*), red-green component (a^*), a^*/b^* ratio, hue angle (h^*), dominant wavelength (DW) and fresh tomato color index (TCI_f) were the parameters that best differentiated the ripening stages of tomato fruit. Dominant wavelength and purity of excitation were correlated with a^* and b^*. Fresh tomato color index (TCI_f) was related to the luminosity (L^*) and yellow-blue component (b^*).*

INTRODUCTION

Color is one of the principal factors which determines the degree of consumer acceptance of tomatoes. Important changes take place during ripening in the chlorophyll (green), lycopene (red) and beta-carotene (orange) contents of the fruit (Davies and Hobson 1981) and various stages of development can be differentiated according to the external color (Hobson *et al.* 1983; Dixon and Hobson 1984; Riquelme 1995).

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TABLE 1.
CIE Y_{XY} CHROMATIC ATTRIBUTES, DOMINANT WAVELENGTH (DW) AND PURITY OF EXCITATION (PURITY), OF THE DIFFERENT CULTIVARS DURING TOMATO FRUIT RIPENING

Cultivar	Mature green		Turning		Red firm		Red ripe	
	DW (nm)	Purity (%)	DW (nm)	Purity (%)	DW (nm)	Purity (%)	DW (nm)	Purity (%)
1411	568.7 b	24.0 e	577.3 c	36.7 c	588.6 b	50.7 cd	597.4 a	53.0 ab
5515	567.4 bc	28.6 c	579.2 b	36.1 c	587.5 c	49.4 d	594.1 b	54.9 a
1411 x 5515	569.4 a	30.9 b	580.4 ab	45.6 a	587.6 c	53.8 b	594.7 b	46.4 d
5515 x 1411	569.5 a	23.7 e	579.2 b	32.0 d	588.4 b	51.5 c	596.3 ab	52.5 b
Daniela	570.0 a	36.6 a	579.4 b	37.4 c	586.6 cd	46.2 e	593.8 bc	47.8 c
Florenta	568.3 b	30.3 b	582.1 a	44.4 a	588.5 b	51.0 c	596.0 ab	55.1 a
Monserrat	567.3 bc	28.9 c	581.9 a	32.9 d	592.8 a	34.8 f	597.0 a	41.3 e
Pendular	568.1 b	31.0 b	579.1 b	41.4 b	586.4 cd	51.1 c	596.5 ab	48.0 c
Red Pear	568.4 b	25.5 e	580.6 ab	38.6 c	588.5 b	51.2 c	596.0 ab	55.3 a
Royesta	567.5 bc	31.9 b	574.7 e	33.5 d	587.1 c	45.5 e	594.4 b	53.0 ab
Rutgers	567.1 c	29.4 bc	576.0 e	47.1 a	585.3 d	57.4 a	593.1 c	54.3 ab
VFN-8	567.4 bc	27.8 d	578.4 bc	36.1 c	587.4 c	54.4 b	594.2 b	53.2 ab

Mean separation by Duncan's multiple range test at 5% level. Means followed by the same letter within column sections do not differ significantly. Each value is the mean of forty replicates.

Color scales or charts exist which make it possible to classify the stage of ripening of tomato fruit subjectively (Difrusa 1991; Riquelme 1995). These scales include all tones and intensities possible in a sample, so that a numerical value can easily be assigned by simple visual comparison. Reference patterns which objectively measure color can also be used. More specifically in the case of tomato, North American producers have proposed determining color by calculating color indices, which are applicable to both dehydrated and whole fresh fruit (Hobson *et al.* 1983; Dodds *et al.* 1991; Calvo 1992).

More recently, good results have been obtained using tristimuli colorimetry in tomato fruits (Burgos *et al.* 1993; Casas *et al.* 1993; Riquelme 1995; Morilla *et al.* 1996). This technique rapidly and easily classifies samples by their external color, measuring the pigment content from the fraction of light reflected for narrow bands of wavelengths, thus enabling the tristimuli values CIE Yxy and CIELAB to be calculated (CIE 1986). When measuring tomato color, hue angle (h*) is more appropriate than a*/b* ratio (Little 1975; Thai and Shewfelt 1991).

The aim of the present work was to assess the coloration of twelve commercial tomato cultivars as they ripened. We describe the different stages of ripening by studying and comparing the chromatic attributes of the CIE Yxy and CIELAB systems obtained from colorimetric measurements of reflection.

MATERIAL AND METHODS

Plant Source and Experimental Design

Twelve selected tomato (*Lycopersicon esculentum* Mill.) cultivars were studied. Eight commercial varieties (Florenta, Royesta, Daniela, Rutgers, Red Pear, Pendular, VFN-8 and Monserrat), and 5515 and 1411 experimental lines together with their corresponding hybrids, (1411♀ × 5515♂) and (5515♀ × 1411♂), obtained by the Centro de Investigación y Desarrollo Agroalimentario (Murcia, Spain). Seedlings were transplanted into sandy soil in a polyethylene greenhouse at the Agricultural Experimental Field of the University of Castilla-La Mancha (Albacete, Spain). Cultivars were grown in random blocks with four replicates per cultivar. Tomato fruits were hand-harvested at four different stages throughout ripening in terms of their external color: (1) mature green; (2) turning; (3) red firm; and (4) red ripe (Rick 1978). Each sample consisted of forty fruits, ten per replicate, for each cultivar selected at random.

Statistical analysis were performed on a Pentium-100 MHz micro-computer using the integrated statistical package SAS/STAT (SAS Institute 1992). Univariate analysis of variance (ANOVA) with subsequently comparisons

TABLE 2

CIELAB CHROMATIC COORDINATES, LUMINOSITY (L^*), RED-GREEN COMPONENT (a^*), YELLOW-BLUE COMPONENT (b^*), CIELAB CHROMATIC ATTRIBUTES, CHROME (C^*), HUE ANGLE (h^*) AND a^*/b^* RATIO OF THE DIFFERENT TOMATO CULTIVARS DURING RIPENING

Ripening State	Cultivar	L*	a*	b*	C*	h*	a*/b*
	1411	59.7 c	-7.3 a	17.5 e	19.0 e	112.8 c	-0.42 c
	5515	62.7 a	-10.4 d	21.9 c	24.2 b	115.5 ab	-0.48 d
	1411 x 5515	60.0 c	-8.3 b	22.5 b	23.9 b	110.3 d	-0.37 b
	5515 x 1411	60.4 c	-6.6 a	17.3 e	18.5 e	110.2 d	-0.38 b
	Daniela	60.3 c	-8.7 b	26.6 a	28.0 a	108.1 f	-0.33 a
Mature Green	Florenta	59.7 c	-9.5 c	22.1 c	24.1 b	113.3 c	-0.43 c
	Monserrat	60.0 c	-10.3 d	21.4	23.7 b	115.7 ab	-0.51 d
	Pendular	59.5 c	-9.8 c	22.6 c	24.6 b	113.5 c	-0.44 c
	Red Pear	62.0 b	-8.3 b	19.2 d	20.9 d	113.4 c	-0.43 c
	Royesta	56.5 d	-10.5 d	22.5 b	24.8 b	114.2 b	-0.47 d
	Rutgers	59.1 c	-10.6 d	21.5 c	23.9 b	116.2 a	-0.49 d
	VFN-8	59.0 c	-9.8 c	20.3 d	22.5 a	115.7 ab	-0.48 d
	1411	57.4 ab	1.5 f	24.2 e	24.2 e	86.5 b	0.06 e
	5515	60.8 a	4.2 c	24.4 e	24.7 e	80.2 c	0.17 c
	1411 x 5515	49.8 c	6.1 b	26.6 b	27.3 b	77.0 d	0.23 b
	5515 x 1411	55.7 b	3.6 d	20.0 g	20.4 f	79.8 c	0.18 c
	Daniela	57.2 ab	4.4 c	24.1 e	24.5 e	79.7 c	0.18 c
Turning	Florenta	50.3 c	8.5 a	25.6 c	27.0 b	71.7 e	0.33 a
	Monserrat	51.6 c	6.4 b	19.0 g	20.1 f	71.3 e	0.34 a
	Pendular	54.0 b	4.2 c	25.7 c	26.1 c	80.7 c	0.16 b
	Red Pear	59.3 a	6.5 b	25.3 c	26.1 c	75.7 d	0.25 b
	Royesta	52.7 c	-1.8 g	21.0 f	21.1 f	94.8 a	-0.08 f
	Rutgers	55.8 b	-0.3 g	31.1 a	31.1 a	90.6 b	-0.01 f
	VFN-8	54.6 b	2.8 e	22.6 f	22.7 f	82.9 c	0.12 d

TABLE 2 (Continuation)

Ripening State	Cultivar	L*	a*	b*	C*	h*	a*/b*
	1411	46.4 b	18.3 b	26.6 d	32.3 b	55.5 c	0.69 a
	5515	48.9 a	17.0 c	27.1 d	32.0 b	57.8 c	0.63 b
	1411 x 5515	45.5 c	17.4 bc	28.4 c	33.3 b	58.4 c	0.61 b
	5515 x 1411	49.1 a	19.0 a	28.4 c	34.2 a	56.2 c	0.67 a
	Daniela	47.0 b	14.4 e	24.5 e	28.5 c	59.6 c	0.59 b
Red	Florenta	45.4 c	18.0 b	26.4 d	31.9 b	55.7 c	0.68 a
Firm	Monserrat	47.0 b	17.7 b	26.9 d	24.4 e	43.7 d	0.66 a
	Pendular	47.7 b	15.5 d	27.9 cd	31.9 b	61.0 b	0.56 c
	Red Pear	44.8 cd	17.8 b	26.3 d	31.7 b	56.0 c	0.68 a
	Royesta	45.1 c	14.4 e	23.3 e	27.4 c	58.3 c	0.62 b
	Rutgers	46.8 b	15.0 d	31.9 a	35.2 a	64.9 a	0.47 d
	VFN-8	45.9 c	17.4 bc	29.0 b	33.8 a	59.0 c	0.60 b
	1411	40.4 b	28.1 a	23.7 b	36.8 b	40.2 d	1.18 b
	5515	42.1 b	25.7 c	26.2 a	36.7 b	45.5 b	0.98 c
	1411 x 5515	37.9 c	21.4 e	19.7 d	29.1 f	42.7 c	1.08 bc
	5515 x 1411	41.1 b	27.0 b	24.0 b	36.1 b	41.6 d	1.13 b
	Daniela	37.6 c	20.9 f	20.5 c	29.2 f	44.5 b	1.02 c
Red	Florenta	42.2 b	28.2 a	26.0 a	38.4 a	42.6 c	1.09 bc
Ripe	Monserrat	44.0 a	23.8 cd	18.8 d	30.3 e	38.3 e	1.27 a
	Pendular	38.3 c	24.0 c	20.3 c	31.4 e	40.3 d	1.18 b
	Red Pear	41.7 b	28.1 a	25.8 a	38.2 a	42.6 c	1.09 bc
	Royesta	40.6 b	24.7 c	24.3 b	34.6 c	44.6 b	1.01 c
	Rutgers	40.9 b	23.6 d	25.5 a	34.7 c	47.1 a	0.93 c
	VFN-8	41.2 b	24.8 c	24.8 b	35.0 c	45.0 b	1.00 c

Mean separation by Duncan's multiple range test at 5% level. For each sampling time means followed by the same letter within column sections do not differ significantly. Each value is the mean of forty replicates.

(Duncan's multiple range test) were used to investigate the differences among cultivars. The univariate approach was applied to understand the hehavior of the variables.

Chromatic Evaluation

Reflected color was measured using a Minolta CR-200 colorimeter with Illuminant D_{65} and an angle of vision of 2°. Measurements for individual fruit were made around 1 cm from the blossom scar, which permits the greatest distinction between different ripening stages (Garret *et al.* 1960). Three color readings were averaged for each tomato at each sampling. Values from forty fruits thus obtained were used to calculate the chromatic attributes of the CIE Yxy system: dominant wavelength (DW) and purity of excitation (purity). CIELAB chromatic coordinates L* (luminosity), a* (red-green component), b* (yellow-blue component) and chromatic attributes C* (chrome) and h* (hue angle), and a*/b* ratio were also determined. A tomato color index of the whole fresh fruit (TCI_f) was calculated as reported by Hobson *et al.* (1983) and Dodds *et al.* (1991):

$$TCI_f = 2000 \times a^*/(L^* \times (a^{*2} + b^{*2})^{1/2})$$

RESULTS AND DISCUSSION

In the mature green stage the dominant wavelength varied in the varieties between 567.1 and 570.0 nm, since chlorophyll is the predominant pigment (Table 1). In the second ripening stage (turning) the values of this attribute increased considerably due to the disappearance of part of the chlorophylls and the increasing presence of lycopenes and betacarotenes as suggested by Rick (1978). As ripening progresses, the dominant wavelength increased until it reached values between 593.1 nm and 597.4 nm. A similar behavior was noted for the purity of excitation the final values varying between 41% and 55%.

In the last stage, Daniela manifested the lowest values of luminosity (L*), although in mature green stage it presented values above the mean of the cultivars (Table 2). These data confirm a lack in the final coloration of the "long shelf life" cultivars. Monserrat, commercial variety, exhibited the highest values of luminosity, showing important differences to the others. Similar results were observed analyzing a*/b* ratio, where Rutgers, 5515, VFN-8, Royesta and Daniela presented the lowest values.

Luminosity (L*), red-green component (a*), a*/b* ratio, hue angle (h*), dominant wavelength (DW) and fresh tomato color index (TCI_f) were the parameters at best differentiated the ripening stages of tomato fruit (Fig. 1). The

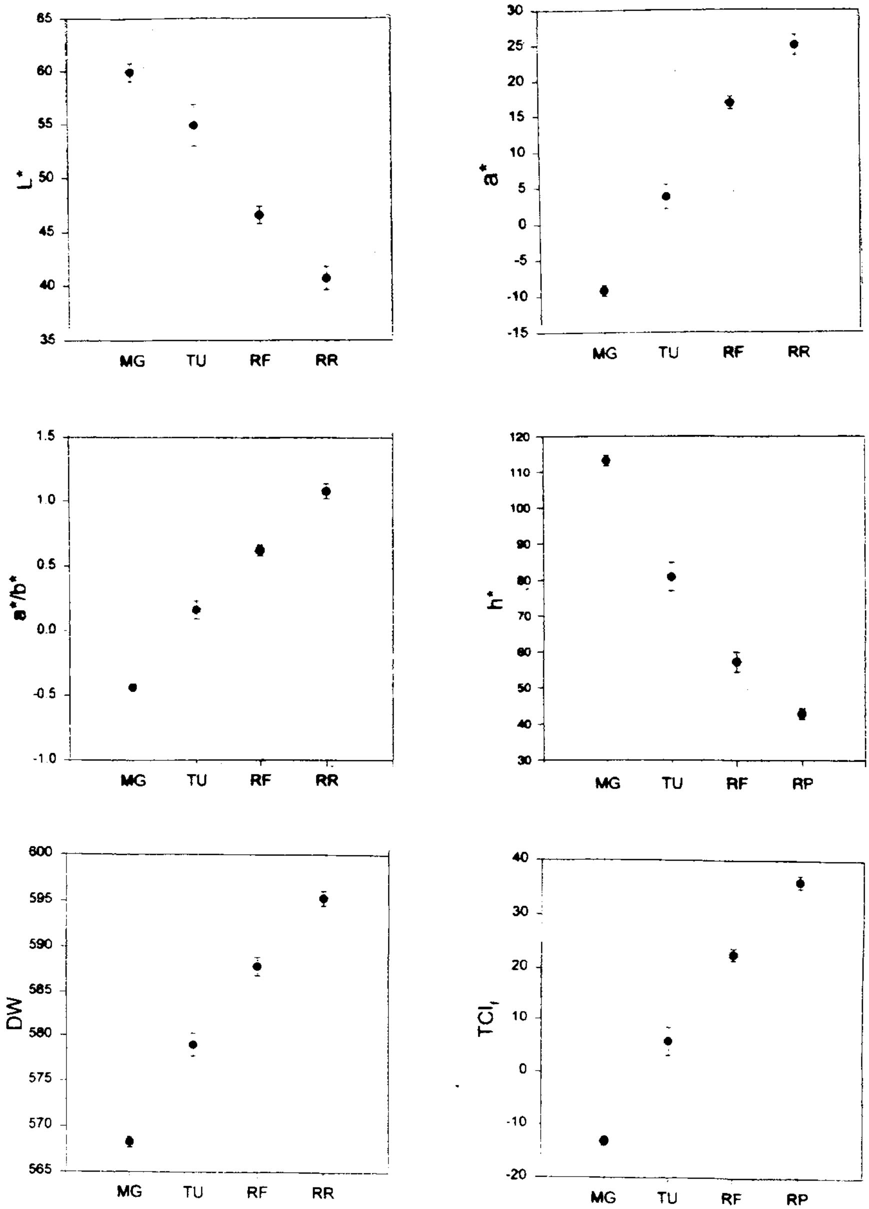

FIG. 1. EVOLUTION OF LUMINOSITY (L*), RED-GREEN COMPONENT (a), a*/b* RATIO, DOMINANT WAVELENGTH (DW), HUE ANGLE (h*) AND TOMATO COLOR INDEX OF THE WHOLE FRESH FRUIT (TCI_f) DURING TOMATO RIPENING

Each value represents a 95% confidence interval for the means of forty replicates.

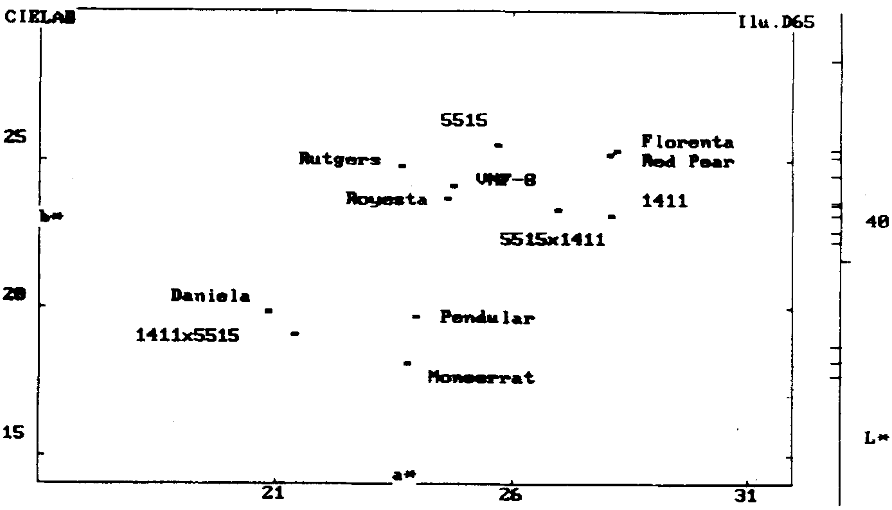

FIG. 2. CIELAB DIAGRAM DISTRIBUTION OF THE TOMATO CULTIVARS DURING THE LAST RIPENING STAGE (RED RIPE)

TABLE 3

TOMATO COLOR INDEX OF THE WHOLE FRESH FRUIT (TCI_f) DURING RIPENING OF THE DIFFERENT CULTIVARS

Cultivar	Mature Green	Turning	Red Firm	Red Ripe
1411	-13.0 c	2.1 e	24.4 a	37.8 c
5515	-13.8 cd	5.6 d	21.8 c	33.3 f
1411 x 5515	-11.6 b	9.0 b	23.0 b	38.8 b
5515 x 1411	-11.8 b	6.4 d	22.7 b	36.4 d
Daniela	-10.3 a	6.2 d	21.5 c	37.9 c
Florenta	-13.2 c	12.5 a	24.8 a	34.8 de
Monserrat	-14.5 d	12.4 a	23.4 b	35.7 d
Pendular	-13.4 c	6.0 d	20.4 d	39.9 a
Red Pear	-12.8 c	8.3 c	25.0 a	35.3 d
Royesta	-14.9 d	-3.1 g	23.3 b	35.1 d
Rutgers	-15.0 d	-0.4 f	18.2 e	33.3 f
VFN-8	-14.7 d	4.5 e	22.4 b	34.3 e

Mean separation by Duncan's multiple range test at 5% level. Means followed by the same letter within column sections do not differ significantly. Each value is the mean of forty replicates.

luminosity (L*) and hue angle (h*) decreased while the other parameters linearly increased during the tomato ripening. For the other parameters studied it was not possible to obtain good discrimination at the different ripening stages (data not shown); the greatest variations among the cultivars were observed in the turning stage of ripening.

Figure 2 shows the different varieties in the CIELAB color diagram during the last ripening stage (red ripe fruit). Note how the cultivars (1411♀ × 5515♂) and Daniela are placed in the lower left with the lowest values of red-green component (a*) and chrome (C*) (Table 2). These two cultivars showed in common the slightly unattractive visual color (coloration defect) found in "long shelf life" tomatoes (Díez 1995). Florenta and Red Pear, on the other hand, appear in the top right of the diagram and showed the highest C* values, due to high values of chromatic coordinates a* and b*.

The cultivars with the least attractive visual colors and lowest a*, b* and L* chromatic coordinates (Pendular, 1411♀ × 5515♂ and Daniela), as expected, showed the highest TCI_f (Table 3).

The color differences among red ripe fruits of the various varieties, determined in terms of its dominant wavelength, was positively correlated with a*/b* ratio (r=0.93) and negatively with h* (r=-0.94)(Table 4). With similar DW values, important differences as for purity, appeared yielding a low relationship (r= -0.25) between these attributes. Purity was greatly related to the presence of yellow pigments (r= 0.97) and to the chrome (r= 0.88) in the red ripe fruits. The other CIELAB attributes were weakly related to the CIE Yxy chromatic coordinates which suggest that there was no direct dependence. On the other hand, the tomato color index in red ripe fresh fruit (TCI_f) was negatively correlated with the luminosity (r=-0.72) and the yellow-blue component (r=-0.73).

TABLE 4

COEFFICIENTS OF LINEAR CORRELATION (r) BETWEEN CIELAB CHROMATIC COORDINATES, CIE Y_{XY} CHROMATIC ATTRIBUTES AND TOMATO COLOR INDEX OF THE WHOLE FRESH FRUIT (TCI_f)

	DW	Purity	TCI_f	L*	a*	b*	C*	h*	a*/b*
DW	1.00								
Purity	-0.25	1.00							
TCI_f	0.44	-0.55	1.00						
L*	0.27	0.17	-0.72	1.00					
a*	0.54	0.64	-0.32	0.57	1.00				
b*	-0.25	0.97	-0.73	0.40	0.68	1.00			
C*	0.16	0.88	-0.58	0.53	0.92	0.92	1.00		
h*	-0.94	0.58	-0.58	-0.15	-0.22	0.57	0.19	1.00	
a*/b*	0.93	-0.59	0.55	0.19	0.21	-0.57	-0.19	-1.00	1.00

This work confirms that "long shelf life" varieties lack a good, final coloration (lowest values of luminosity (L*), red-green component (a*) and chrome (C*)). L*, a*, a*/b* ratio, h*, DW and TCI_f were the parameters at best differentiated the ripening stages of tomato fruit.

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