are present, whether or not an orchard or an area has experienced several years of fire blight, has also been documented (9). All recordings of fire blight were directly associated with the cicada wounds. In retrospect, the antibiotic spray program should have been started with the arrival of the first cicadas, about one week prior to the onset of fire blight symptoms.

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Colorimetric Characterization of Red Pear Cultivars

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Abstract

Fruit color was characterized in eight red pear cultivars by measurement using the Commission Internationale d'Eclairage L* a* b* color space coordinates. Color was measured on sun-exposed and shaded fruit surfaces at mid-summer and three times during harvestable fruit maturity. All cultivars gained red color (a* value) on the sun-exposed surface during the growing season, but varied in yellowness (b* value). Hue angles calculated from these values described differences in color change and color at final harvest. Color response on the shaded fruit surface varied among cultivars to a greater extent than on the sun-exposed surface. 'Rosired Bartlett' and 'Rogue Red' became darker (decreased in L* value) and redder (decreased in hue angle) with maturity on both sun-exposed and shaded fruit surfaces. All other cultivars became lighter and less red with maturity. 'Rogue Red' and 'Cascade' showed the greatest difference in hue between sun-exposed and shaded fruit surfaces, indicating a strong degree of bi-color. The least contrast between fruit surfaces was in 'Starkrimson' and 'Gebhard Red Anjou.'

Introduction

Red pear cultivars grown commercially in the United States originated either as bud mutations on green-fruited trees (e.g., 'Max Red Bartlett,' 'Sensation Red Bartlett,' 'Rosired Bartlett,'

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'Columbia Red Anjou,' 'Gebhard Red Anjou,' and 'Starkrimson' ['Red Clapp's Favorite']) or as hybrids (e.g., 'Cascade' = 'Max Red Bartlett' x 'Comice' [12], 'Rogue Red' = 'Seckel' x [Comice x Farmingdale #122] (8)). Pigments causing red coloration in pears are mainly anthocyanins (4, 5), and cultivars differ in which histogenic layers of the fruit peel express red pigmentation (3). Red pear cultivars have been described in grower publications (2), course and meeting proceedings (13, 14), and variety registries (1), but have not been compared with respect to color quality in scientific journals.

Devices which measure Commission Internationale d'Eclairage L^* a^* b^* color space coordinates offer an opportunity to numerically compare color quality among cultivars, and to describe changes in color over time. The hue angle, which is derived from measured a^* and b^* values, is considered a useful estimate of human visual color experience (6, 9). L^* and some mathematical combinations of L^*, a^*, and b^* have been shown to correlate moderately to strongly with anthocyanin content in apple (10) and pear (4).

The purpose of this study was to evaluate changes in color in red pear cultivars from mid-summer through the period of harvestable maturity, and to compare cultivars with respect to color change and color parameters at final harvest.

Materials and Methods

Fruit color was studied in eight red pear cultivars in 1992. Color was measured in six of the cultivars in 1991, with similar results; only 1992 data is presented. For each cultivar, 20 fruit around the periphery of each of four replicate trees were selected and marked. Color was measured at the same spot on each fruit at each evaluation. Trees of 'Cascade,' 'Rogue Red,' and 'Starkrimson' were located at the Southern Oregon Research and Extension Center in Medford, Oregon, while trees of 'Max Red Bartlett,' 'Sensation Red Bartlett,' 'Rosired Bartlett,' 'Columbia Red Anjou,' and 'Gebhard Red Anjou' were located in various commercial orchards in the Medford growing district.

Color was measured at mid-summer and three times during harvestable fruit maturity, as determined by flesh firmness. Measurements were taken on an 8-mm-diameter marked spot on the fruit at approximately the midpoint between the stem and calyx on both sun-exposed and shaded fruit surfaces, using a Minolta CR-200b portable tristimulus colorimeter. Chromaticity was recorded in Commission Internationale de l'Eclairage L^*, a^* and b^* (CIELAB) color space coordinates (7, 10, 11) after calibration at illuminant condition C (6774K) with a white standard (Minolta calibration plate CR.A43; $L^* = 97.6$, $a^* = -0.5$, $b^* = 2.4$). L^* represents the relative lightness of colors with a range from 0 to 100, being small for dark colors and large for light colors. Both a^* and b^* scales extend from -60 to 60; a^* is negative for green and positive for red, while b^* is negative for blue and positive for yellow. The hue angle was calculated as $\tan^{-1} b^*/a^*$ (in degrees), and chroma, representing color saturation or vividness, was calculated as $(a^{*2} + b^{*2})^{1/2}$ (9).

Results and Discussion

All cultivars gained red color (increased in a^* value) and saturation (chroma) on the sun-exposed fruit surface during the growing season (Table 1). The amount of increase in a^* value among cultivars ranged from 3.4-7.2 (Table 2). Greater differences in both the magnitude and direction of color change on the sun-exposed surface were observed in the b^* value (yellowness) (Tables 1 and 2). Accordingly, some cultivars differed from others in change in hue angle (Table 2) and hue angle at final harvest (Table 3) on the sun-exposed surface. Differences in all color measurements among culti-

Table 1. Colorimetric values of fruit of red pear cultivars at mid-summer and at three times during harvestable maturity.

		Sun-exposed surface[z]					Shaded surface[z]				
Cultivar	DAFB[y]	L*	a*	b*	hue°	chroma	L*	a*	b*	hue°	chroma
Max Red Bartlett	80	33.6	14.4	6.4	24.0	15.8	40.6	12.7	12.4	44.3	17.7
	111	36.1	17.1	10.1	30.6	19.9	43.8	10.0	17.7	60.5	20.3
	123	37.8	18.6	12.3	33.5	22.3	46.2	8.7	20.5	67.0	22.3
	133	40.6	18.9	15.3	39.0	24.3	48.7	6.8	24.8	74.7	25.7
LSD (0.05)[x]		1.3	1.4	0.9	4.0	0.8	2.1	2.5	1.6	7.2	1.1
Sensation Red Bartlett	80	33.6	14.0	6.0	23.2	15.2	38.5	14.3	9.6	33.9	17.2
	111	34.5	16.4	8.4	27.1	18.4	39.1	14.0	13.4	43.7	19.4
	123	37.1	18.2	10.4	29.7	21.0	42.3	14.3	15.3	46.9	20.9
	133	38.1	20.8	13.6	33.2	24.9	43.5	14.5	20.0	54.1	24.7
LSD (0.05)		1.7	1.5	1.6	5.0	1.2	2.0	ns	2.8	10.3	0.8
Rosired Bartlett	84	37.5	9.9	12.2	50.9	15.7	52.4	-8.5	31.1	105.3	32.2
	114	34.2	13.5	8.4	31.9	15.9	42.8	5.8	16.8	71.0	17.8
	122	32.2	16.6	8.4	26.8	18.6	40.1	10.0	13.9	54.3	17.1
	133	33.0	15.2	7.0	24.7	16.7	37.4	11.7	10.4	41.6	15.7
LSD (0.05)		2.4	2.7	2.3	10.5	1.8	1.4	1.4	1.9	5.2	1.8
Cascade	88	35.3	12.8	6.4	26.6	14.3	44.7	4.0	18.7	77.9	19.1
	117	36.6	15.4	10.2	33.5	15.4	46.1	4.2	21.1	78.7	21.5
	124	37.8	15.5	11.7	37.0	19.4	47.1	3.1	22.2	82.1	22.4
	135	39.9	16.6	11.4	34.5	20.1	49.7	2.4	24.8	84.5	24.9
LSD (0.05)		1.4	1.2	1.1	3.5	1.1	ns	ns	ns	ns	ns
Rogue Red	95	43.2	16.6	17.0	45.7	23.8	62.2	-10.7	37.8	105.8	39.3
	145	41.4	22.1	14.5	33.3	26.4	57.6	-0.5	31.0	90.9	31.0
	152	41.4	23.7	15.6	33.4	28.4	57.6	1.0	31.6	88.2	31.6
	159	42.2	23.8	16.6	34.9	29.0	59.0	0.9	32.0	88.4	32.0
LSD (0.05)		ns	2.7	ns	6.7	1.3	2.2	2.9	2.5	5.1	2.5
Starkrimson	59	31.0	11.2	2.0	10.1	11.4	34.2	15.9	4.7	16.5	16.6
	89	31.7	13.2	3.7	15.7	13.7	33.8	15.1	5.8	21.0	16.2
	97	32.3	16.5	5.4	18.1	17.6	34.9	17.6	7.6	23.4	19.2
	102	33.9	16.6	6.2	20.5	17.7	36.4	17.2	8.2	25.5	19.1
LSD (0.05)		1.1	0.5	0.6	2.1	0.6	1.8	1.0	0.9	2.2	1.2
Columbia Red Anjou	99	33.6	13.5	4.6	18.8	14.3	38.4	16.1	7.7	25.6	17.8
	142	35.9	14.8	7.1	25.6	16.4	42.6	12.7	10.5	39.6	16.5
	146	35.4	15.7	7.2	24.6	17.3	42.7	12.7	11.4	41.9	17.1
	154	36.1	16.9	8.0	25.3	18.7	43.6	13.1	12.9	44.6	18.4
LSD (0.05)		0.7	2.0	1.1	1.5	2.3	1.2	1.9	0.6	4.5	1.3
Gebhard Red Anjou	99	33.9	13.5	4.4	18.1	14.2	38.8	14.1	7.4	27.7	15.9
	142	36.9	14.3	6.9	25.8	15.9	43.3	12.2	10.6	41.0	16.2
	146	38.4	15.3	7.2	24.9	16.9	42.0	14.7	9.5	32.8	17.5
	154	34.8	20.1	9.6	25.6	22.3	41.0	16.7	10.5	32.1	19.7
LSD (0.05)		0.8	2.5	0.9	3.6	2.5	1.8	1.4	1.4	5.3	1.1

[z]L = lightness, from 0 (black) to 100 (white): a* = hue component from -60 (green) to 60 (red); b* = hue component from -60 (blue) to 60 (yellow); hue° = arctangent b*/a*; chroma = saturation, $[(a^{*2} + b^{*2})^{1/2}]$.
[y]DAFB = days after full bloom.
[x]Least Significant Difference where ANOVA yielded significant F value ($P \leq 0.05$). ns = F value non-significant. Values are means of four replicate trees, 20 fruit measured on each tree.

Table 2. Change (Δ) in colorimetric values of fruit of red pear cultivars between mid-summer (59-99 DAFB[z]) and late harvest (102-159 DAFB).

Cultivar	Sun-exposed surface[y]					Shaded surface[y]				
	ΔL*	Δa*	Δb*	Δhue	Δchroma	ΔL*	Δa*	Δb*	Δhue	Δchroma
Max Red Bartlett	7.0	4.5	8.9	15.0	8.5	8.1	-5.9	12.4	30.4	8.0
Sensation Red Bartlett	4.5	6.8	7.6	10.0	9.7	5.0	0.2	10.4	20.2	7.5
Rosired Bartlett	-4.5	5.3	-5.2	-26.2	1.0	-15.0	20.2	-20.7	-63.7	-16.5
Cascade	4.6	3.8	5.0	7.9	5.8	5.0	-1.6	6.1	6.6	5.8
Rogue Red	-1.0	7.2	-0.4	-10.8	5.2	-3.2	11.6	-5.8	-17.4	-6.7
Starkrimson	2.9	4.9	4.2	10.4	6.3	2.2	1.3	3.5	9.0	2.5
Columbia Red Anjou	2.5	3.4	3.4	6.5	4.4	5.2	-3.0	5.2	19.0	0.6
Gebhard Red Anjou	0.9	5.4	5.3	8.9	6.9	1.9	3.0	3.6	5.6	4.3
LSD (0.05)[x]	1.5	2.1	1.7	7.0	1.5	2.0	2.7	2.1	6.7	1.7

[z]DAFB = days after full bloom.
[y]L = lightness, from 0 (black) to 100 (white): a* = hue component from -60 (green) to 60 (red); b* = hue component from -60 (blue) to 60 (yellow); hue° = arctangent b*/a*; chroma = saturation, $[(a^{*2} + b^{*2})^{1/2}]$.
[x]Least Significant Difference where ANOVA yielded significant F value ($P \leq 0.05$). Values are means of four replicate trees, 20 fruit measured on each tree.

vars were much greater on the shaded than on the sun-exposed fruit surface, indicating that the response of a cultivar to low light intensity is more important in determining the overall fruit color than is the response to ample light. This also suggests that color in some cultivars can be influenced by cultural practices which affect the light exposure of the fruit.

'Rosired Bartlett' and 'Rogue Red' became darker (decreased in L* value) and redder (decreased in hue angle) with maturity on both sun-exposed and shaded fruit surfaces. All other cultivars became lighter and less red with maturity. This corresponds to the authors' observation that fruit of both 'Rosired Bartlett' and 'Rogue Red' appear green following initial fruit set, while the other cultivars initially appear dark red. It is interesting to note that 'Rosired Bartlett' differs so greatly in the pattern of red color develop-

Table 3. Differences in fruit colorimetric values among red pear cultivars at final harvest in 1992.

Cultivar	Sun-exposed surface[z]					Shaded surface[z]					Hue difference[y]
	L*	a*	b*	hue	chroma	L*	a*	b*	hue	chroma	
Max Red Bartlett	40.6	18.9	15.3	39.0	24.3	48.7	6.8	24.8	74.7	25.7	35.7
Sensation Red Bartlett	38.1	20.8	13.6	33.2	24.9	43.5	14.5	20.0	54.1	24.7	20.5
Rosired Bartlett	33.0	15.2	7.0	24.7	16.7	37.4	11.7	10.4	41.6	15.7	17.0
Cascade	39.9	16.6	11.4	34.5	20.1	49.7	2.4	24.8	84.5	24.9	43.4
Rogue Red	42.2	23.8	16.6	34.9	29.0	59.0	0.9	32.0	88.4	32.0	53.4
Starkrimson	33.9	16.6	6.2	20.5	17.7	36.4	17.2	8.2	25.5	19.1	5.0
Columbia Red Anjou	36.1	16.9	8.0	25.3	18.7	43.6	13.1	12.9	44.6	18.4	19.3
Gebhard Red Anjou	34.8	20.1	9.6	25.6	22.3	41.0	16.7	10.5	32.1	19.7	6.5
LSD (0.05)[x]	1.5	1.8	1.4	4.2	1.5	2.3	3.5	2.7	9.0	2.1	9.3

[z]L = lightness, from 0 (black) to 100 (white): a* = hue component from -60 (green) to 60 (red); b* = hue component from -60 (blue) to 60 (yellow); hue° = arctangent b*/a*; chroma = saturation, $[(a^{*2} + b^{*2})^{1/2}]$.
[y]Hue difference = hue at final harvest on shaded surface minus sun-exposed surface.
[x]Least Significant Difference where ANOVA yielded significant F value ($P \leq 0.05$). Values are means of four replicate trees, 20 fruit measured on each tree.

ment from 'Max Red Bartlett' and 'Sensation Red Bartlett,' even though all are reported to be bud mutations of 'Bartlett' (1).

'Max Red Bartlett' was the first red pear to be grown in significant volume in the United States, but was gradually replaced by 'Sensation Red Bartlett' due to growers' perception of improved red coloration in the latter. Our results show that 'Sensation Red Bartlett' is redder than 'Max Red Bartlett' on both sun-exposed and shaded surfaces, with the greatest difference on the shaded surface. There was no difference in color saturation (chroma). 'Cascade,' which has 'Max Red Bartlett' as a parent, showed similar color values, with slightly more red on the sun-exposed surface and less red on the shaded surface.

On the sun-exposed surface, 'Rosired Bartlett,' 'Starkrimson,' 'Columbia Red Anjou,' and 'Gebhard Red Anjou' had lower L^* values (darker color), and were lower in hue angle (redder) than the other cultivars (Table 3). 'Starkrimson' and 'Rosired Bartlett' had the lowest b^* values (least yellow). 'Starkrimson' also had the lowest hue values on both the sun-exposed and shaded surfaces. 'Rogue Red' had the most highly chromatic (vivid) color on both fruit surfaces.

By comparing the difference in hue between sun-exposed and shaded fruit surfaces, a ranking of the degree of bi-color among cultivars is possible. The desirability of bi-color varies among commercial markets; there appears to be a preference for bi-color pears in countries growing fruit for European markets, while most U.S. producers seek completely red fruit (D. Sugar, personal observation). The greatest difference in hue between sun-exposed and shaded fruit surfaces in this study was in 'Rogue Red' and 'Cascade'; the least difference was in 'Starkrimson' and 'Gebhard Red Anjou' (Table 4).

Conclusion

Differences exist among red pear cultivars in the pattern of red color development over the growing season, in the color responses of sun-exposed and shaded surfaces, and in ultimate color quality at harvest. Measuring color with CIELAB color space coordinates provided a means of numerically describing cultivars and identifying potentially useful differences among them.

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