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The Effect of Year, Cultivar, Location, and Storage Regime on Pecan Kernel Color

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Abstract. **The Munsell color system was used to study kernel color differences between four pecan [*Carya illinoinensis* (Wangenh.) K. Koch] cultivars ('Cheyenne', 'Choctaw', 'Western', and 'Wichita') grown at four locations (Tulare, Calif., and Brownwood, Crystal City, and El Paso, Texas) during two seasons (1987 and 1988) and stored under different temperatures (20 to 24 °C and –5 °C). Kernel color changed over time from yellow to red hues and from lighter to darker values, but changed very little in chroma. Initial ratings of each color attribute by cultivar were positively correlated with patterns of change in that attribute over time. Kernels collected in 1987 were more yellow and had greater color saturation than kernels collected in 1988. 'Cheyenne' kernels were the most yellow of the cultivars tested and 'Wichita' kernels were the most red. 'Cheyenne' kernels were lighter than those of any other cultivar. Kernels frozen 6 or 12 months were more red in hue than unfrozen kernels, but could not be distinguished on the basis of value (lightness). Kernels frozen 12 months had reduced chroma compared to those frozen 6 months or unfrozen. Shelled kernels of 'Wichita' changed hue more in storage than kernels of other cultivars. Shelled kernels held at 20 to 24 °C became darker and developed red coloration quicker than unshelled pecans. Variation in hue and value accounted for the majority of color difference between cultivars. Changes in hue accounted for the majority of color change over time. Differences among cultivars in value (lightness) were consistent over time.**

Kernel color influences the market value of pecans. Lighter kernels receive higher grades and command higher prices than darker kernels (Kays, 1977; U.S. Department of Agriculture, Food Safety and Quality Service–Federated Pecan Growers Association, 1980). In a survey of Texas pecan shellers (Ocker and Storey, 1996), color was ranked as the most important trait in the grading system used to determine sample market value. Other traits considered were percent kernel, moisture content and various kernel defects that cause sample rejection.

Kernel color development is caused in part by oxidation of endogenous leucoanthocyanidins (a class of colorless flavonoids) located in the testa (Senter et al., 1978). Those compounds oxidize to form phlobaphenes, cyanidin and delphinidin. Phlobaphenes, sometimes called tannin reds, are a group of colored polymers derived from condensed tannins (Robinson, 1975). Cyanidin and delphinidin, along with pelargonidin, are the three basic nuclei from which the water-soluble, red anthocyanin pigments form (Jurd, 1972; Robinson, 1975). Phlobaphenes were 10 times more abundant than anthocyanidins in pecan kernels and concentrations increased in direct relationship to changes in kernel color over time (Senter et al., 1978). Concentrations of anthocyanidins were poorly correlated with kernel color changes. There is a correlation between peroxide values (an indication of oil saturation level) and kernel color change over time (Senter et al., 1978).

Kernels darken throughout the harvest period beginning around shuck split (Heaton et al., 1975). Nuts harvested soon after shuck split, promptly dried, and refrigerated maintained color better than those harvested later. McLean (1988) found that kernels from three cultivars of pecans harvested early were lighter in color than kernels from those same cultivars harvested traditionally. Neither dates of harvest nor criteria for considering the harvest early were provided. Kernel color was measured using a Hunter LabScan Colorimeter (Hunter Assoc., Reston, Va.).

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Kays and Wilson (1978) reported that shelled pecans stored in open trays at ambient room temp (24 to 26 °C) darkened more than unshelled pecans. Color change was greatest during the first 4 weeks of storage.

In addition to the above sources of variation, seasonal differences may influence kernel color within a cultivar, since color varies with fatty acid composition, which is sensitive to variation in crop load (Storey et al., 1995). Heaton et al. (1975) reported differences in kernel color over 3 years of a test that were attributed to differences in seasonal growing conditions.

This report analyzes kernel color differences among four pecan cultivars grown at four locations during two seasons and stored under different temperatures and shelling class for extended periods of time. Color was evaluated using the Munsell color system (Munsell Color Co.; Gretag Macbeth Worldwide Headquarters, New Windsor, N.Y.) according to Thompson et al. (1996).

Materials and Methods

Nut samples were collected at maturity, as judged by shuck dehiscence, from 'Cheyenne', 'Choctaw', 'Western', and 'Wichita' trees at each of four locations (Tulare, Calif., and Brownwood, Crystal City, and El Paso, Texas) in 1987 and 1988. Ten nuts from each lot were subjected to destructive quality analysis to determine nut mass and kernel mass for the calculation of kernel percentage. Kernel percentage was calculated as the ratio of the kernel mass in grams for the ten nut sample to the total nut mass in grams for the same sample. Seven 10-nut samples for each cultivar at each location were stored in-shell at 20 to 24 °C in January following the crop year of production. Beginning the January following harvest, a fresh 10-nut sample was cracked every 60 d and kernel color was evaluated. In addition, the shelled kernels from the previous cracking date were reevaluated. More than 5000 kernels were evaluated on the last rating date each year. Data collection was completed in <1 week for the initial cracking period, but required ≈3 weeks for the final rating.

To determine the effect of freezing on color stability, two 10-nut samples for each cultivar at each location were frozen in-shell at –5 °C in January following the crop year of production. They were removed at 6- and 12-month intervals for kernel color evaluation. Kernels from the 6-month storage test were reevaluated on subsequent rating dates.

Table 1. The influence of season, cultivar, and location on pecan nut size and kernel percentage.

Main effect level	N	Nut mass (g)	Kernel mass (g)	Kernel percentage
Season				
1987	16	6.67 b[z]	3.95 b	59.1
1988	16	7.52 a	4.50 a	60.0
$P > T$		0.0145	0.0101	NS
Cultivar				
Choctaw	8	8.44 a	5.00 a	59.4 ab
Wichita	8	7.12 b	4.44 a	62.2 a
Cheyenne	8	6.56 b	3.78 b	57.7 b
Western	8	6.25 b	3.68 b	58.8 b
$P > T$		0.0004	0.0002	0.0400
Location				
Crystal City	8	8.90 a	5.28 a	59.6
Tulare	8	7.07 b	4.17 b	58.8
Brownwood	8	6.21 b	3.70 b	59.6
El Paso	8	6.20 b	3.75 b	60.1
$P > T$		0.0001	0.0001	NS

[z]Least square means in columns within main effects followed by the same letter are not statistically different ($P \leq 0.05$ by paired t test). Interactions were not significant.
[NS]Nonsignificant at $P \leq 0.05$ by paired t test.

At each cracking date, each 10-nut sample yielded 20 kernel halves, which were sorted into three kernel groups: plump, thin, and diseased. Only the analysis of plump kernels is included in this report. Kernel halves were oriented with dorsal surface up and with apices to the right. Color was determined on the right half of the upper shoulder of each kernel half. The Munsell notation for the closest matching color chip was recorded for each kernel half. Lighting and viewing conditions in the laboratory were as recommended in standard test methods (American Society for Testing and Materials, 1989).

Table 2. The influence of season, cultivar, location, and storage regime on hue, value, and chroma of pecan kernels over 6 months.

Main effect		Hue[z]				Value[y]				Chroma[x]			
		Month											
level	N	0	2	4	6	0	2	4	6	0	2	4	6
Season													
1987	833	19.11 a[w]	17.65 a	16.22 a	14.45 a	6.16 a	5.56	5.18	4.86	4.95 a	5.09 a	4.93 a	4.83 a
1988	933	16.72 b	15.24 b	14.22 b	12.64 b	5.87 b	5.55	5.34	5.02	4.01 b	4.07 b	4.02 b	3.96 b
$P > T$		0.0001	0.0001	0.0001	0.0001	0.0109	NS	NS	NS	0.0001	0.0001	0.0001	0.0001
Cultivar													
Cheyenne	434	18.76 a	17.69 a	16.70 a	15.24 a	6.31 a	5.98 a	5.64 a	5.29 a	4.34	4.54	4.46	4.43
Choctaw	455	17.87 b	16.68 b	15.53 b	13.74 b	5.96 b	5.43 b	5.18 b	4.90 b	4.36	4.40	4.30	4.21
Western	438	17.83 b	16.63 b	15.28 b	13.29 b	5.95 b	5.44 b	5.15 b	4.89 b	4.5	4.61	4.53	4.38
Wichita	439	17.21 c	14.78 c	13.36 c	11.92 c	5.83 b	5.38 b	5.06 b	4.68 b	4.71	4.76	4.63	4.56
$P > T$		0.0001	0.0001	0.0001	0.0001	0.0172	0.0086	0.0041	0.0042	NS	NS	NS	NS
Location													
El Paso	453	18.69 a	17.03	15.71	13.99	6.26 a	5.64	5.31	5.03 a	4.58	4.82 a	4.68	4.60
Brownwood	450	17.67 b	16.50	15.46	13.82	5.95 b	5.65	5.38	5.13 a	4.49	4.58 a	4.45	4.36
Crystal City	433	17.70 b	16.15	15.07	13.31	6.03 ab	5.63	5.26	4.92 ab	4.27	4.35 b	4.35	4.40
Tulare	430	17.60 b	16.10	14.63	13.08	5.81 b	5.31	5.08	4.68 b	4.57	4.57 a	4.43	4.23
$P > T$		0.0013	NS	NS	NS	0.0353	NS	NS	0.0409	NS	0.0238	NS	NS
Freeze storage													
Unfrozen	565	18.50 a	16.94 a	15.56 a	13.76	5.93	5.61	5.17	4.80 b	4.77 a	4.60	4.79 a	4.81 a
6 months	598	17.77 b	15.95 b	14.88 b	13.33	5.98	5.50	5.35	5.08 a	4.75 a	4.56	4.16 b	3.98 b
12 months	603	17.48 b	---	---	---	6.12	---	---	---	3.92 b	---	---	---
$P > T$		0.0009	0.0020	0.0425	NS	NS	NS	NS	0.0141	0.0001	NS	0.0001	0.0001

[z]Hue family 22.5 = yellow, 10.0 = red, with intermediate numbers being mixtures of those hues.
[y]Value 0 = black, 10.0 = white, with intermediate numbers being shades of gray.
[x]Chroma 0 = neutral gray, with increasing numbers indicating increased color saturation.
[w]Least square means in columns within main effects followed by the same letter are not statistically different ($P \leq 0.05$ by paired t test). Error was specified as the four-way interaction of main effects. Interactions were not significant.
[NS]Nonsignificant at $P \leq 0.05$ by paired t test.

Changes in hue, value, and chroma were calculated by subtracting the color attribute from a standard rating for that sample. For example, by subtracting the 2-month hue rating from the initial hue ratings for the sample, the change in hue over 2 months is calculated. That figure can be compared with changes in hue experienced at different levels of the test. Kernels from unfrozen and 6-month storage regimes were compared over a 6-month period. Kernels frozen 1 year were evaluated only upon removal from the freezer and were not followed over time. The initial rating of frozen kernels was compared to the initial rating of unfrozen kernels, rather than to samples of equal age stored under ambient conditions.

Data were analyzed using the GLM procedure of SAS (SAS Institute, Cary, N.C.). Least square means were separated using paired *t* tests.

Results

Nut quality varied between seasons, between cultivars, and between locations, as indicated by standard quality analysis (Table 1). Nuts were heavier in 1988 than in 1987, with 'Choctaw' having the heaviest nuts of any cultivar. Nuts from Crystal City were heavier and kernel mass was greater than from any other location. Kernel mass was highly correlated with nut mass, and differed between years, cultivars and locations. Kernel mass of 'Wichita' could not be separated from that of 'Choctaw', despite heavier nuts in the latter cultivar, due to the increased kernel percentage of 'Wichita' nuts. Kernel percentage of all cultivars fell within a range of 57.7% to 62.2%, which indicates high quality nuts.

At the initial color determination, nuts sampled in 1987 were more yellow, lighter in value, and more intensely colored than those sampled in 1988 (Table 2). At each subsequent date of evaluation, hue and chroma differed between years. Kernel value did not differ between seasons after the initial rating (Table 2).

Pecan cultivars could be consistently distinguished on the basis of hue, with kernels of 'Cheyenne' being more yellow than any other cultivar (Table 2). Kernels of 'Choctaw' and 'Western' were intermediate in hue, and were indistinguishable from each other, but more yellow than 'Wichita'. Cultivars were distinguished on the basis of hue at each date of evaluation, and maintained an identical pattern of mean separation (Table 2). However, 'Wichita' kernels changed hue at a different rate than other cultivars (Table 3). When change in hue is expressed as a percentage of the initial hue rating, 'Wichita' changed 47.9% over the duration of the test, ≈10% more than the change measured in 'Western'.

Cultivars were consistently distinguished on the basis of value (Table 2). 'Cheyenne' kernels were lighter (higher value) than those of any cultivar at each date of rating. There were no significant differences between cultivars in the change in kernel value over time (Table 3). Total reduction in value over the 6 months of observation was ≈20% to 24% of the initial value rating.

Cultivars could not be distinguished on the basis of chroma at any date (Table 2). Patterns of chroma change were also not different between cultivars (Table 3).

Samples collected in El Paso were more yellow than from other locations at the initial rating (Table 2). At subsequent ratings, differences were not significant. Patterns of change in hue did not differ by location (Table 3).

Samples collected in El Paso were lighter (higher value) than kernels from Brownwood or Tulare at the initial rating (Table 2). Samples from Brownwood maintained value better than other locations (Table 3) and were among the lightest group in the final evaluation (Table 2).

Table 3. The influence of season, cultivar, location, and storage regime on changes in hue, value, and chroma of pecan kernels over 6 months.

Main effect		Change[z]														
		Hue					Value					Chroma				
		Difference														
level	N	0–2	2–4	4–6	Total	%	0–2	2–4	4–6	Total	%	0–2	2–4	4–6	Total	%
Season																
1987	833	1.67	1.43 a[y]	1.77	4.87	37.1	0.50 a	0.38 a	0.32	1.20 a	26.9	0.34 a	0.16	0.10	0.60 a	16.7 a
1988	933	1.71	1.02 b	1.57	4.30	36.7	0.30 b	0.21 b	0.32	0.83 b	19.7	0.02 b	0.05	0.06	0.13 b	05.5 b
$P > T$		NS	0.0102	NS	NS	NS	0.0086	0.0116	NS	0.0004	0.0002	0.0048	NS	NS	0.0021	0.0012
Cultivar																
Cheyenne	434	1.47 b	0.98	1.47	3.92 b	28.8 b	0.33	0.33	0.36	1.02	19.9	0.11	0.09	0.03	0.22	07.2
Choctaw	455	1.32 b	1.15	1.79	4.26 b	33.2 b	0.51	0.25	0.28	1.04	23.2	0.18	0.11	0.08	0.37	11.5
Western	438	1.41 b	1.35	1.98	4.75 ab	37.8 b	0.46	0.29	0.25	1.00	22.1	0.14	0.08	0.15	0.37	10.5
Wichita	439	2.56 a	1.41	1.44	5.42 a	47.9 a	0.30	0.32	0.39	1.01	23.9	0.30	0.13	0.07	0.50	15.2
$P > T$		0.0011	NS	NS	0.0322	0.0020	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Location																
El Paso	453	1.86	1.32	1.72	4.90	37.8	0.53 a	0.32	0.28	1.14 a	24.2	–0.01	0.14	0.08	0.22 bc	07.2 bc
Tulare	450	1.85	1.47	1.55	4.87	39.4	0.41 ab	0.23	0.40	1.05 a	25.2	0.34	0.14	0.19	0.67 a	18.3 a
Brownwood	433	1.43	1.03	1.64	4.10	32.9	0.24 b	0.27	0.25	0.77 b	15.8	0.25	0.13	0.10	0.48 ab	14.2 ab
Crystal City	430	1.63	1.07	1.76	4.47	37.6	0.41 ab	0.36	0.34	1.12 a	24.0	0.13	0.00	–0.05	0.08 c	04.7 c
$P > T$		NS	NS	NS	NS	NS	0.0447	NS	NS	0.0281	0.0119	NS	NS	NS	0.0249	0.0173
Freeze storage																
Unfrozen	565	1.56	1.38 a	1.79	4.73	37.2	0.32 b[x]	0.44 a	0.37	1.13 a	25.3	0.17	–0.19 b	–0.02	–0.04	01.3 b
6 months	598	1.82	1.07 b	1.55	4.44	36.7	0.48 a	0.16 b	0.26	0.90 b	19.3	0.19	0.39 a	0.18	0.27 a	20.9 a
$P > T$		NS	0.0458	NS	NS	NS	0.0298	0.0001	NS	0.0203	0.0093	NS	0.0001	NS	0.0001	0.0001

[z]Hue change = the difference in hue over the time period specified. Value change = the difference in value over the time period specified. Chroma change = the difference in chroma over the time period specified. Percent change = total change divided by the intial rating × 100.

[y]Least square means in columns within main effects followed by the same letter are not statistically different ($P \leq 0.05$ by paired *t* test). Error was specified as the four-way interaction of main effects. Interactions were not significant.

[x]Nonsignificant at $P \leq 0.05$ by paired *t* test.

Table 4. The effect of shelling date[z] on pecan kernel color attributes (hue,[y] value,[x] and chroma[w]) from nuts of four pecan cultivars collected at four locations over two seasons and stored at 21 to 24 °C temperature for 1 year.

Date shelled	n	Color attribute	Time 2 months	4 months	6 months	8 months	10 months	1 year
		Hue						
1	565		16.94	15.56	13.76 c[v]	12.72	12.26 b	11.45 b
2	583		17.20	15.94	14.08 bc	12.92	12.40 b	11.74 b
3	574			16.06	14.48 ab	13.31	12.66 ab	11.83 b
4	620				14.78 a	13.38	12.87 ab	11.86 b
5	610					13.27	12.87 ab	11.89 b
6	623						13.20 a	11.95 b
7	611							12.79 a
$P > t$			NS	NS	0.0175	NS	0.0452	0.0034
		Value						
1	565		5.61 b	5.17 b	4.80 c	4.65 c	4.53 d	4.38 e
2	583		5.91 a	5.31 b	4.94 bc	4.76 c	4.60 cd	4.50 de
3	574			5.52 a	5.01 b	4.78 bc	4.61 cd	4.50 de
4	620				5.20 a	4.96 b	4.79 bc	4.59 cd
5	610					5.26 a	4.91 b	4.73 bc
6	623						5.18 a	4.80 b
7	611							5.16 a
$P > t$			0.0274	0.0103	0.0007	0.0001	0.0001	0.0001
		Chroma						
1	565		4.60	4.79	4.81	4.49	4.24	4.06
2	583		4.66	4.74	4.82	4.52	4.18	4.11
3	574			4.64	4.91	4.46	4.10	4.11
4	620				4.66	4.41	4.12	3.95
5	610					4.21	4.07	4.04
6	623						3.96	4.09
7	611							3.90
$P > t$			NS	NS	NS	NS	NS	NS

[z]Nuts shelled at 60-d intervals.
[y]Hue family 22.5 = yellow; 10.0 = red; intermediate numbers are mixtures of those hues.
[x] Value 0 = black, 10.0 = white; intermediate numbers are shades of gray.
[w]Chroma 0 = neutral gray; increasing numbers indicate increased color saturation.
[v]Least square means in columns within main effects followed by the same letter are not statistically different ($P \leq 0.05$ by paired t test). Error was specified as the four way interaction of shelling date × year × cultivar × location. There was significant interaction between cultivar and location for some rating dates, as noted in text.
[NS]Nonsignificant at $P \leq 0.05$ by paired t test.

Locations could not be separated on the basis of kernel chroma at the initial rating, although kernels from Crystal City had reduced chroma at the 2-month evaluation (Table 2). Patterns of chroma change did vary by location, with kernels from Crystal City having less change over time than those from Tulare or Brownwood (Table 3).

Freezing kernels for either 6 or 12 months resulted in significant reductions in hue compared to initial ratings of unfrozen kernels (Table 2). At the 2- and 4-month rating, kernels frozen 6 months could still be distinguished from unfrozen kernels by their more reddish hue. At the 6-month rating, kernels could not be distinguished on the basis of hue. Unfrozen kernels showed greater loss in hue during the 2- to 4-month interval than kernels frozen 6 months (Table 3). Total change in hue over the 6-month period of comparison did not differ due to storage regime.

Value (lightness) did not differ due to storage regime until the 6-month rating, when unfrozen kernels were darker than those previously frozen (Table 2). Frozen kernels had a greater reduction in value in the first 2 months after being removed from the freezer (Table 3). However, they changed less over subsequent rating intervals and had less total change in value over the course of the test than unfrozen kernels.

Chroma was significantly reduced in samples frozen 1 year (Table 2). Samples frozen 6 months had reduced chroma as compared to unfrozen kernels at the 4- and 6-month evaluations (Table 2) and experienced greater total reduction in chroma (20.9%) over the course of evaluations (Table 3).

Color saturation (chroma) did not vary significantly between shelled and unshelled pecans over time (Table 4).

Shelled kernels became more reddish with time compared to previously unshelled pecans at a given rating date (Table 4). Differ-

Table 5. Variation in hue[z] between samples of each pecan cultivar collected from four locations, 10-month rating.

Location	Cultivar Cheyenne	Western	Choctaw	Wichita
El Paso	15.53 a[y]	14.31 a	13.30 ab	12.38 a
Brownwood	15.44 a	13.07 ab	13.96 a	11.19 b
Crystal City	15.33 a	12.28 b	13.22 ab	10.79 b
Tulare	13.23 b	12.09 b	12.83 b	10.97 b

[z]Hue family 22.5 = yellow; 10.0 = red; intermediate numbers are mixtures of those hues.
[y]Least square means in columns within main effects followed by the same letter are not statistically different ($P \leq 0.05$ by paired t test).

Table 6. Variation in hue[z] between samples of four pecan cultivars collected from each location, 10-month rating.

	Location			
Cultivar	El Paso	Brownwood	Crystal City	Tulare
Cheyenne	15.53 a[y]	15.44 a	15.33 a	13.23 a
Western	14.31 a	13.07 b	12.28 b	13.07 a
Choctaw	13.30 b	13.96 b	13.22 b	12.81 a
Wichita	12.38 b	11.19 c	10.79 c	10.97 b

[z]Hue family 22.5 = yellow; 10.0 = red; intermediate numbers are mixtures of those hues.
[y]Least square means in columns within main effects followed by the same letter are not statistically different ($P \leq 0.05$ by paired t test).

Table 7. Variation in value[z] (lightness) between samples of each pecan cultivar collected from four locations, 10-month rating.

	Cultivar			
Location	Cheyenne	Western	Choctaw	Wichita
El Paso	5.31 a[y]	4.86 a	4.55 bc	4.54 a
Brownwood	5.18 a	4.95 a	4.87 a	4.62 a
Crystal City	5.19 a	4.41 b	4.65 ab	4.13 b
Tulare	4.55 b	4.43 b	4.34 c	4.09 b

[z]Value 0 = black, 10.0 = white; intermediate numbers are shades of gray.
[y]Least square means in columns within main effects followed by the same letter are not statistically different ($P \leq 0.05$ by paired t test).

Table 8. Variation in value[z] (lightness) between samples of four pecan cultivars collected from each location, 10-month rating.

	Location			
Cultivar	El Paso	Brownwood	Crystal City	Tulare
Cheyenne	5.31 a[y]	5.18 a	5.19 a	4.55 a
Western	4.86 b	4.95 ab	4.41 bc	4.43 a
Choctaw	4.55 b	4.87 b	4.65 b	4.34 ab
Wichita	4.54 b	4.61 c	4.13 c	4.09 b

[z]Value 0 = black, 10.0 = white, with intermediate numbers being shades of gray.
[y]Least square means in columns within main effects followed by the same letter are not statistically different ($P \leq 0.05$ by paired t test).

ences in hue were not significant until the 6-month rating, when previously unshelled pecans could be distinguished from those that had been shelled on dates 1 and 2 (6 and 4 months earlier, respectively). Hue of freshly shelled kernels was distinguishable from some previously shelled samples at the 10-month and 1-year rating. At the 10-month hue rating, interaction between cultivar and location was significant, indicating that cultivars did not have the same pattern of separation at each location (Table 5), and that locations did not have consistent patterns of separation for each cultivar (Tables 6). Samples from El Paso were consistently among the most yellow and those from Tulare were among the most red, for each cultivar (Table 5). However, hue of 'Cheyenne' samples from Brownwood and Crystal City were inseparable from samples from El Paso, while hue of 'Wichita' samples from the former locations were comparable to samples from Tulare. At all locations, 'Cheyenne' was in the most yellow group and 'Wichita' was in the most red group (Table 6). 'Western' and 'Choctaw' were intermediate in hue, and distinct from 'Wichita' and 'Cheyenne' at Brownwood and Crystal City, while both were inseparable from 'Cheyenne' at Tulare. Hue of 'Western' was inseparable from that of 'Cheyenne', while 'Choctaw' was inseparable from 'Wichita' on the basis of hue, in samples collected at El Paso (Table 6).

Shelled kernels darkened more with time than the kernels of previously unshelled pecans (Table 4). Differences in value due to shelling date were apparent at each rating date. Once shelled, kernels darkened quickly and were inseparable from shelled samples of the immediately preceding lot. At the 12-month rating, interaction between cultivar and location was significant, indicating that cultivars did not have the same pattern of separation at each location (Table 7), and that locations did not have consistent patterns of separation for each cultivar (Tables 8). Samples of 'Cheyenne', 'Western', and 'Wichita' from El Paso were among the lightest samples compared to those same cultivars at other locations. Samples of 'Choctaw' from El Paso were among the darkest samples compared to samples of that cultivar from other locations (Table 7). 'Choctaw' samples from El Paso had the highest kernel percentage (62.2%) for that cultivar than at any other location (data not shown). The reduction in value after 1 year might be due to degradation of oil, a factor correlated with kernel darkening (Senter et al., 1978). 'Cheyenne' kernels were in the lightest cultivar group from each location and 'Wichita' kernels were in the darkest (Table 8). However, samples of 'Western' from Brownwood were in the lightest group, while samples of that cultivar from Crystal City were in the darkest group (Table 8).

There was a significant correlation between initial ratings of each color attribute and change of that attribute over time (Table 9); i.e., kernels with the highest value (or hue or chroma) also had the greatest change in value (or hue or chroma, respectively) over time, for each of the four cultivars evaluated. Other relationships were less consistent across cultivars and showed lower levels of correlation. Initial hue was related to value in all cultivars except 'Western', and to chroma in all cultivars except 'Cheyenne'. Initial value was negatively related to chroma and to change in chroma in all cultivars except 'Cheyenne' (Table 9). Initial chroma was directly related to changes in hue in all cultivars except 'Cheyenne'.

Discussion

Variation in hue and value accounted for the majority of color difference among cultivars (Table 2). Changes in hue accounted for the majority of change over time (Table 3), with 'Wichita' showing higher levels of hue change. Although cultivars were consistently distinguished on the basis of value (Table 2), patterns of change in value were uniform across cultivars (Table 3). Although chroma changed over a more narrow range than hue or value, chroma differences by year may reflect critical differences in nut quality. Chroma was significantly higher in samples collected in 1987, a year with significantly smaller nuts and greater changes in value than in the following year.

These data are consistent with the observations of Kays and Wilson (1978), which showed that pecans stored with shells removed darkened more than those stored unshelled. In our study, differences in value between freshly shelled and previously shelled kernels were consistent (Table 4). Separation of previously shelled kernels by shelling date was ephemeral. Kays and Wilson (1978) reported increased rate of color change in the first 4 weeks of observation, which began with removal of nuts from the tree. In our study, observations did not include the immediate postharvest period, and therefore were not comparable. Patterns of color change varied by cultivar, with 'Wichita' changing hue more in the 0- to 2-month period than other cultivars. 'Choctaw' and 'Western' had the greatest incremental change in hue during the 4- to 6-month period. Kays and Wilson (1978) used a different group

Table 9. Pearson Correlation Coefficients for initial pecan kernel color attributes and change in those attributes over time, by cultivar.

	Initial value	Initial chroma	Δ Hue	Δ Value	Δ Chroma	Initial value	Initial chroma	Δ Hue	Δ Value	Δ Chroma
	Cheyenne (n = 138)					**Choctaw (n = 148)**				
Initial hue	0.664	0.115	0.244	0.334	–0.062	0.369	0.367	0.566	0.361	0.267
$P > \|R\|$	0.0001	NS	0.004	0.0001	NS	0.0001	0.0001	0.0001	0.0001	0.001
Initial value		0.009	–0.145	0.754	–0.103		–0.313	0.127	0.581	–0.441
$P > \|R\|$		NS	NS	0.0001	NS		0.0001	NS	0.0001	0.0001
Initial chroma			0.128	0.118	0.644			0.185	0.026	0.915
$P > \|R\|$			NS	NS	0.0001			0.0246	NS	0.0001
Δ Hue				–0.018	0.118				0.199	0.2166
$P > \|R\|$				NS	NS				0.0155	0.0088
Δ Value					–0.009					–0.114
$P > \|R\|$					NS					NS
	Western (n = 134)					**Wichita (n = 145)**				
Initial hue	0.128	0.429	0.672	0.176	0.394	0.195	0.695	0.881	0.012	0.578
$P > \|R\|$	NS	0.0001	0.0001	0.0423	0.0001	0.0190	0.0001	0.0001	NS	0.0001
Initial value		–0.349	0.070	0.622	–0.318		–0.227	0.082	0.580	–0.297
$P > \|R\|$		0.0001	NS	0.0001	0.0002		0.0060	NS	0.0001	0.0003
Initial chroma			0.426	–0.108	0.879			0.633	–0.231	0.816
$P > \|R\|$			0.0001	NS	0.0001			0.0001	0.0052	0.0001
Δ Hue				0.101	0.383				–0.028	0.497
$P > \|R\|$				NS	0.0001				NS	0.0001
Δ Value					–0.052					–0.345
$P > \|R\|$					NS					0.0001

[NS]Nonsignificant at $P \leq 0.05$ by paired t test.

of cultivars, but also found differences in initial color and color stability due to genotype.

The Munsell system should be used to evaluate pecan kernel color in samples subjected to thorough oil and pigment analysis to determine if visible color attributes are accurate indications of variation in other nut quality parameters. The relationship between phlobaphene (red pigment) accumulation and color change reported by Senter et al. (1978) suggests that variation in hue might be directly related to phlobaphene concentration, although a component of that variation could also be reflected by changes in value. Comparative analyses of 'Wichita' versus 'Cheyenne' might contribute to an understanding of hue variation, since the former was more red (Table 2) and changed more over time (Table 3) than the latter. In these data, samples with different shelling dates could be better distinguished by value than by either hue or chroma (Table 4), but all cultivars were uniform in the progression of value change over time (Table 3). The oxidation of fatty acids over time might be accurately reflected by changes in value. Senter et al. (1978) reported a correlation between peroxidation and Hunter colorimeter values of 0.90.

In this study nuts were harvested at maturity, which varies by cultivar in the order of 'Wichita', 'Western', 'Cheyenne', and 'Choctaw'. 'Choctaw' is the last to mature nuts, generally being ≈4 d later than 'Cheyenne' and 8 to 9 d later than 'Wichita' and Western', respectively (Sparks, 1992). Maturation date does not explain color variation in this study, since the lightest, most yellow color was observed in 'Cheyenne', which had an intermediate date of maturation. Ideally, samples should be collected and analyses begun promptly in relation to cultivar phenology, rather than calendar date. Storey et al. (1995) reported variation in patterns of fatty acid composition related to season of maturation, while patterns of color variation were related to fatty acid composition. The precision of the Munsell visual color rating system for monitoring subtle color change over time might provide an interpretable linkage to other biochemical parameters of pecan nut quality measurement.

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