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Husk Softening and Kernel Characteristics of Three Black Walnut Cultivars at Successive Harvest Dates

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***Abstract*. Eastern black walnuts (*Juglans nigra* L.) were collected weekly in September and October to identify a method to determine the optimal harvest date and to develop a quantifiable color classification system for kernels. Husk hardness, measured by a durometer, decreased over a 5-week period. During the collection periods, the greatest percent kernel for 'Emma K', 'Kwik Krop', and 'Sparrow' was recorded when durometer values (i.e., force measurements) of husks were 5.2, 5.5, and 3.4 N, respectively. Husk softening was also detected using the denting method, but the perception of denting did not consistently correspond with a specific husk hardness value. Of the three cultivars, 'Kwik Krop' kernels were the most difficult to visually sort into light, medium, and dark colors. Kernel LCH sum (L* + chroma + hue angle values), measured by a handheld spectrophotometer, provided a reliable color classification for all black walnut cultivars in which light kernels had LCH sums ≥150, medium kernels had sums of 149 to 126, and dark kernels had values ≤125.**

In the United States, an average of 11,340 t of hulled Eastern black walnuts (*Juglans nigra* L.) is sold at buying stations annually (Reid et al., 2004). The supply of black walnuts does not meet the current demand for kernels (B. Hammons, pers. comm.). One reason for the limited supply is that the majority of the nuts are harvested from wild trees. These trees generally produce few fruits per tree, nuts with small kernel size relative to the shell (i.e., small percent kernel), and dark-colored kernels. Black walnut cultivars such as 'Emma K' and 'Sparks 147' produce nuts with an average of ≥34% kernel, whereas those from wild trees average 17% kernel (Reid et al., 2004). At buying stations, producers may receive more than $1.65 per kilogram for nuts harvested from black walnut cultivars, whereas nuts from wild trees are generally priced at $ 0.26 per kilogram (B. Hammons, pers. comm.).

In recent years, black walnut cultivars have been planted in orchards and managed to produce a crop with a higher mean kernel percentage. Black walnuts can be harvested using a tree shaker but are more often picked up from the ground after falling naturally from the tree. Subsequently, yield loss occurs from competition with wildlife and kernel quality is poor. Nuts harvested from the ground have dark-colored husks and kernels (Duke, 2001; Taylor and Perry, 1986). Although there are no industry-wide color standards currently for black walnuts, light-colored kernels are considered desirable (Stoke, 1941). Fancy and standard grades of black walnut kernels used by the major processor are based on kernel particle size and the absence of shriveled, very dark-colored kernels (D. Steinmuller, unpublished data).

When walnuts are mechanically harvested, a dent test is commonly used to determine date of harvest. This is performed by holding the walnut between the fingers and thumb and depressing the husk with the thumb (Taylor and Perry, 1986). Recommendations for optimum harvest dates are when 5% to 50% of the black walnut husks remain dented when the thumb is lifted (Reid, 1992; Reid et al., 2007). Other methods for determining the date of black walnut harvest have not been developed. Recently, Warmund and Coggeshall (2006) used a durometer to measure husk softening of black walnuts. However, there is a paucity of information on the relationships between husk softening, harvest date, and kernel size and color for black walnut cultivars. Therefore, the objectives of this study were to: 1) identify a quantifiable method to determine optimal times of harvest for 'Emma K', 'Kwik Krop', and 'Sparrow' black walnuts; 2) assess kernel color at successive harvest dates; and 3) develop a quantifiable color classification system for these cultivars.

Materials and Methods

Five trees each of 'Emma K', 'Kwik Krop', and 'Sparrow' growing in a nonirrigated orchard near Windsor, MO, were selected based on similarity in tree age (28 to 30 years old), crop load, and location within the site. Trees had been grafted onto seedling black walnut rootstock and were spaced 6.1 × 6.1 m apart. Fertilizer (13N–5.7P–10.8K) was applied annually in February at 112 kg·ha^{-1}. Hourly temperature data at the orchard were recorded by a MetData1 weather station (Campbell Scientific, Logan, UT).

In 2004, each tree had ≈200 fruits. Fifteen fruits per walnut tree were randomly sampled from all quadrants of the tree weekly for 5 consecutive weeks. Based on historical data collected in Missouri (Reid et al., 2007), sampling dates were selected for each cultivar with the third date as the "usual" time of harvest. 'Emma K' and 'Sparrow' were harvested 1 Sept. to 29 Sept. 'Kwik Krop' was harvested 15 Sept. to 13 Oct. Walnuts were removed from the tree with a 3.8-m long fruit picker (Ez Connect; Village Blacksmith, Industry, CA).

Immediately after harvest, husk hardness (i.e., firmness) and color were recorded. Husk firmness was determined by the dent method and by durometer measurements. The first method, the dent test, is the current method used by producers who mechanically harvest (Taylor and Perry, 1986). For the dent test, an unhulled fruit was firmly grasped and pressure was exerted on the surface of the husk with the thumb. When the thumb left an impression in the husk, it was scored as a "dented" fruit. Two dent tests were performed on opposite sides of each fruit. A durometer (Shore-O; New Age Testing Instruments, Southampton, PA) was used to quantify husk firmness from 0 (soft) to 100 (firm) at two locations per fruit. Mean hardness values of husks that dented or did not dent were calculated. Husk firmness values were converted to newtons (N) for data presentation. Husk color was measured using a handheld spectrophotometer (CM-2600d; Konica Minolta, Corp., Ramsey, NJ) with a 10-mm diameter aperture and specular light was included. Two readings of husk color values (L*, chroma, and hue angle) measured on opposite sides of the unhulled fruit were averaged. The L* value ranges from 0 (black) to 100 (white). Chroma (C) is the departure from white toward pure hue color and represents brightness (McGuire, 1992). Hue (H) angle quantifies color, where 0° = purplish red, 90° = yellow, 180° = bluish green, and 270° = blue (Voss, 1992). After husk firmness and color measurements were recorded, walnuts were hulled immediately with a locally produced hulling machine (Lane, 2000) and stored at 21 °C at 50% relative humidity without air movement for 5 weeks to dry. After drying, walnuts were cracked with a mechanized cracker (Lane, 2000) and kernel and shell weights were obtained. The largest piece of each nut was visually sorted into

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light, medium, and dark categories for each cultivar. Kernel color (L*, C, and H) of this piece was recorded as previously described using a 6-mm diameter aperture. The LCH sum was also calculated to compare the accuracy of visual sorting with quantitative measurement using the spectrophotometer. Using the kernel LCH sums, means were calculated for light, medium, and dark categories for each cultivar.

In 2005, fruit collection from the same 'Emma K', 'Kwik Krop', and 'Sparrow' trees was conducted on the same five consecutive sampling dates and experimental procedures were similar to those previously described. However, 'Emma K' fruits were harvested an additional week (6 Oct.) to evaluate the relationship between 100% husk denting and percent kernel. Data from harvest dates were analyzed using a repeated measures analysis of variance with the PROC MIXED procedure of SAS (version 9.1; SAS Institute, Cary, NC) and means were separated by Fisher's protected least significant difference test ($P \leq 0.05$). Linear and quadratic orthogonal contrasts were performed to test the trend of different harvest dates. Denting data were not statistically analyzed as a result of the subjective nature of this assessment of husk softening. Preliminary data indicated that L*, C, and H values decrease as kernels progressively appeared darker in color. Thus, L*, C, and H values for individual kernels that had been visually sorted into light, medium, and dark categories were subjected to stepwise discriminant analysis (PROC STEPDISC procedure) to determine R^2 values for each of the following models: L*, C, H, L* + H, and L* + C + H. Using the parameters selected by the stepwise discriminant analysis, a discriminant analysis (PROC DISC) was performed to determine how well the discriminant function correctly classified visually sorted kernels.

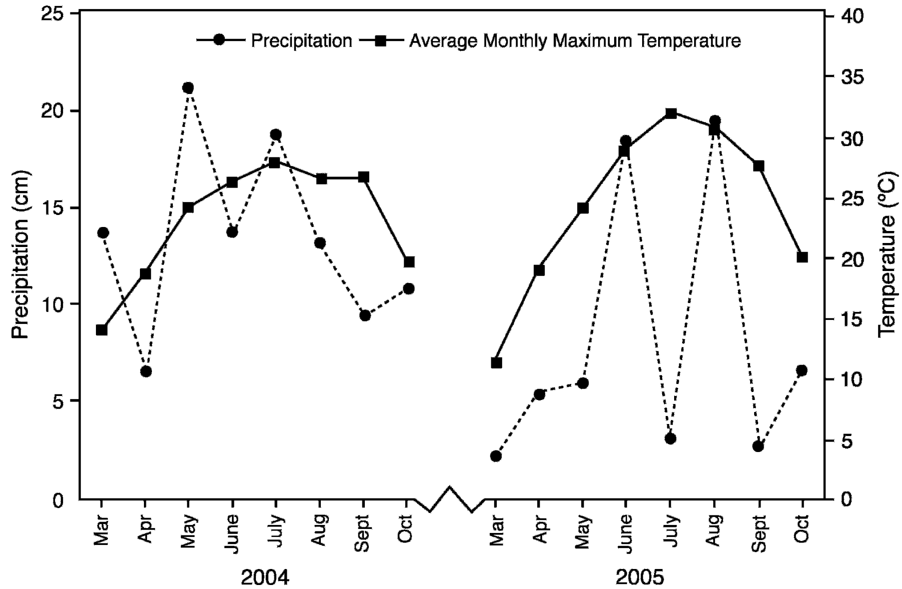

Fig. 1. Monthly precipitation and average monthly maximum temperatures during 2004 and 2005 growing seasons at Windsor, MO.

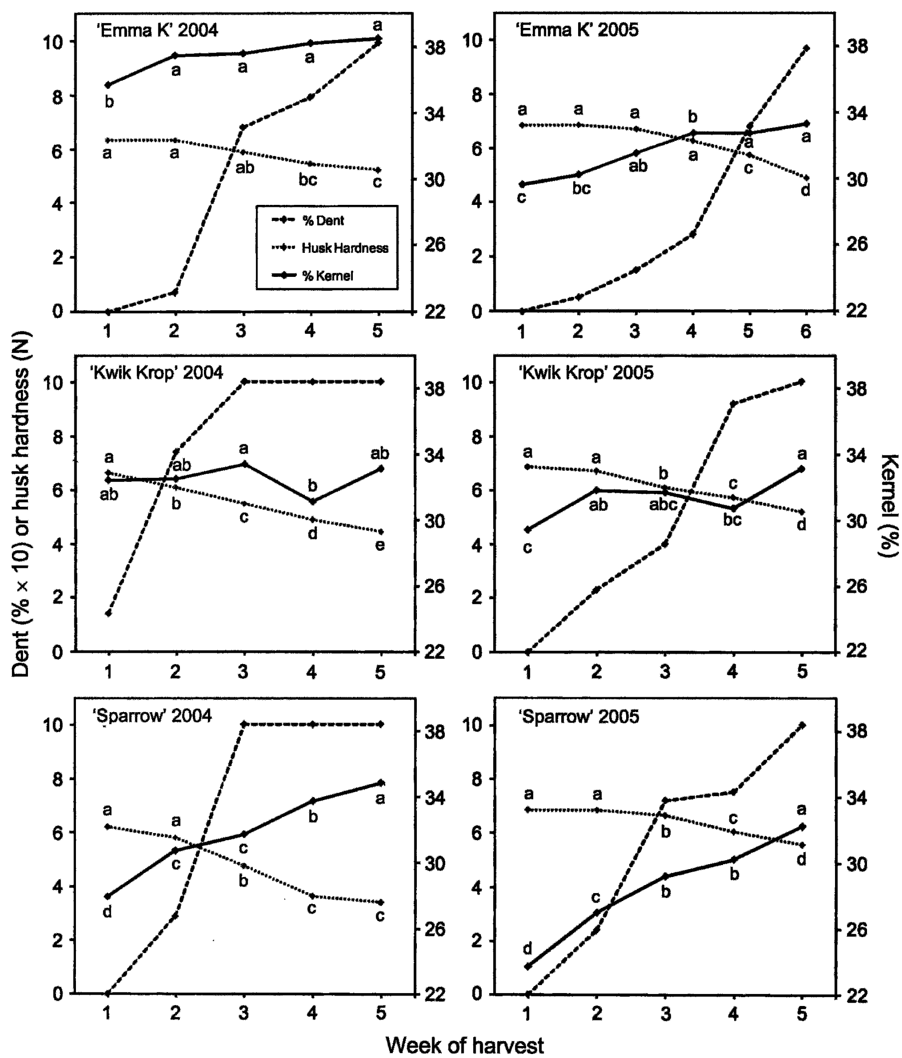

Fig. 2. Percent dent, husk hardness, and percent kernel of 'Emma K', 'Kwik Krop', and 'Sparrow' black walnuts harvested at weekly intervals in 2004 and 2005. For data presentation, actual percent dent values were divided by 10. Weekly means for each cultivar and year with different letters were significantly different by Fisher's protected least significant difference test ($P \leq 0.05$).

Results

Climatic conditions were more favorable for nut production in 2004 than in 2005 (Fig. 1). Rainfall during the growing seasons (March through September) was 107.9 cm in 2004 as compared with 64.5 cm in 2005. The lack of rainfall was especially severe in July and September 2005 with only 3.3 cm and 2.8 cm, respectively, whereas rainfall for July and September 2004 was 19.0 and 9.4 cm, respectively. It was also warmer during June through August 2005 with average monthly maximum temperatures 3 to 4.5 °C higher than those recorded in 2004. These environmental conditions likely contributed to the small percent kernel of walnuts at early harvest dates in 2005.

Husk softening. The percentage of walnut husks that dented generally increased with successive harvest dates for all cultivars (Fig. 2). In 2004, all husks of 'Kwik Krop' and 'Sparrow' dented by the third harvest date (15 Sept. and 29 Sept., respectively). In 2005, a sixth harvest date (6 Oct.) was necessary for 'Emma K' to achieve 97% husk denting.

Durometer values of husk hardness for all black walnut cultivars decreased linearly in most cases with successive harvest dates (Fig. 2; Table 1). 'Sparrow' husks tended to soften relatively more than the other cultivars late in the 2004 harvest season (Fig. 2). Additionally, the mean husk hardness values of walnuts that dented were always lower than those that did not dent for each date of harvest (Table 2). However, the perception of denting did not consistently correspond with a specific husk hardness value. For example, 'Sparrow' husks measuring 6.25 N did not dent on the fourth harvest date in 2005, but husks dented with durometer readings of 6.70 N at the second harvest date. Such inconsistencies in the perception of husk denting also occurred for the other cultivars harvested in 2005.

Percent kernel. Percent kernel of all cultivars increased linearly over harvest dates in both years, except for 'Kwik Krop' in 2004 (Table 1; Fig. 2). Although not statistically significant, the percent kernel of 'Kwik Krop' in 2004 increased from 32.4% to 33.4% with the percent denting from the first to the third harvest date, but it did not increase once 100% of the nuts dented. 'Sparrow' nuts had a particularly large increase in percent kernel over the five sampling dates relative to other cultivars.

Table 1. Significance of linear and orthogonal contrasts performed to test the effect of weekly harvest dates on husk hardness and percent kernel of 'Emma K', 'Kwik Krop', and 'Sparrow' black walnuts in 2004 and 2005.[z]

Year	Cultivar	Husk hardness (N)	Percent kernel (%)
2004	Emma K	L***	L***
	Kwik Krop	L***	NS
	Sparrow	L***	L***
2005	Emma K	L***Q***	L***
	Kwik Krop	L***	L*
	Sparrow	L***Q***	L***

[z]Significant linear (L) or quadratic (Q) effect.
[NS, *, ***]Nonsignificant or significant at $P \leq 0.05$ or 0.001, respectively.

Husk color. Hue angle was the only component of husk color that changed consistently from the first harvest date to the last date for all four cultivars (Table 3). Hue angle values generally decreased (i.e., became more yellow–green) over time. In both 2004 and 2005, chroma values of 'Sparrow' increased linearly with successive harvest dates, whereas those of other cultivars varied by year. L* values of husks of 'Emma K' were similar at all harvest dates in 2005. Although some changes in husk color were recorded, none of the components of color were consistently related to husk softening or percent kernel for all black walnut cultivars (Table 3; Fig. 2).

Kernel color. Husks softened and percent kernel increased at successive harvest dates, but mean kernel L* values for 'Emma K' were similar at all harvest dates, whereas those of 'Kwik Krop' and 'Sparrow' had varying responses over time in 2004 (Table 3). Mean chroma values for kernels remained fairly constant and hue angles generally decreased (i.e., changed from tan to darker brown) at successive harvest dates except for 'Sparrow' in 2004. When 100% denting of 'Kwik Krop' and 'Sparrow' husks occurred early in the 5-week period, average kernel LCH sum rapidly decreased, although nuts were still harvested from the tree (not from the ground). During the warm, dry 2005 growing season, components of kernel color were variable. When stepwise discriminant analysis was performed on kernels visually sorted into light, medium, and dark classes, all color variables were individually significant at $P \leq 0.001$ for all cultivars (Table 4). LCH sum for 'Emma K' kernels had the greatest discriminatory power ($R^2 = 0.816$) of all color variables tested. R^2 values for LCH sum and L* + hue angle were 0.656 for 'Kwik Krop' kernels. For 'Sparrow' kernels, R^2 values for hue angle and chroma alone were lower (≤0.673), whereas those for LCH sum, L* + hue angle, and L* were nearly similar.

When kernels were visually sorted, mean LCH sum values of light-, medium-, and dark-colored kernels varied by cultivar (Table 5). 'Kwik Krop' kernels were the most difficult to sort as a result of the narrower range in color values as compared with those of other cultivars. When kernels of all cultivars were visually sorted, the light-colored ones had mean LCH sum values ranging from 154 to 161. Mean LCH sums of medium-colored kernels for all cultivars varied from 137 to 141. However, mean LCH sums of dark-colored kernels ranged from 110 to 125.

Based on the color means derived from visual sorting (Table 5), kernels with LCH sums ≥150 were considered light-colored, those with sums of 149 to 126 were medium-colored, and kernels with LCH sums ≤125 were considered dark-colored. The discriminant function correctly classified by visual sorting 91%, 80%, and 85% of 'Emma K', 'Kwik Krop', and 'Sparrow' kernels, respectively (Table 6). With the exception of 'Emma K', light- and dark-colored kernels of the other cultivars were correctly identified at relatively higher percentages than the medium-colored kernels (Table 6). When light kernels of all cultivars were incorrectly classified, they were always misidentified as medium-colored (data not shown). For 'Emma K' and 'Kwik Krop', most medium kernels were misclassified equally as light- or dark-colored. For 'Sparrow', medium-colored kernels were most often misidentified as light-colored. When dark kernels of all cultivars were incorrectly classified, they were always misidentified as medium-colored.

Discussion

Results from this study indicated that as the husks softened, the percent kernel increased for all cultivars except 'Kwik Krop' in 2004 (Fig. 2). Although denting the husk with the thumb and using a durometer both detected husk softening, the use of denting was less reliable because the perception of denting did not consistently correspond with a specific husk hardness value as determined by the durometer (Table 2). Although the same individual conducted the dent and durometer tests for each year of this study, different testers could introduce an additional source of error in the dent test. In contrast, the durometer would presumably quantify husk hardness with little variation among users. Thus, it could be used to standardize time of harvest for different cultivars and might minimize error among trained users.

Uniform quality standards for kernel flavor and color have not been developed for black walnut. Because of this, cultivars that produce high yields and large kernels that are free of defects are more profitable. Thus, the optimal time of black walnut harvest is when percent kernel is the greatest. When using the husk denting method, the greatest percent

Table 2. Mean durometer values of husk hardness of walnut cultivars that dented and did not dent at successive harvest dates in 2004 and 2005.

		Husk hardness (N)[z]			
		2004		2005	
Cultivar	Week of harvest	No husk denting	Husk denting	No husk denting	Husk denting
Emma K	1	6.33	—[y]	6.85	—[y]
Emma K	2	6.33	5.65	6.85	6.33
Emma K	3	6.44	5.65	6.70	5.95
Emma K	4	6.33	5.20	6.40	5.58
Emma K	5	6.40	5.20	6.10	4.98
Kwik Krop	1	6.70	5.88	6.85	—[y]
Kwik Krop	2	6.63	5.88	6.78	6.48
Kwik Krop	3	—[x]	5.80	6.40	5.85
Kwik Krop	4	—[x]	4.90	6.03	5.35
Kwik Krop	5	—[x]	4.45	—[x]	5.20
Sparrow	1	6.18	—[y]	6.85	—[y]
Sparrow	2	6.03	5.20	6.85	6.70
Sparrow	3	—[x]	4.75	6.78	6.40
Sparrow	4	—[x]	3.63	6.25	5.80
Sparrow	5	—[x]	3.40	—[x]	5.58

[z]Force measurements were obtained using a Shore O durometer and are presented in newtons (N).
[y]None of the husks dented at this date.
[x]All of the husks dented at this date.

Table 3. Husk and kernel color of black walnut cultivars harvested at weekly intervals in 2004 and 2005.[z]

Cultivar	Harvest date	Husk color L*	Husk color Chroma	Husk color Hue	Kernel color L*	Kernel color Chroma	Kernel color Hue angle	Kernel color LCH sum[y]
				2004				
Emma K	1	49.85 bc[x]	31.75 c	97.82 a	52.73 a	28.94 a	72.15 ab	153.81 a
Emma K	2	48.59 c	33.40 bc	98.64 a	57.95 a	30.62 a	75.30 a	163.87 a
Emma K	3	48.56 c	36.79 a	98.46 a	58.00 a	30.85 a	74.02 a	162.87 a
Emma K	4	50.35 b	36.63 a	97.57 a	54.44 a	29.63 a	71.39 ab	155.47 a
Emma K	5	52.04 a	36.08 ab	92.26 b	53.54 a	30.04 a	67.72 b	153.30 a
Significance[w]		L***, Q***	L***, Q***	L***, Q***	Q*	NS	L*, Q*	NS
Kwik Krop	1	50.46 ab	33.38 ab	95.55 a	58.01 a	24.24 bc	74.22 a	156.48 a
Kwik Krop	2	51.66 a	34.07 ab	95.10 a	56.69 ab	25.63 ab	73.83 a	156.14 a
Kwik Krop	3	51.16 ab	34.79 ab	91.02 ab	55.34 b	26.29 a	72.69 a	154.29 a
Kwik Krop	4	51.85 a	38.29 a	87.62 b	50.89 c	25.82 ab	69.08 b	145.79 b
Kwik Krop	5	46.97 b	30.94 b	78.03 c	45.64 d	23.75 c	65.20 c	134.59 c
Significance		Q*	Q*	L***, Q**	L***, Q**	Q***	L***, Q***	L***, Q***
Sparrow	1	53.76 c	35.71 c	97.97 a	45.23 d	25.46 a	66.79 c	137.48 d
Sparrow	2	53.58 c	37.89 bc	97.99 a	54.71 a	25.62 a	73.52 a	153.85 a
Sparrow	3	55.36 bc	39.27 b	96.19 a	47.94 cd	24.59 a	68.31 c	140.84 cd
Sparrow	4	57.81 b	45.29 a	91.30 b	52.17 ab	25.45 a	71.09 ab	148.71 ab
Sparrow	5	64.10 a	47.50 a	85.57 c	49.85 bc	25.33 a	68.81 bc	143.99 bc
Significance		L***, Q***	L***	L***	Q**	NS	Q*	Q*
				2005				
Emma K	1	51.74 a	29.73 b	100.33 a	46.36 a	23.74 a	68.22 ab	138.32 a
Emma K	2	49.11 a	31.56 ab	99.22 a	48.23 a	24.57 a	70.44 a	143.24 a
Emma K	3	49.31 a	32.41 ab	98.71ab	47.23 a	23.04 a	68.28 ab	138.54 a
Emma K	4	49.45 a	36.68 a	98.81 ab	49.57 a	23.62 a	67.22 ab	140.41 a
Emma K	5	51.55 a	29.90 b	97.30 b	44.93 a	22.25 a	64.98 b	132.16 a
Emma K	6	52.08 a	31.43 ab	95.24 c	44.95 a	24.10 a	65.58 b	134.63 a
Significance		NS	Q*	L*	NS	NS	L*	NS
Kwik Krop	1	51.07 c	33.74 cd	96.43 a	54.12 a	25.39 ab	70.87 ab	150.36 a
Kwik Krop	2	48.45 d	34.65 bc	95.34 ab	56.07 a	26.28 a	72.14 a	154.48 a
Kwik Krop	3	52.42 b	35.06 ab	94.65 b	57.17 a	26.48 a	72.03 a	155.68 a
Kwik Krop	4	53.01 b	32.79 d	94.98 b	54.71 a	26.38 a	70.59 ab	151.68 a
Kwik Krop	5	55.51 a	36.08 a	93.41 c	55.85 a	24.30 b	69.51 b	149.67 a
Significance		L***, Q***	L*	L***	NS	Q**	L*, Q*	L*, Q*
Sparrow	1	52.43 b	35.11 c	98.46 ab	39.35 c	23.32 b	62.84 c	125.51 c
Sparrow	2	54.21 ab	35.13 c	99.08 a	43.27 b	23.41 b	66.50 b	133.19 b
Sparrow	3	52.32 b	35.69 c	97.83 b	44.68 b	22.87 b	66.68 b	134.23 b
Sparrow	4	53.34 b	40.13 a	97.52 b	44.98 b	24.24 ab	62.27 c	136.49 b
Sparrow	5	56.12 a	38.30 b	95.13 c	54.63 a	25.40 a	71.90 a	151.93 a
Significance		L**	L***	L***, Q***	L***, Q**	L**	L***	L***, Q**

[z]Harvest dates 1, 2, 3, 4, and 5 were 1, 8, 15, 22, and 29 Sept., respectively for 'Emma K' and 'Sparrow', whereas harvest dates 1, 2, 3, 4, and 5 were 15, 22, 29 Sept. and 6, 13 Oct., respectively, for 'Kwik Krop' and Football.
[y]LCH sum = the sum of the values for L*, chroma, and hue angle.
[x]Means within each column followed by different letters are significantly different by least significant difference ($P \leq 0.05$).
[w]Significance of linear, L, or quadratic, Q, effects of date of harvest.
NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 4. R^2 values of color variables used to discriminate categories of light, medium, and dark brown kernels of black walnut cultivars.[z]

Color variable[y]	R^2 Emma K	R^2 Kwik Krop	R^2 Sparrow
L* + C + H	0.8164	0.6558	0.7448
L* + H	0.7870	0.6560	0.7564
L*	0.7685	0.6431	0.7698
H	0.7466	0.5729	0.6730
C	0.5342	0.1399	0.3964

[z]R^2 values obtained from stepwise discriminant analysis ($P \leq 0.05$).
[y]Color variables of L*, chroma (C) and hue angle (H) were measured by a spectrophotometer.

Table 5. Mean LCH sums of light, medium, and dark brown kernels of black walnut cultivars that were visually sorted.[z]

Color category	LCH sums Emma K	LCH sums Kwik Krop	LCH sums Sparrow
Light brown	161	157	154
Medium brown	139	141	137
Dark brown	111	125	110

[z]LCH sum = L* + chroma + hue angle. The ranges of LCH sums for light, medium, and dark brown kernels of all cultivars were 175 to 140, 157 to 117, and 130 to 75, respectively.

kernel was generally obtained when nearly all or all of the husks dented for each of the cultivars, except 'Sparrow' in 2004 (Fig. 2). In this case, all of the husks of 'Sparrow' dented by week 3, but percent kernel continued to increase. Using durometer measurements, it was found that 'Sparrow' husks softened rapidly between harvest weeks 3 and 4 and by week 5 had a very low mean hardness value. The reason for this result in 2004 but not in 2005 is unknown. However, in 2005, 'Sparrow' had the greatest percent kernel at a husk hardness value of 5.58 N (Fig. 2). For 'Emma K' and 'Kwik Krop', durometer values of ≤5.2 N resulted in large percent kernel values in both years. In a preliminary study, Warmund and Coggeshall (2006) reported that the optimal time of harvest for 'Surprise' and 'Thomas' was when durometer values were 76 (6.25 N) and 79 (6.48 N), respectively. However, in the earlier study, percent kernel was not measured and the optimal harvest date was determined by the time when 5% of the husks dented, which is the method commonly used by growers. Results from the current study demonstrated that percent kernel was generally the greatest at or near 100% denting.

Although durometer values were associated with percent kernel, the consequence of later harvest dates on kernel size and color was not specifically tested in this study. However, when all 'Kwik Krop' husks dented consistently for the last three harvest dates in 2004, percent kernel fluctuated and kernels became darker in color (L* value) as the harvest date was delayed (Table 3). 'Sparrow' kernels also became darker from week 2 (29% husk denting) to week 3 (100% denting), but the decrease in LCH sum was small thereafter (Fig. 2; Table 3). Although these results may indicate that delayed

Table 6. Percent of kernels correctly classified as light, medium, or dark brown for black walnut cultivars harvested in 2004 and 2005 when the LCH sum values were compared with visual sorting.[z]

Kernel color classification	Cultivar		
	Emma K	Kwik Krop	Sparrow
	Kernels correctly identified (%)		
Light brown	92.3	90.6	89.4
Medium brown	89.5	66.0	77.6
Dark brown	88.8	73.8	94.2
Overall	90.7	80.0	85.3

[z]LCH sum = L* + chroma + hue angle. Light, medium, and dark brown-colored kernels had LCH sums of ≥150, 149 to 126, and ≤125, respectively. Percentages of kernels correctly identified were determined by discriminant analysis. Sample size was 750 kernels per cultivar.

harvest could result in darker-colored kernels, this merits further investigation using quantifiable methods to assess kernel color and percent kernel. Husk hue was the only other parameter measured in this study that consistently changed with percent kernel (Table 3). However, the slight weekly changes in hue would be difficult to visually perceive without the aid of a spectrophotometer.

For Persian walnut (*Juglans regia* L.), 'Chandler' is highly valued for its light kernel color and is considered the standard of comparison for kernel color in new cultivar development (Gale McGranahan, personal communication). For black walnut, Stoke (1941) reported that lighter-colored black walnuts were favorable. However, color standards have not been developed for black walnut. Results from this study demonstrated that the LCH sum was a reliable value for kernel color sorting (Table 4). Kernel LCH sum values of ≥150, 149 to 126, and ≤125 quantified light, medium, and dark brown kernel categories that were visually sorted. Medium brown-colored kernels were generally the most difficult to visually sort (Table 5). Also, 'Kwik Krop' kernels, which had a narrower range of LCH sums, were more difficult to visually sort into medium and dark brown categories than other cultivars that had wider ranges of LCH sums (Tables 5 and 6). Thus, the measurement of LCH sums could be used commercially to sort kernels by color.

For Persian walnut, the important quality factors affecting kernel value are large size, light color, lack of insect damage and mold, and freedom from adhering husk tissue (Olson et al., 1998). The optimal time of harvest for Persian walnuts is when kernels are light brown and the packing tissue surrounding the kernel halves turns brown, which generally occurs 1 to 4 weeks before husk dehiscence (Olson et al., 1998). Thus, the harvest date is determined by the time at which ≈80% of the nuts can be removed from the tree and 95% of them can be hulled (Olson, et al., 1998). In black walnut, hulls must be mechanically removed because the hulls do not naturally dehisce from the shell. Because there are currently no standards for black walnut kernel color, nor price advantage for the grower for harvesting lighter nuts, most growers currently harvest at 5% husk denting (M.V. Coggeshall, pers. comm.). However, results from this study indicated that percent kernel increased with increasing percent denting with a maximum at or near 100% denting. Although the dent test could be used as a low-cost method for estimating time of harvest, the durometer provided a quantitative method for determining the harvest date based on husk hardness and maximum percent kernel.

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