HUSK SOFTENING AND KERNEL CHARACTERISTICS OF EASTERN BLACK WALNUT (*Juglans nigra* L.) CULTIVARS AT SUCCESSIVE HARVEST DATES

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By

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The undersigned, appointed by the Dean of the Graduate School, have examined the thesis entitled

HUSK SOFTENING AND KERNEL CHARACTERISTICS OF EASTERN BLACK WALNUT (*Juglans nigra* L.) CULTIVARS AT SUCCESSIVE HARVEST DATES

Presented by Scott Brawner

A candidate for the degree of Master of Science

And hereby certify that in their opinion it is worthy of acceptance.

Professor Michele Warmund

Professor Christopher Starbuck

Professor Michael Gold

DEDICATION

I would like to dedicate this thesis as I would dedicate any accomplishment or achievement in my life, to my family. The single happiest time in my life is every moment shared with my family. They are the first ones to congratulate me when things go well, and the first to offer support when things don't. My mom is always there for me when I need someone to talk to, even when it's multiple times a day and she is in meetings. My dad is always good at letting me figure things out myself, and offering advice when I need it. Thomas gets the "good sport" award for almost always going along with my plans or ideas even when he didn't think it would work and we would probably either get in trouble or hurt. Rachel receives the "spice girl" award for adding the entertainment and flavor to the family. Ashley gets the "trusty cohort" award for her teamwork in fishing, hunting (though a very short career) and most importantly in making fun of Rachel for the things she says and does. From watching "All My Children" with grandma and grandpa Brawner during a lunch break of a long day of farming to having tacos at grandma and grandpa Schmitz's, my family has shown me what the key to happiness is, and has taught me what is really important in life…family.

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ABSTRACT

Eastern black walnut (*Juglans nigra* L.) nuts were collected weekly to: 1) identify a method to determine the optimal harvest date; 2) develop a quantifiable color classification for kernels; and 3) quantify the effect of delayed husk removal on kernel color. Husk denting, husk hardness (measured with a durometer), and husk color were evaluated. The durometer was a reliable for determining husk softening. Maximum percent kernel for 'Emma K', 'Sparrow', 'Kwik Krop', and 'Football' was recorded when durometer values were ≈ 62, 67, and 71 to 73, respectively. Kernel LCH sum provided a reliable color classification in which light kernels had values ≥ 150, medium kernels had LCH sums of 149 to126, and dark kernels had values ≤ 125. When hulling was delayed two weeks in, kernel LCH sums of 'Emma K', 'Kwik Krop', and 'Sparrow' were lower (e.g. darker in color) than when nuts were husked immediately after harvest.

Chapter 1

INTRODUCTION

In the United States, an average of 11,340 metric tonnes (t) of hulled Eastern black walnuts (*Juglans nigra* L.) are sold to buying stations annually (Reid et al., 2004). The supply of black walnuts does not currently meet the demand (Hammons, 1998). One reason for the limited supply is that the majority of the black walnuts are harvested from wild trees. These trees produce an unpredictable crop that varies in crop yield, kernel size, and quality. In recent years, black walnut cultivars have been planted in orchards and managed to produce a more consistent crop with larger kernels. Black walnut cultivars such as ‘Emma K’ and ‘Sparks 147’ produce nuts with ≥ 34 % kernel while those from seedling trees average 17% kernel (Reid et al., 2004).

Many of the wild black walnuts are harvested after they fall to the ground. Subsequently, yield loss occurs from competition with wildlife and kernel quality is poor. Nuts harvested from the ground have dark-colored indehiscent husks and kernels inside the shell are also dark-colored (Taylor and Perry, 1986). A stain from the husk can penetrate the shell and result in discolored kernels and strong flavors. Although there are no color standards currently for black walnuts, light-colored kernels are desirable (Stoke, 1941).

Mechanical harvesting is a common practice in commercial production of nut crops such as almonds and Persian walnuts. Though not yet widely used for black walnut harvest, it is a labor saving practice for large orchards (Jones, 1998). Reid (1990) and Reid and Coggeshall (in press) recommended that the optimum harvest date was when 5 to 50% of the husks remain dented after applying pressure with the thumb. Recently, Warmund and Coggeshall (2006) used a durometer to determine the harvest dates of four black walnut cultivars. However, there is a paucity of information on the relationship between harvest date and kernel size and quality of black walnut cultivars. Therefore, 'Emma K', 'Football', 'Kwik Krop', and 'Sparrow' nuts were harvested at weekly intervals to: 1) identify a method to determine the optimal harvest date; 2) develop a quantifiable color classification for black walnut cultivars; and 3) evaluate the effect of delayed husk removal on kernel color.

Chapter 2

LITERATURE REVIEW

Black walnut (*Juglans nigra* L.) trees produce valuable nut crops and the timber can also be harvested. While the species is native to most of the eastern United States, most of the nut production is concentrated in the Midwest (Funk, 1979). Currently 900 to 1,300 t of black walnut kernels are consumed annually in the U.S. (Hammons, 1998; Reid, et al., 2004). There is considerable variation in the time of which black walnut trees begin to bear nuts. Grafted trees may start producing a few nuts the second year after planting. Seedling trees do not commonly produce a nut crop until 7 years after planting (Rink et al., 1997; Bratsch, 2004).

When black walnut trees begin flowering, 20 to 30 staminate catkins (5 to 12 cm long) per flowering branch are produced. There are two to five pistillate flowers per flowering branch (Rehder, 1986). Two to five globose to pear shaped fruit (3.5 to 5 cm in diameter) are produced at the terminal of the branch’s current season’s growth (Rehder, 1986; Reid, 1990).

The ripening season for black walnuts varies by cultivar and growing season. Typically in an area with 160-day frost free growing season, walnuts ripen 1 Sept. through early Oct. (Reid and Coggeshall, 2006). Walnuts can be mechanically harvested with a tree shaker, but are more often picked up from the ground after falling from the tree. Subsequently, yield loss occurs from competition with wildlife and kernel quality is poor. Nuts harvested from the ground have dark-colored indehiscent husks and kernels inside the shell are also dark-colored (Duke, 2001; Taylor and Perry, 1986).

When walnuts are mechanically harvested, a dent test is commonly used to determine date of harvest. This is performed by holding the walnut and depressing the husk with the thumb (Taylor and Perry, 1986). Reid (1990) and Reid and Coggeshall (2006) recommended that the optimum harvest date was when 5 to 50% of the black walnut husks remain dented when the thumb is released.

Measuring walnut husk firmness quantitatively is a relatively new idea. Recently, Warmund and Coggeshall (2006) compared O-scale durometer measurements with denting to determine the optimum harvest dates of four black walnut cultivars. Though new to walnuts, determining harvest date by firmness is commonly used in fruit and vegetable production (Blankenship et al., 1997).

Once black walnuts are harvested, the outer fleshy layer (husk) is removed (Taylor and Perry, 1986). Next, the hulled nuts are washed and dried at least 3 weeks before cracking. Kays (2003) reported that temperature was the most critical environmental parameter affecting kernel quality during storage. Walnut kernels have an approximate storage life of eight months at 10º C - 21º C and 15 months at 0º C (Kays, 2003).

Nut quality may be defined by shell thickness, kernel size, kernel percent, tendency to yield large pieces of kernels when cracked, kernel color, flavor and storage life (Funk, 1979). Because walnuts have been typically purchased from the growers at buying stations on a per pound basis, total nut weight has been an important factor in nut production (Bratsch, 2004). However, on a per nut basis, a cultivar's potential performance is often measured by percent kernel (Hammons, 1998). There is great variation in percent kernel and kernel quality among black walnut trees grown in Missouri (Reid and Coggeshall, 2006). For example, black walnut cultivars such as 'Emma K' and 'Sparks 147' consistently produce nuts with ≥ 34 % kernel by weight while those from seedling trees average 17% kernel (Reid et al., 2004).

While kernel color has been identified as a component of black walnut quality, color standards have not been developed. Currently the major processor and supplier of black walnuts in Missouri, Hammons Products Company, packages medium-colored kernels for retail sales (Brian Hammons, personal communication). However Stoke (1941) reported that light-colored kernels were desirable. Thus, the use of medium-colored nuts may be due to the lack of availability of light colored kernels due to the harvesting of nuts from the ground or at the improper time. Dark staining of kernels following delayed hulling has been observed (Chase, 1941; Stokes, 1941; Reid et al., 2004) but not confirmed by quantifiable methods.

Chapter 3

MATERIALS AND METHODS

Five trees each of ‘Emma K’, ‘Football’, ‘Kwik Krop’, and ‘Sparrow’ growing in a commercial orchard near Windsor, Missouri were selected based on similarity in tree age (25-30 years old), crop load, and location within the site. Trees had been grafted onto seedling rootstock and were spaced 6.1 x 6.1 m apart. Fertilizer (13N-5.7P-10.8K) was applied annually in February at 22.7 $kg \cdot ha^{-1}$. Trees received only natural rainfall.

In 2004, 30 walnuts per tree were randomly sampled weekly for five consecutive weeks. Based on historical data collected in Missouri (Mark Coggeshall, unpublished data), 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’ and ‘Football’ were 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 firmness and color were recorded. Husk firmness was determined by two methods. The first method, the dent test, is routinely used by growers (Taylor and Perry, 1986). Thumb pressure was applied to the husk of unhulled walnuts. When the thumb left an impression in the husk, it was scored as a “dented” nut. Two dent tests were performed on opposite side of each nut. A durometer (Shore-O, New Age Testing Instruments, Inc., Southampton, PA) was used to quantify husk firmness from 0 (soft) to 100 (firm). Husk color was measured using a hand-held spectrophotometer (CM-2600d, Konica Minolta, Corp., Ramsey, N.J. with a 10 mm diameter aperture. Two readings of color values (L*, chroma, and hue angle) of the husk measured on opposite sides of the nut walnut 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^o=purplish red, 90^o=yellow, 180^o=bluish green, and 270^o=blue (Voss, 1992). Color measurements were recorded with specular light included. When specular light is included, measurements are unaffected by the specimen surface condition (i.e., amount of gloss) producing values closer to the true color of the specimen (Konica Minolta, 1998). The sum of L*, chroma, and hue angle (LCH sum) was also calculated for each kernel.

After husk firmness and color measurement, 15 walnuts from each tree were hulled immediately with a locally produced hulling machine (Bill Lane, Fair Play, MO) and remnants of the hull were removed using an electric bench grinder with a 15.2 cm-diameter wire brush. Fresh weights of intact nuts were recorded and they were stored at 21ºC for five weeks to dry. The remaining 15 nuts per tree from each cultivar were stored at 5ºC for two weeks before hulling to determine the effect of delayed hulling on kernel color. After two weeks, the walnuts were hulled as previously described and dried at 21ºC for five weeks.

After drying, all walnuts were cracked with a locally produced lever action cracker (Gerald Gardner, Sarcoxie, MO) in 2004. Kernel and shell weights were obtained. Kernel color (L*, chroma, and hue angle) was recorded with a 6 mm diameter aperture as previously described. The sum of these three components of color was also recorded for comparison of kernel color at successive harvest dates using a single value. Kernels were also visually sorted into light, medium, and dark nuts for each cultivar to compare the accuracy of visual sorting to quantitative measurement using the spectrophotometer. Using the kernel LCH sums, means were calculated for light, medium, and dark categories.

In 2005, the experimental procedure was repeated at the five consecutive sampling dates. However, 'Emma K' was harvested an additional week (6 Oct.) to evaluate the relationship between 100% husk denting and percent kernel. Due to a shortage of walnuts in 2005, 15 nuts were sampled from trees of all cultivars. An additional 10 nuts per collection date were sampled from 'Sparrow' and 'Football' trees to evaluate the effect of delayed hulling on kernel color. The effect of delayed hulling was not evaluated for 'Emma K' and 'Kwik Krop' due to the light crop load. Walnuts were cracked with a locally produced mechanized cracker (Bill Lane, Fair Play, MO). Other experimental procedures were similar to those previously described.

Statistical analyses were done with SAS software package (Version 9.1; SAS Institute, Cary, N.C.). Data from harvest dates were analyzed using a repeated measures analysis of variance with the PROC MIXED procedure of SAS and means were separated by Fisher's protected least significant difference (LSD) test, $P \leq 0.05$. Linear and quadratic orthogonal contrasts were performed to test the trend of different harvest dates. Kernel color variables (L*, chroma, hue angle, L*+hue angle, and L*+chroma+hue angle) were subjected to stepwise discriminate analysis (PROC STEPDISC procedure) to determine which variables were most effective in discriminating categories of light, medium, and dark brown kernels. Using the parameters selected by the stepwise discriminate analysis, a discriminate analysis (PROC DISC) was performed to determine how well the discriminate function correctly classified kernels.

Chapter 4

RESULTS

Climatic conditions were more favorable for nut production in 2004 than in 2005. Rainfall during the growing seasons (Mar. through Sept.) was 107.9 cm in 2004 as compared to 64.5 cm in 2005 (Fig. 1). The lack of rainfall was especially severe in July and Sept. 2005 with only 3.3 cm and 2.8 cm, whereas rainfall for July and Sept. was 9.4 and 19 cm, respectively. Average temperatures during June through August were also warmer in 2005 than in 2004 (Fig. 1). During these months, the average daily maximum temperatures averaged 3º to 4.5º C warmer in 2005 than in 2004

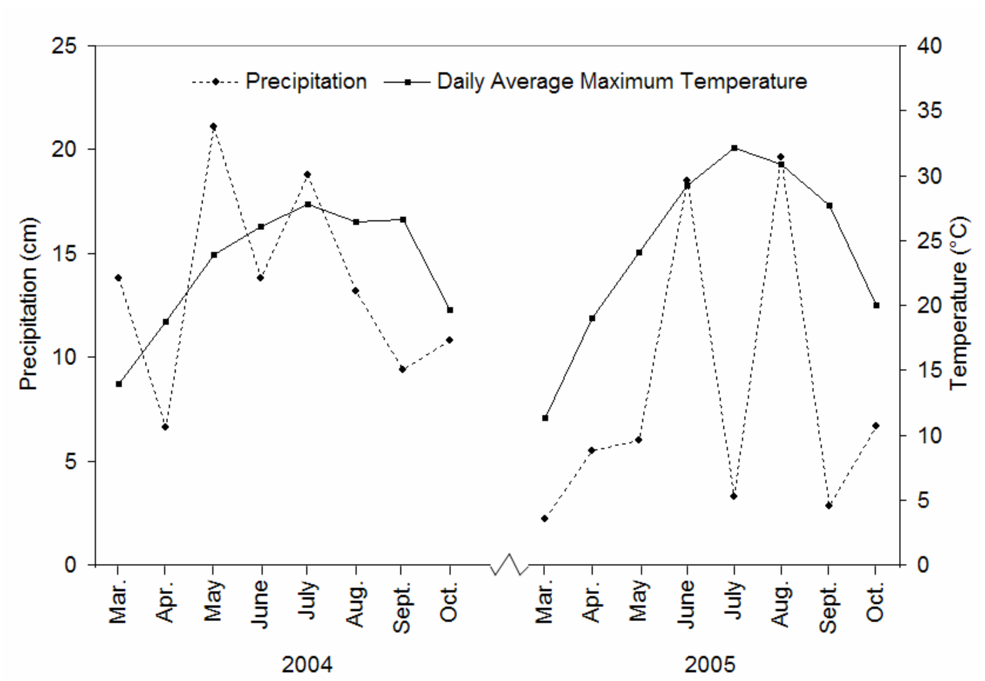

Figure 1. Monthly precipitation and maximum temperatures during 2004 and 2005 growing seasons.

Husk Hardness

The percentage of walnut husks that dented generally increased with successive harvest dates (Table 1). However, in 2004, all husks of ‘Kwik Krop’ and ‘Sparrow’ dented by the third harvest date (15 Sept. and 29 Sept. respectively). In 2005, more than five harvests were necessary for ‘Emma K’ to achieve nearly 100% denting. While all cultivars had increased denting over harvest dates, only 21 to 25% of ‘Football’ husks dented by the fourth harvest date followed by a particularly large increase in denting ($\geq$ 64%) at the last harvest date in 2004 and 2005.

Durometer values of husk hardness for all black walnut cultivars decreased with successive harvest dates (Table 1). While husk hardness among cultivars were not statistically compared in this study, ‘Sparrow’ husks tended to soften relatively more than the other cultivars in 2004. In comparison with the durometer measurements, the mean husk hardness values of walnuts that dented were always lower than those that did not dent (Table 2). However, the perception of denting did not consistently correspond with a specific husk hardness value. For example, 25% of the ‘Sparrow’ husks with durometer values of 76 did not dent on the fourth harvest date in 2005, but 24% of the husks dented with durometer readings of 82 at the second harvest date.

Percent Kernel

Percent kernel of all cultivars increased linearly over harvest dates in both years, except for ‘Kwik Krop’ in 2004 (Table 1). Although percent kernel of ‘Kwik

Krop' increased (32.4% to 33.4%) with the percent denting from the first to the third harvest date, 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. In 2004 and 2005, percent kernel of 'Football' nuts was relatively low (26.5%) at the last date of collection in 2004.

Table 1. Percent denting, husk hardness, percent kernel, and husk and kernel color of four black walnut cultivars harvested at weekly intervals in 2004 and 2005[z].

Cultivar	Harvest date	Percent dent (%)	Husk hardness[y]	Percent kernel (%)	Husk color L*	Husk color Chroma	Husk color Hue angle	Kernel color L*	Kernel color Chroma	Kernel color Hue angle	Kernel color LCH sum[x]
2004											
'Emma K'	1	0	77 a[w]	35.7 b	49.85 bc	31.75 c	97.82 a	52.73 a	28.94 a	72.15 ab	153.81 a
'Emma K'	2	7	77 a	37.5 a	48.59 c	33.40 bc	98.64 a	57.95 a	30.62 a	75.30 a	163.87 a
'Emma K'	3	68	71 ab	37.6 a	48.56 c	36.79 a	98.46 a	58.00 a	30.85 a	74.02 a	162.87 a
'Emma K'	4	79	65 bc	38.2 a	50.35 b	36.63 a	97.57 a	54.44 a	29.63 a	71.39 ab	155.47 a
'Emma K'	5	99	62 c	38.5 a	52.04 a	36.08 ab	92.26 b	53.54 a	30.04 a	67.72 b	153.30 a
Significance[v]											
Date $_l$		--	***	***	***	***	***	NS	NS	*	NS
Date $_q$		--	NS	NS	***	***	***	*	NS	*	NS
'Football'	1	0	86 a	23.0 a	47.33 a	32.19 ab	94.97 a	33.65 a	17.36 a	61.36 a	112.37 a
'Football'	2	3	84 a	23.3 a	47.92 a	29.63 c	94.77 ab	30.62 a	16.31 a	58.89 a	106.62 a
'Football'	3	0	85 a	24.1 a	48.20 a	30.26 bc	95.43 a	31.42 a	15.09 a	56.91 a	102.62 a
'Football'	4	21	80 b	25.6 a	46.69 a	33.22 a	93.72 ab	32.19 a	15.68 a	59.62 a	107.49 a
'Football'	5	85	73 c	26.5 a	48.43 a	30.56 bc	93.13 b	32.63 a	16.12 a	56.41 a	105.16 a
Significance											
Date $_l$		--	***	*	NS	NS	*	NS	NS	NS	NS
Date $_q$		--	**	NS	NS	NS	NS	NS	NS	NS	NS
'Kwik Krop'	1	14	81 a	32.4 ab	50.46 ab	33.38 ab	95.55 a	58.01 a	24.24 bc	74.22 a	156.48 a
'Kwik Krop'	2	74	74 b	32.5 ab	51.66 a	34.07 ab	95.10 a	56.69 ab	25.63 ab	73.83 a	156.14 a
'Kwik Krop'	3	100	66 c	33.4 a	51.16 ab	34.79 ab	91.02 ab	55.34 b	26.29 a	72.69 a	154.29 a
'Kwik Krop'	4	100	58 d	31.1 b	51.85 a	38.29 a	87.62 b	50.89 c	25.82 ab	69.08 b	145.79 b
'Kwik Krop'	5	100	52 e	33.1 ab	46.97 b	30.94 b	78.03 c	45.64 d	23.75 c	65.20 c	134.59 c
Significance											
Date $_l$		--	***	NS	NS	NS	***	***	NS	***	***
Date $_q$		--	NS	NS	*	*	**	**	***	***	***
'Sparrow'	1	0	75 a	27.9 d	53.76 c	35.71 c	97.97 a	45.23 d	25.46 a	66.79 c	137.48 d
'Sparrow'	2	29	70 a	30.7 c	53.58 c	37.89 bc	97.99 a	54.71 a	25.62 a	73.52 a	153.85 a
'Sparrow'	3	100	56 b	31.7 c	55.36 bc	39.27 b	96.19 a	47.94 cd	24.59 a	68.31 c	140.84 cd
'Sparrow'	4	100	41 c	33.7 b	57.81 b	45.29 a	91.30 b	52.17 ab	25.45 a	71.09 ab	148.71 ab
'Sparrow'	5	100	38 c	34.8 a	64.10 a	47.50 a	85.57 c	49.85 bc	25.33 a	68.81 bc	143.99 bc
Significance											
Date $_l$		--	***	***	***	***	***	NS	NS	NS	NS
Date $_q$		--	NS	NS	***	NS	NS	**	NS	*	*

-2005-											
‘Emma K’	1	0	84 a	29.6 c	51.74 a	29.73 b	100.33 a	46.36 a	23.74 a	68.22 ab	138.32 a
‘Emma K’	2	5	84 a	30.2 bc	49.11 a	31.56 ab	99.22 a	48.23 a	24.57 a	70.44 a	143.24 a
‘Emma K’	3	15	82 a	31.5 ab	49.31 a	32.41 ab	98.71 ab	47.23 a	23.04 a	68.28 ab	138.54 a
‘Emma K’	4	28	76 b	32.7 a	49.45 a	36.68 a	98.81 ab	49.57 a	23.62 a	67.22 ab	140.41 a
‘Emma K’	5	68	69 c	32.7 a	51.55 a	29.90 b	97.30 b	44.93 a	22.25 a	64.98 b	132.16 a
‘Emma K’	6	97	58 d	33.3 a	52.08 a	31.43 ab	95.24 c	44.95 a	24.10 a	65.58 b	134.63 a
Significance											
Date $_{l}$		--	***	***	NS	NS	*	NS	NS	*	NS
Date $_{q}$		--	***	NS	NS	*	NS	NS	NS	NS	NS
‘Football’	1	0	87 a	27.2 c	51.16 ab	31.34 b	95.68 a	45.34 c	22.19 a	68.13 c	134.66 b
‘Football’	2	0	85 ab	27.7 bc	48.12 c	33.81 a	95.57 a	47.57 bc	22.24 a	70.22 bc	140.03 ab
‘Football’	3	0	84 ab	29.3 ab	49.95 bc	30.63 bc	94.37 bc	51.09 ab	22.64 a	73.44 a	147.18 a
’Football’	4	25	82 b	28.4 bc	51.19 ab	29.57 c	94.73 b	48.89 abc	22.75 a	70.96 abc	142.61 ab
‘Football’	5	97	71 c	31.3 a	53.44 a	31.43 b	93.86 c	52.39 a	22.05 a	71.85 ab	146.29 a
Significance											
Date $_{l}$		--	***	***	**	*	***	***	NS	**	**
Date $_{q}$		--	***	NS	*	NS	NS	NS	NS	*	NS
‘Kwik Krop’	1	0	84 a	29.4 c	51.07 c	33.74 cd	96.43 a	54.12 a	25.39 ab	70.87 ab	150.36 a
‘Kwik Krop’	2	23	82 a	31.8 ab	48.45 d	34.65 bc	95.34 ab	56.07 a	26.28 a	72.14 a	154.48 a
‘Kwik Krop’	3	40	74 b	31.7 abc	52.42 b	35.06 ab	94.65 b	57.17 a	26.48 a	72.03 a	155.68 a
‘Kwik Krop’	4	92	69 c	30.7 bc	53.01 b	32.79 d	94.98 b	54.71 a	26.38 a	70.59 ab	151.68 a
‘Kwik Krop’	5	100	62 d	33.1 a	55.51 a	36.08 a	93.41 c	55.85 a	24.30 b	69.51 b	149.67 a
Significance											
Date $_{l}$		--	***	*	***	*	***	NS	NS	*	*
Date $_{q}$		--	NS	NS	***	NS	NS	NS	**	*	*
‘Sparrow’	1	0	84 a	23.7 d	52.43 b	35.11 c	98.46 ab	39.35 c	23.32 b	62.84 c	125.51 c
‘Sparrow’	2	24	84 a	27.0 c	54.21 ab	35.13 c	99.08 a	43.27 b	23.41 b	66.50 b	133.19 b
‘Sparrow’	3	72	81 b	29.2 b	52.32 b	35.69 c	97.83 b	44.68 b	22.87 b	66.68 b	134.23 b
‘Sparrow’	4	75	73 c	30.2 b	53.34 b	40.13 a	97.52 b	44.98 b	24.24 ab	62.27 b	136.49 b
‘Sparrow’	5	100	67 d	32.2 a	56.12 a	38.30 b	95.13 c	54.63 a	25.40 a	71.90 a	151.93 a
Significance											
Date $_{l}$		--	***	***	**	***	***	***	**	***	***
Date $_{q}$		--	***	NS	NS	NS	***	**	NS	NS	**

[z] Harvest dates 1, 2, 3, 4, 5 were Sept 1, 8, 15, 22, 29 respectively for Emma K, and Sparrow, while harvest dates 1, 2, 3, 4, 5 were Sept 15, 22, 29, and Oct 6, 13 respectively for Kwik Krop and Football.

[y] Husk hardness values range from 0 (soft) to 100 (hard) on the Shore O Durometer.

[x] LCH sum = the sum of the values for L*, chroma, and hue angle.

[w] Means within each column followed by different letters are significantly different by LSD (*P*≤ 0.05)..

[v] Linear and quadratic orthogonal contrasts were performed to test the trend of different harvest dates. NS, *, **, *** (Nonsignificant, significant at *P*≤ 0.05, 0.01, 0.001, respectively.

Table 2. Husk hardness of walnut cultivars that dented and did not dent at weekly intervals.[z]

		Week of harvest				
Cultivar	Denting	1	2	3	4	5
		2004				
'Emma K'	-[y]	77	77	78	77	78
'Emma K'	+	- - (0)[x]	68 (7)	68 (68)	63 (79)	62 (99)
'Football'	-	86	85	85	83	82
'Football'	+	- - (0)	73 (3)	- - (0)	69 (21)	72 (85)
'Kwik Krop'	-	82	81	- -	- -	- -
'Kwik Krop'	+	71 (14)	71 (74)	66 (100)	58 (100)	52 (100)
'Sparrow'	-	75	73	- -	- -	- -
'Sparrow'	+	- - (0)	62 (27)	56 (100)	40 (100)	38 (100)
		2005				
'Emma K'	-	84	84	82	78	74
'Emma K'	+	- - (0)	77 (5)	72 (15)	67 (28)	58 (68)
'Football'	-	87	85	84	85	76
'Football'	+	- - (0)	- - (0)	- - (0)	80 (25)	71 (97)
'Kwik Krop'	-	85	83	78	73	- -
'Kwik Krop'	+	- - (0)	79 (23)	68 (40)	64 (92)	62 (100)
'Sparrow'	-	84	84	83	76	- -
'Sparrow'	+	- - (0)	82 (24)	78 (72)	70 (75)	67 (100)

[z] Husk hardness values range from 0 (soft) to 100 (hard) on the Shore O Durometer.
[y] - Husks did not dent; + husks dented.
[x] - - No denting occurred. Values in parenthesis represent the percent nuts that dented.

Husk Color

Hue angle was the only component of husk color that consistently changed from the first harvest date to the last date for all four cultivars (Table 1). Hue angle values generally increased (i.e., became more yellowish-green) over time. In both 2004 and 2005, chroma values of ‘Sparrow’ increased linearly with successive harvest dates, while those of other cultivars varied by year. While changes in husk color were recorded, none of the components of color were consistently related to husk softening or percent kernel.

Kernel Color

As husk softening was detected and percent kernel increased at successive harvest dates, mean kernel L* and hue angles generally decreased (Table 1). Mean chroma values of kernels remained fairly constant. When stepwise discriminate analysis was performed, all color variables were individually significant at $P \leq 0.001$ for all cultivars (Table 3). LCH sum for ‘Emma K’ kernels had the greatest discriminatory power (R^2= 0.8164) of all color variables tested. For ‘Football’ and ‘Sparrow’ kernels, R^2 values for hue angle and chroma alone were lower (≤ 0.725), while R^2 values for LCH sum, L*+hue angle, and L* were nearly similar. R^2 values for LCH sum and L*+hue angle were 0.65 for ‘Kwik Krop’ kernels. The discriminate function correctly identified 90% of ‘Emma K’ according to visual classification.

Table 3. R^2 values of color variables used to discriminate categories of light, medium, and dark brown kernels. [z]

Color Variable[y]	R^2			
	'Emma K'	'Football'	'Kwik Krop'	'Sparrow'
L* + C + H	.8164	.8360	.6558	.7448
L* + H	.7870	.8292	.6562	.7564
L*	.7685	.8521	.6431	.7698
H	.7466	.7250	.5729	.6730
C	.5342	.5563	.1399	.3964

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

When kernels were visually sorted, mean LCH sum values of light, medium, and dark colored kernels varied by cultivar when measured by the spectrophotometer (Table 4). 'Kwik Krop' kernels were the most difficult to sort due to the narrower range in color values as compared to those of other cultivars. When kernels of all cultivars were visually sorted, the light colored ones had mean LCH sum values ranging from 153 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.

Table 4. Light, medium, and dark brown kernel classification system based on mean LCH sums.[z]

Color category	LCH sums 'Emma K'	'Football'	'Kwik Krop'	'Sparrow'
Light brown	161	153	157	154
Medium brown	139	139	141	137
Dark brown	111	105	125	110

[z] LCH sum = L* + chroma + hue angle.

Based on the color means (Table 4), 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 discriminate function correctly classified by visual sorting 91%, 88%, 80%, and 85% of 'Emma K', 'Football', 'Kwik Krop', and 'Sparrow' kernels, respectively (Table 5). 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 5). When light kernels of all cultivars were incorrectly classified, they were always misidentified as medium colored (Table 6). For 'Emma K' and 'Kwik Krop', most medium kernels were misclassified as dark colored. For 'Football' and '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.

Table 5. Percent of kernels correctly classified as light, medium, or dark brown for four black walnut cultivars harvested in 2004 and 2005 when the LCH sum values were compared to visual sorting.[z]

Kernel color classification	Cultivar			
	‘Emma K’	‘Football’	‘Kwik Krop’	‘Sparrow’
	---------- Kernels correctly identified (%) ----------			
Light brown	92.3	87.5	90.6	89.4
Medium brown	89.5	83.9	66.0	77.6
Dark brown	88.8	94.7	73.8	94.2
Overall	90.7	88.2	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, ≤ 125, respectively. Percentages of kernels correctly identified were determined by discriminate analysis.

Table 6. Percent of kernels by category incorrectly classified into light, medium, or dark brown categories for four black walnut cultivars harvested in 2004 and 2005 when the LCH sums were compared with visual sorting.[z]

Kernel color classification	Kernels incorrectly classified (%)		
	Light brown	Medium brown	Dark brown
	‘Emma K’		
Light brown	--	7.7	0.0
Medium brown	6.4	--	4.0
Dark brown	0.0	11.4	--
	‘Football’		
Light brown	--	12.5	0.0
Medium brown	15.5	--	0.6
Dark brown	0.0	5.3	--
	‘Kwik Krop’		
Light brown	--	9.4	0.0
Medium brown	18.8	--	15.2
Dark brown	0.0	26.2	--
	‘Sparrow’		
Light brown	--	10.6	0.0
Medium brown	17.0	--	5.3
Dark brown	0.0	5.8	--

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

Delayed Husk Removal

When walnut husk removal was delayed by two weeks, L* and hue angle values of kernels were lower than those recorded without delayed hulling (control kernels) for ‘Emma K’, ‘Kwik Krop’, and ‘Sparrow’ in 2004 (Table 7). Chroma values were also generally lower when husk removal was delayed. Color values of ‘Football’ kernels were very low in 2004 as compared to those of other cultivars in 2004. Thus, lack of a statistical difference between dates was likely due to the low color values (visually dark brown color of the ‘Football’ kernels even after immediate hulling. In 2005, ‘Football’ kernels with delayed hulling were generally darker than those with immediate hulling. The different results for ‘Sparrow’ kernel color in the two years may be attributed to the unusually hot, dry climatic conditions in 2005.

Table 7. The effect of a two week delay in hulling on kernel color of black walnut cultivars in 2004 and 2005.

Cultivar	Husk removal date[z]	Kernel color			
		L*	Chroma	Hue angle	LCH sum[y]
		2004			
'Emma K'	1	55.03 a[x]	29.93 a	72.31 a	157.28 a
'Emma K'	2	46.28 b	28.06 b	65.69 b	140.03 b
'Football'	1	33.07 a	16.97 a	59.52 a	109.57 a
'Football'	2	30.97 a	15.48 a	58.64 a	105.09 a
'Kwik Krop'	1	53.22 a	25.11 a	70.94 a	149.28 a
'Kwik Krop'	2	48.71 b	24.92 a	67.76 b	141.38 b
'Sparrow'	1	49.96 a	25.38 a	69.73 a	145.07 a
'Sparrow'	2	40.19 b	22.24 b	61.06 b	123.49 b
		2005			
'Football'	1	48.64 a	22.02 a	70.68 a	141.34 a
'Football'	2	47.99 a	22.27 a	69.61 a	139.87 a
'Sparrow'	1	45.25 b	23.81 a	66.91 b	135.97 b
'Sparrow'	2	47.90 a	23.21 a	69.21 a	140.32 a

[z] 1 = husks were removed immediately after harvest and 2 = husks were removed two weeks after harvest.
[y] LCH sum = L* + chroma (C) + hue (H) angle.
[x] Cultivar means for husk removal dates followed by different letters are significantly different by LSD ($P \leq 0.05$).

DISCUSSION

Results from this study indicated that husk softening occurred as the percent kernel increased (Table 1). While denting the husk with the thumb and using a durometer both detected husk softening, the use of denting may not always be reliable because it was not always perceived at the same hardness value among the different weeks of harvest for a specific cultivar. 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 contrast, the durometer quantified husk hardness. Thus, it could be used to standardize time of harvest for different cultivars and might minimize error among trained users.

Currently, 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. In this study, the greatest percent kernel was generally obtained when nearly all or all of the husks dented for all cultivars, except ‘Sparrow’ in 2004 (Table 1). In this case, all of the husks of ‘Sparrow’ dented by week 3, but percent kernel continued to increase. Additionally, ‘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 occurrence in 2004, but not in 2005 is unknown. However, in 2005, ‘Sparrow’ had the greatest percent kernel at a hardness value of 67 (Table 1). For ‘Emma

K' and 'Kwik Krop', durometer values of ≈ 62 resulted in large percent kernel values in both years. Percent kernel was greatest for 'Football' when husks had hardness values of 71-73. In a preliminary study (Warmund and Coggeshall, 2006), it was reported that the optimal time of harvest for 'Surprise' and 'Thomas' was when durometer values were 76 and 79, respectively. Additionally, 'Football' was slightly over mature when husk hardness was 73. However, in the earlier study, percent kernel was not measured and the optimal harvest date was determined by the time when husks first began denting, 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. Thus, the optimal time of harvest for 'Football' is at a husk hardness of 71.

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 3 harvest dates in 2004, percent kernel fluctuated and kernels became darker in color (L* value) as the harvest date was delayed (Table 1). While these results may indicate that delayed harvest could result in darker colored kernels, this merits further investigation using quantifiable methods to assess kernel color and percent kernel. None of the other parameters measured in this study consistently changed with percent kernel (Table 1).

For English walnut (*Juglans regia*), the 'Chandler' cultivar is highly valued for its light kernel color and is considered the standard of comparison for kernel color in new cultivar development (Gail 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 3). Kernel LCH sum values of ≥ 150, 149-126, and ≤ 125 quantified light, medium, and dark brown kernel categories that were visually sorted. Medium brown colored kernels were the most difficult to visually sort (Table 5 and 6). Also, Kwik Krop kernels, which had a narrower range of LCH sums were more difficult to visually sort than other cultivars that had wider ranges of LCH sums (Table 4, 5, and 6). Thus, the measurement of LCH sums could be used commercially to sort kernels by color.

The two week delay in hulling generally resulted in darker kernel color with the exception of 'Sparrow' nuts harvested in 2005 (Table 7). Previous researchers (Chase, 1941; Stoke, 1941) noted that delayed hulling resulted in a visible change in kernel color and altered flavor. Reid et al. (2004) attributed this change in kernel color to black-staining alkaloids that are leached from the husks into the kernels, but such a compound has not been identified. Nevertheless, our results quantified the color change that occurred with a two week delay in husk removal. 'Emma K' and 'Sparrow' kernels were most notably altered in 2004 when their kernel color shifted from the light to the medium category after husk removal was delayed for two weeks (Tables 4 and 7).

For English walnut (*Juglans regia*), the important quality factors affecting kernel value are large nut size, light kernel color, lack of insect damage and mold, and nuts free of adhering husk tissue (Olson et al., 1998). The optimal time of harvest for English walnuts (*Juglans regia*) is when kernels are light brown and the packing tissue surrounding the kernel halves turns brown, which generally occurs one to four weeks before hull 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, the date of harvest is determined by the nut size. Thus, results from this study indicated that percent kernel was generally associated with husk softening, which occurred at or near 100% denting. While 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.

Chapter 5

SUMMARY AND CONCLUSIONS

Mature ‘Emma K’, ‘Football’, ‘Kwik Krop’, and ‘Sparrow’ black walnut trees growing in a commercial orchard near Windsor, Missouri were selected for the study. In 2004, 30 walnuts per tree were randomly sampled weekly for five consecutive weeks with the third week being the “usual” time of harvest. In 2005, the same cultivars were selected, however ‘Emma K’ was harvested an additional week (6 Oct.) to evaluate the relationship between 100% husk denting and percent kernel. Due to a shortage of walnuts in 2005, 15 nuts were sampled from all cultivars. An additional 10 nuts per collection date were sampled from ‘Sparrow’ and ‘Football’ trees to evaluate the effect of delayed hulling on kernel color. The effect of delayed hulling was not evaluated for ‘Emma K’ and ‘Kwik Krop’ due to light crop load. Immediately after harvest, husk firmness was determined by two methods, the dent test and the O scale durometer.

Climatic conditions were more favorable for nut production in 2004 than in 2005. Daily temperatures were moderate during the growing season (Mar. through Sept.) with a more consistent rainfall in 2004 than in 2005 (Fig. 1). Thus, the reduced percent kernel in 2005 as compared to that of 2004 was likely due to the adverse climatic conditions.

The percentage of walnuts that dented generally increased with successive harvest dates with nearly 100% denting occurring by the fifth collection date (Table 2). In 2004, however, all nuts of ‘Kwik Krop’ and ‘Sparrow’ dented by the third harvest date. Also, in 2005, more than five harvests were necessary for ‘Emma K’ to achieve nearly 100% denting.

Durometer values of husk hardness for all black walnut cultivars decreased with successive harvest dates (Table 2). Percent kernel of all cultivars increased linearly over harvest dates in both years, except for ‘Kwik Krop’ in 2004 (Table 1). Percent kernel of ‘Kwik Krop’ increased up to 33.4% by the third harvest date when 100% of the husks dented, but did not increase thereafter. When comparing the dent test with the durometer values, the mean husk hardness values of nuts that dented were always lower than those that did not dent. The perception of denting did not consistently correspond with a specific husk hardness value. Thus, the durometer values provided a quantitative measurement of husk softening at each harvest date. Durometer values of 62, 67, and 71 to 73 resulted in maximum percent kernel for ‘Emma K’, ‘Sparrow’ and ‘Kwik Krop’ and ‘Football’, respectively.

Changes in husk color were recorded at successive harvest dates (Table 2). Generally husks changed from green to a more yellow-green color at the later harvest dates. However, none of the values were consistently associated with percent kernel.

When stepwise discriminate analysis was performed, step 1 showed kernel LCH sum reliably sorted kernels by color (Table 3) for all cultivars tested. After visual sorting, light colored nuts had mean LCH sums ranging from 153 to

161 for all cultivars (Table 4). Medium colored kernels had LCH sums ranging from 137 to 141, while dark colored kernels had sums from 105 to 125. Based on these color means, three kernel color categories were established. Kernels with LCH sums $\geq$ 150 were considered light colored, those with sums from 149-126 were medium colored, and kernels with LCH sums $\leq$ 125 were dark colored. ‘Kwik Krop’ medium and light kernels were the most difficult to sort to visually sort due their narrow range of color (Tables 4, 5, and 6).

A two week delay in husk removal generally resulted in a lower kernel LCH sum in 2004 and kernels appeared darker in color (Table 7). The inconsistent results of delayed hulling for ‘Sparrow’ in 2005 may be attributed to the adverse climatic conditions.

In conclusion, husk softening, measured by a durometer, provided a reliable and quantitative method for determining date of harvest to maximize percent kernel. The dent test also measured husk softening, but the perception of denting was not always reliable when compared to durometer values. While color standards do not currently exist for Eastern black walnut kernels, this study demonstrates that three color categories (light, medium, and dark) can be established from spectrophotometer values for all four of the cultivars tested.

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