Pecan Nut and Kernel Traits Are Related to Shelling Efficiency

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Abstract. The U.S. Dept. of Agriculture, Agricultural Research Service conducts the largest and oldest pecan [*Carya illinoensis* (Wangenh.) K. Koch] breeding program in the world. This program evaluates thousands of nut and kernel samples each year using a standard nut and kernel evaluation system developed and refined for more than 70 years. This report relates the effectiveness of these evaluations to commercial shelling efficiency by direct comparison of these data to commercially shelled samples from the same clone performance test. Visual ratings of shelled kernel samples (1–5, with 1 = best) were correlated with time required to hand clean kernel samples ($r = 0.55$). As percent kernel increased, visual ratings of shelled kernels improved (decreased) ($r = -0.73$). More intact halves were recovered from shelled samples with the best (lowest) visual ratings ($r = -0.67$). Conversely, fewer pieces of any size were present in samples with the best visual ratings. Visual ratings improved as nut density decreased ($r = 0.33$). Samples with the lightest kernel color also had the best visual ratings ($r = 0.38$). These data show that the standard U.S. Dept. of Agriculture pecan nut and kernel evaluation system needs to be refined by modifying selection pressure placed on various standard evaluation traits.

A century ago, almost all pecans were collected from natural stands (native trees). The nuts were small and had thick shells that were hard to remove. The portion of the U.S. crop that is collected from native trees has steadily decreased due to habitat annihilation and poor economic returns. Breeding efforts to improve pecan nut quality have been successful (Grauke and Thompson, 1996).

The U.S. Dept. of Agriculture, Agricultural Research Service pecan breeding program is headquartered at College Station, and Brownwood, Texas. This program, which began in ≈ 1932 , has released 24 cultivars in cooperation with various state agricultural experiment stations (Thompson and Grauke, 1991; Thompson and Young, 1985). Controlled crosses are made between selected parents, trees are evaluated under field conditions, and the best clones are selected for further testing in the National Pecan Advanced Clone Testing System (NPACTS). In NPACTS orchards, clones are vegetatively propagated and their performance is compared to standard commercial cultivars. Tests are conducted in several major pecan production areas to determine specific environmental suitability of new cultivars. The average time from crossing to cultivar release is 27.25 years (shortest time 13 years; longest time 60 years). Considering the year to make the controlled cross, the 10-year cycle for evaluation in the Basic Breeding Program (BBP), and the 9- to 15-year evaluation period in NPACTS, a development time of 20 years is required.

Since about 90% of pecans are shelled before retail sale, and all are eventually shelled, ease of shelling and yield of large kernel halves or pieces is of major economic importance. Yet little is known about the effects of basic nut and kernel traits in determining ease of machine shelling. In this breeding program, ease of shelling and removal of packing material from the dorsal grooves, ventral grooves, and other kernel surfaces are major continuous selection criteria.

In the NPACTS program, basic nut evaluation is routine, but the relationship of these measurements to actual commercial shelling efficiency has been inadequate. Therefore, the objective of this study was to compare data collected in the laboratory with results obtained from commercial shelling operations.

Materials and Methods

Nut samples were collected from trees in an NPACTS test established on a DeLeon silty clay soil (fine, mixed, thermic Udic Haplustolls) at Brownwood, Texas. Rootstocks were grafted in Apr. 1996 to 50 clones (Table 1), consisting of 46 advanced selections from the BBP, and four standard control cultivars ('Desirable', 'Navaho', 'Pawnee', and 'Wichita'). Spacing was 9.14 m $\times$ 10.7 m, with single-tree plots, and eight replications. Standard Texas Agricultural Extension Service recommendations for culture and irrigation were followed.

During Sept. and Oct. 2001, trees were individually hand harvested. The nut samples were dried at 35 °C for 3 to 10 d until moisture content had been reduced to about 4%. Samples were then stored in brown paper bags under frost-free refrigeration at 2 °C.

A five-nut sample from each of eight single-tree replications was analyzed according to the standard NPACTS nut analysis system. A

flow chart of procedures and acronyms were assigned to different parameters measured (Fig. 1). Data included nut length (NL), nut width (diameter across suture) (NWth), nut height (diameter perpendicular to suture) (NH), nut weight (NW), and nut buoyancy (NB). Nut buoyancy was determined by submerging individual nuts in a weighted screen container in water below a Mettler digital balance (modified method described by Waugh, 1938). The balance was supported by a wooden frame above a container of water. The difference in weight of the empty screen container suspended in the water and the decreased weight of the container with the nut submerged was buoyancy. These whole-nut data were used to calculate nut length:width ratio (NL:NWth), nut length:height ratio (NL:NH), nut volume (NV), and nut density (ND). Buoyancy in grams was added to nut weight to determine nut volume in milliliters since density of water is 1.0. Nut density was determined by dividing weight by volume.

Nuts were then individually shelled and kernel weight (KW) was determined, along with percent packing material retained in the dorsal and ventral grooves (DGP% and VGP%, respectively), percent testa covered with fuzz (Fz%), and 1–5 visual kernel color rating (1 = best or lightest) (KC) (Thompson et al., 1996). Kernel percent (kernel weight divided by nut weight) (K%) was also determined. Shell weight was used to determine the shell weight to nut volume ratio (ShWt:NV).

Bulked nut samples from the above NPACTS test were also used to run a cracking test and a shelling test (Fig. 1). In the cracking experiment, a few nuts were used to set the Edible Nut Cracker (Meyer Manufacturing Co., San Antonio, Texas) before each of the 500-g test samples was cracked. This test sample was then screened using a wire screen with square 6.35-mm openings. Small kernel fragments >5mm in diameter that passed through this screen were removed, and the remaining shell portion was weighed. Percent shell fragments was then computed.

A larger 2.5-kg nut sample was also cracked using the Meyer cracker, adjusting the machine for every sample. The sample was then shelled using a pecan sheller (Thomson, model 0092, T.I. Thomson Inc., Cairo, Ga.). This sheller produced two samples: one mostly kernels, and the other mostly shells (Fig. 1). The kernel fraction was rated by Mr. Kenneth Fangue, an experienced commercial pecan sheller. He made a single visual rating on each kernel fraction (1–5, with 1 the most desirable). In making this rating, he considered ease of shelling based upon general appearance, amount of shell retained on kernels, amount of dorsal and ventral packing material retained on kernels, degree of kernel breakup, and other general shelling traits. He also made general comments on shelling traits.

The kernel and shell portions from the shelling process were further analyzed in the laboratory. The kernel fraction was divided into four subsamples, one of which was analyzed further. Percent packing material retained in the dorsal grooves (ShDGP%), percent pack-

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Table 1. USDA–ARS selections and standard cultivars in 2001 pecan shelling test. Clone numbers indicate last two digits of year cross was made, cross number, and seed or clone number. Fangue visual rating of shelled kernel samples are from 1–5, 1 = best. Time is minutes to hand-clean kernel samples from sheller. ShK%K is percent kernel of shelled kernel fraction. See Fig. 1 for additional notation.

Clone	Female parent	Male parent	Nut shape	Visual rating	Time (min·kg ⁻¹)	ShK%K	K (%)	ShWt:NV (g·mL ⁻¹)
81-07-0133	Wichita	Cherokee	Oblong elliptic	3	72.39	0.818	53.4	0.36
81-07-0502	Wichita	Cherokee	Ovate	5	85.62	0.761	53.7	0.39
82-10-0003	Wichita	Pawnee	Elliptic	1	47.13	0.861	53.8	0.38
82-10-0135	Wichita	Pawnee	Oblong elliptic	2	68.09	0.880	60.1	0.33
82-10-0149	Wichita	Pawnee	Elliptic	2	76.93	0.862	60.7	0.31
82-13-0015	53-9-1	Pawnee	Elliptic	3	70.18	0.762	49.8	0.35
82-16-0014	Pawnee	Wichita	Elliptic	3	46.24	0.824	58.5	0.35
83-03-0075	Wichita	Pawnee	Elliptic	2	67.07	0.896	61.2	0.32
84-03-0030	Cheyenne	Pawnee	Orbicular	2	100.43	0.863	54.4	0.38
85-01-0002	BW-1	Osage	Oblong elliptic	1	52.54	0.940	56.6	0.33
85-02-0225	Cheyenne	Pawnee	Oblong elliptic	2	32.26	0.901	56.2	0.33
85-03-0822	Cheyenne	Creek	Oblong elliptic	1	37.86	0.929	52.5	0.37
86-02-0063	Wichita	Pawnee	Elliptic	2	41.18	0.846	59.6	0.33
86-02-0245	Wichita	Pawnee	Oblong	5	91.80	0.781	56.3	0.38
86-02-0255	Wichita	Pawnee	Oblong	1	57.89	0.832	60.3	0.33
86-02-0417	Wichita	Pawnee	Oblong	3	70.14	0.791	53.9	0.38
86-02-0486	Wichita	Pawnee	Oblong	1	75.36	0.918	45.5	0.33
86-02-1217	Wichita	Pawnee	Elliptic	2	60.49	0.815	52.9	0.36
86-02-1348	Wichita	Pawnee	Elliptic	2	56.25	0.865	57.7	0.34
86-02-1513	Wichita	Pawnee	Ovate	1	35.78	0.862	57.6	0.35
86-02-1516	Wichita	Pawnee	Elliptic	2	66.45	0.821	50.8	0.35
86-02-1568	Wichita	Pawnee	Oblong elliptic	3	55.99	0.733	49.9	0.36
86-02-1709	Wichita	Pawnee	Oblong	2	61.83	0.890	59.0	0.33
86-02-1868	Wichita	Pawnee	Elliptic	3	67.44	0.809	57.4	0.36
86-02-1910	Wichita	Pawnee	Oblong	3	50.73	0.876	57.3	0.35
86-02-2030	Wichita	Pawnee	Oblong elliptic	4	76.92	0.754	57.4	0.35
86-02-2186	Wichita	Pawnee	Oblong	2	46.89	0.853	55.9	0.37
86-02-2313	Wichita	Pawnee	Oblong elliptic	2	62.85	0.858	58.3	0.33
86-02-2645	Wichita	Pawnee	Oblong elliptic	1	78.06	0.945	54.9	0.34
86-02-2734	Wichita	Pawnee	Elliptic	3	65.59	0.766	49.8	0.38
86-02-2889	Wichita	Pawnee	Oblong	1	63.36	0.875	57.4	0.31
86-02-2899	Wichita	Pawnee	Elliptic	1	76.38	0.861	59.7	0.31
86-03-0006	Cheyenne	Pawnee	Ovate	3	67.19	0.810	55.1	0.35
86-03-0008	Cheyenne	Pawnee	Oblong elliptic	2	86.85	0.834	54.2	0.39
86-03-0032	Cheyenne	Pawnee	Ovate	1	69.67	0.891	56.3	0.31
86-03-0040	Cheyenne	Pawnee	Elliptic	5	167.08	0.657	56.6	0.37
86-03-0072	Cheyenne	Pawnee	Elliptic	1	61.18	0.826	54.9	0.36
86-03-0356	Cheyenne	Pawnee	Ovate	3	80.68	0.723	55.3	0.38
86-03-0357	Cheyenne	Pawnee	Elliptic	3	63.73	0.771	57.3	0.34
86-03-0505	Cheyenne	Pawnee	Elliptic	2	44.06	0.932	64.9	0.29
86-03-0624	Cheyenne	Pawnee	Ovate	2	38.04	0.840	55.4	0.36
86-03-0627	Cheyenne	Pawnee	Elliptic	2	60.20	0.816	57.5	0.36
86-03-0666	Cheyenne	Pawnee	Oblong elliptic	3	73.70	0.787	61.1	0.31
87-01-0016	Cheyenne	Pawnee	Oblong elliptic	1	44.89	0.817	56.5	0.34
87-12-0029	Wichita	Pawnee	Oblong	2	35.43	0.825	62.3	0.30
Desirable	Success	Jewett	Elliptic	3	91.55	0.711	50.5	0.36
Navaho	49-13-311	Wichita	Oblong elliptic	1	38.69	0.925	58.5	0.32
Pawnee	Mohawk	Starking	Oblong elliptic	1	44.81	0.899	56.2	0.37
Wichita	Halbert	Mahan	Oblong	2	85.11	0.758	60.0	0.34

ing material retained in the ventral grooves (ShVGP%), and percent of kernel shoulders damaged in the cracking and shelling process (ShDSh%) were determined. The subsample was then hand-cleaned, and time required per kilogram to clean was recorded (time). Weight of clean kernel, shell, and weight of insect-damaged kernels were recorded, and percent kernel (ShK%) was computed. The cleaned kernel portion was then separated into four kernel size classes, each weighed, and percentage of each determined: complete halves (>80% intact) (CH%), large pieces (80% to 50% intact) (LP%), small pieces (50% to 25% intact) (SP%), and remaining chips (Chips%).

Kernel pieces in the shell portion out of shelling machine that were >5-mm diameter were removed by hand. Shell and kernel portions were weighed, and percent kernel in the shell portion was determined (ShShK%).

The GLM and other procedures of SAS (SAS Institute, Cary, N.C.) were used in all statistical tests.

Results and Discussion

The cracking test was conducted to determine the amount of shell fragment that would be shattered and immediately removed from the nut. This could be an indication of how easily the shelling process could separate shell and kernel. The percent shell removed was not significantly different for the five subjective shellability ratings, although there was a slight trend with the most shell removed from the samples rated 1 (1 = 11.0%, 2 = 10.7%, 3 = 10.0%, 4 = 3.4%, and 5 = 7.3%). Pearson correlation coefficients of these two traits were nonsignificant, possibly due to the small sample size.

Of most interest were the subjective ratings made by Mr. Fangue (Table 1), the time to hand-clean the shelled samples, and the amount of shell removal from the shelled kernel samples [percent kernel (ShK%K)]. Of the control cultivars, ‘Navaho’ and ‘Pawnee’ were rated 1 (best), above ‘Desirable’ (rated 3). This was somewhat surprising since ‘Desirable’ is considered to be an excellent shelling cultivar by the industry at large. Overall, there seemed to be little or no general parental effects upon shellability of different clones because full sibs often differed markedly in rating and other parameters.

The quantitative measurements of the kernel and shell samples from the sheller (Fig. 1) were compared using visual ratings as treatments (Table 2). Time required to hand-clean the kernel sample showed significant differences among the five visual rating classes. The

Eight trees representing a single entry

Fig. 1. Flow diagram of pecan shelling procedure. Notations in parenthesis are used in tables and elsewhere to refer to these parameters.

accuracy of these visual ratings made by Mr. Fangue was impressive, and reflects years of hand-cleaning of samples from the sheller.

The percent kernel (ShK%K) was highest for the lowest visual ratings (Table 2). This is logical because the higher percent samples would exhibit greater kernel visibility, with shell parts less obvious.

Surprisingly, the visual ratings for percent dorsal (ShDGP%) and ventral groove packing material (ShVGP%) did not differ significantly. This is a routine measurement made on all samples in all phases of the breeding program, both BBP and NPACTS. Perhaps this lack of difference reflects strong past selection of

the USDA-advanced selections in this test. Overall, the percentages of foreign material retained were low.

A major evaluation criterion in all pecan shelling operations is final kernel piece size, with a premium often being paid for intact halves or large pieces. All four measurements of kernel size differed for visual ratings. Percent intact halves (CH%) showed strong association with visual ratings, with a >30% difference between visual ratings 1 and 5. A near-perfect inverse relationship to percent intact halves is shown for the other three kernel sizes. This inverse relationship must reflect the large quantity of kernel in intact halves for the

lower visual ratings. There was an ≈ 6 -fold increase between ratings 1 and 5 for percent chips (the least valuable kernel size pieces by weight (Table 2)).

Damaged kernel shoulders (ShDSh%) showed nonsignificance, although an interesting trend is present. Perhaps with more samples, this measurement could be significant and useful. This damage is sheller related, in that the pressure to crack the nuts is closely dependent upon shell strength, nut shape, and many other factors. Skill in setting the sheller for each specific nut sample may have been a source of error in this determination.

The proportion of kernel that came out of

the sheller with the shell fraction (ShShK%) did not differ significantly between different visual rating classes (Table 2). The 4% to 7% kernel in this fraction is of economic importance to large shelling operations, and techniques to recover at least a portion of this kernel is routine. Obviously, the lower percentages are desirable in any shelling operation.

Nut quality data taken from individual nuts collected from each of eight trees were evaluated in relation to visual rating classes (Table 3). Nut density (ND), kernel color (KC), and shell weight ratio to nut volume (ShWt:NV) differed with visual ratings. The less dense nuts shelled better, indicating that internal air spaces contribute to ease of shelling. Breeders have always considered high nut density as a quality attribute, but perhaps there is an upper limit that should not be exceeded in the genetic selection process. Romberg (1952) suggested that cultivars could differ in shell thickness per nut volume, which would reduce kernel percentages but increase nut density. This parameter was positively correlated with visual rating classes (Table 4). As shell weight per volume of nuts increased, the shelling rating increased (poorer performance). The shell thickness per nut volume was the single best predictor of shelling performance of all parameters determined in the nut quality analysis, despite the fact that the parameter varied over a narrow range (Table 1). As shell weight per nut volume increased, the time required to shell the samples increased, the shelled percent kernel decreased, the percent complete halves decreased, the percent of all size classes for pieces increased, and the amount of shoulder damage increased (Table 4). Kernel color (KC) differed between visual rating classes (Table 3), with the best ratings (lower values) being brighter. In pecan, dark color of kernels is associated with nut age (Grauke et al., 1998), which leads to rancidity. This association is reflected in the visual ratings made by Ken Fangue.

Other nut quality measurements were not related to visual ratings (Table 3). Nut shape (NL, NWth, NL:NWth, NH, NL:NH) was not related to visual ratings. Grauke and Thompson (1997) used the ratio of nut length

to nut height to describe pecan nut shape, in the following ranking: 1 to 1.39 = orbicular; 1.40 to 1.59 and widest at base = ovate; 1.40 to 1.59 and widest at apex = obovate; 1.40 to 1.59 and widest in middle = oval elliptic; 1.60 to 1.79 = elliptic; 1.80 to 1.99 = oblong elliptic; >2.00 = oblong. Using that scale, samples in this test ranged from orbicular to oblong, the entire range of the scale, but did not differ in shelling performance (Table 1). Standard nut and kernel lab measurements, such as nut weight (NW), buoyancy (NB), volume (NV); or kernel weight (KW) or percent (K%) had no bearing on ease of shelling. Especially surprising is the absence of effect for percent kernel. Nuts in this test ranged from 45.5% kernel (86-02-0486) to 64.9% kernel (86-03-0505) (Table 1). The ratio of kernel to shell affects many economic traits, such as value per pound, and is considered a strong indicator of nut quality, but did not impact shelling performance in this test.

Many traits were correlated (Table 4), with values statistically significant at any level ($P < 0.05$) shown in bold type. The hand-cleaning time (time) varies in relation to the different visual rating classes (rating), which is in general agreement with above results. Rating classes were negatively related to percent kernel in the kernel sample out of the sheller (ShK%K), as expected. There was also a negative association between visually rated class and percent complete halves (CH%), meaning that the lower, or better the rating, the higher this percent. Positive relationships existed between rating and the other three sizes of kernel pieces [large pieces (LP%), small pieces (SP%), and chips (Chips%)]. As discussed above, this inverse association must result from a large proportion of the shelled kernels remaining in complete halves.

The percent kernel in the shell portion out of the sheller (ShShK%) (Fig. 1) was related only to the percent chips (Chips%) in the kernel portion out of the sheller. This is logical because smaller pieces have a greater tendency to be blown out with the shell fragments.

The amount of packing material retained in the ventral groove (ShVGP%) was negatively

related to visual ratings. This was surprising, since no significance for this trait was shown above in either the replicated lab analysis or the single mechanically shelled samples. This r value is not high, and is only significant at $P = 0.04$. As expected from the above data, the dorsal groove packing percent (ShDGP%) was nonsignificant.

Kernel color (KC) was positively related to visual rating class (rating), meaning that lighter color contributed to more desirable (lower) visual ratings. This reinforces the importance of this trait to most people rating pecans. Nut density (ND) was also positively related to rating, explaining a small portion of this variability. As nut density increased, visual rating deteriorated (increased).

Time to hand-clean kernel samples out of the sheller (time) was negatively related to shelled kernel percent (ShK%K) and percent complete halves (CH%), and positively related to percent large pieces (LP%), percent small pieces (SP%), percent chips (Chips%), and kernel color (KC). All of these relationships are similar to those for visual ratings discussed above. Nut density (ND) was not significantly correlated with cleaning time (time) as visual rating (rating) was.

Shelled kernel percent (ShK%K) correlations were very similar to those for visual rating (rating) and cleaning time (time). This characteristic was studied earlier in the NPACTS program (Thompson et al., 1989), and shown to be negatively associated with nut buoyancy, kernel percent fuzz, dorsal groove width, and dorsal groove packing retention. It was positively related to nut density and dorsal groove packing percentage.

The measurements of degree to which kernels broke up during the shelling process [percent complete halves (CH%), percent large pieces (LP%), percent small pieces (SP%), and percent chips (Chips%)], were related to many other measurements. Generally, if the relationship with one of these traits was positive for percent complete halves (CH%), it was negative for the other three kernel size measurements. The reverse effect was also evident. The relationships of these four kernel size classes with nut shape measurements were often significant. For example, there was no relationship between nut length (NL) and percent complete halves (CH%), but there was a negative relationship between percent complete halves and nut width (NWth) and nut height (NH). Importance of nut width in determining kernel breakup is also shown by percent complete halves (CH%) being negatively related to nut width and height, meaning that nuts with greater diameters produced lower percentages of complete halves. The positive

Table 2. Shelling test evaluation parameter means for five visual rating classes. See Fig. 1 for definition of parameters.

Visual rating	Time (min·kg ⁻¹)	ShK%K	ShDGP%	ShVGP%	CH%	LP%	SP%	Chips%	ShDSh%	ShShK%
		%								
1	55 b ^a	88 a	0.50 a	0.50 a	82 a	12 b	3 c	0.9 c	37 a	4.4 a
2	60 b	85 a	0.11 a	0.44 a	72 ab	19 ab	6 bc	2.1 bc	44 a	3.2 a
3	67 b	78 b	0.38 a	0.00 a	60 bc	26 a	9 b	2.6 bc	48 a	3.8 a
4	76 b	75 b	0.00 a	0.00 a	49 c	27 a	19 a	3.9 ab	45 a	4.6 a
5	114 a	73 b	0.33 a	0.00 a	49 c	28 a	16 a	5.6 a	70 a	6.8 a

^aMeans within columns with a common letter are not significantly different according to Duncan's multiple range test, $P < 0.05$.

Table 3. Mean nut parameters of replicated nut and kernel samples from Brownwood, Texas, NPACTS test. See Fig. 1 for definition of parameters.

Rating	NL (mm)	NWth (mm)	NL:NWth (NL:NWth ⁻¹)	NH (mm)	NL:NH (NL:NH ⁻¹)	NW (g)	NB (g)	NV (mL)	ND (g·mL ⁻¹)	KW (g)	K% (%)	DGP% (%)	VGP% (%)	Fz% (%)	KC (1-5)	ShWt:NV (ShWt:NV ⁻¹)
1	44 a ^a	24a	1.8 a	24 a	1.9 a	11.4 a	2.8 a	12 a	0.78 b	5.4 a	56 a	3.1 a	13 a	7.4 a	2.7 b	0.34 b
2	43 a	24a	1.8 a	24 a	1.8 a	10.5 a	2.5 a	13 a	0.81 ab	6.1 a	58 a	4.1 a	12 a	5.5 a	2.9 ab	0.34 b
3	44 a	25a	1.8 a	25 a	1.8 a	10.9 a	3.0 a	13 a	0.79 ab	5.9 a	55 a	3.4 a	14 a	7.4 a	2.9 ab	0.35 ab
4	44 a	26a	1.8 a	24 a	1.8 a	11.5 a	2.4 a	13 a	0.82 ab	6.6 a	57 a	5.9 a	10 a	8.8 a	3.3 a	0.35 ab
5	42 a	24a	1.7 a	23 a	1.8 a	9.9 a	1.6 a	11 a	0.86 a	5.5 a	56 a	8.2 a	6 a	5.2 a	3.3 a	0.38 a

^aMeans within columns with a common letter are not significantly different according to Duncan's multiple range test, $P < 0.05$.

Table 4. Pearson correlation values (r) for pecan shelling traits. See Fig. 1 for definition of parameters. Values that are significant at any level ($P < 0.05$, 0.01, or 0.001) are in bold type.

1	Rating														
2	Time	0.546													
3	ShK%K (%)	-0.732	-0.556												
4	ShShK% (%)	0.105	0.244	-0.140											
5	CH% (%)	-0.671	-0.485	0.577	-0.128										
6	LP% (%)	0.550	0.287	-0.477	0.054	-0.950									
7	SP% (%)	0.720	0.642	-0.605	0.168	-0.878	0.694								
8	Chips% (%)	0.627	0.686	-0.561	0.302	-0.806	0.659	0.782							
9	ShDGP% (%)	-0.047	0.139	0.073	0.118	0.240	-0.300	-0.115	-0.082						
10	ShVGP% (%)	-0.298	0.104	0.291	0.205	0.127	-0.119	-0.114	-0.105	0.317					
11	ShDSh% (%)	0.279	0.124	-0.128	0.152	-0.227	0.262	0.082	0.286	0.016	0.008				
12	NL (mm)	-0.039	-0.223	-0.050	0.026	-0.009	0.054	-0.042	-0.087	-0.184	-0.295	-0.178			
13	NWth (mm)	0.136	0.078	-0.356	0.110	-0.575	0.601	0.427	0.396	-0.096	0.062	-0.133	0.079		
14	NL:NWth	-0.118	-0.221	0.173	-0.030	0.322	-0.300	-0.281	-0.300	-0.104	-0.272	-0.066	0.809		
15	NH (mm)	0.060	-0.048	-0.232	0.084	-0.470	0.505	0.349	0.258	-0.232	0.113	-0.125	-0.010		
16	NL:NH	-0.079	-0.107	0.129	-0.030	0.315	-0.305	-0.270	-0.247	0.027	-0.271	-0.035	0.721		
17	NW (g)	0.179	-0.089	-0.330	-0.028	-0.505	0.524	0.396	0.313	-0.314	-0.187	-0.208	0.458		
18	NB (g)	-0.164	-0.149	-0.040	0.096	-0.166	0.242	0.032	0.023	0.039	0.124	-0.230	0.459		
19	KC	0.385	0.359	-0.377	0.191	-0.280	0.150	0.391	0.424	-0.076	-0.038	0.247	0.052		
20	KW (g)	0.124	-0.163	-0.198	-0.091	-0.384	0.382	0.333	0.229	-0.343	-0.175	-0.275	0.363		
21	DGP% (%)	0.225	0.058	0.038	-0.112	-0.052	0.038	0.075	0.018	0.019	0.163	0.294	0.051		
22	VGP% (%)	-0.107	-0.208	0.030	-0.054	0.117	-0.086	-0.119	-0.177	-0.078	0.039	0.141	-0.379		
23	Fz% (%)	-0.017	0.092	-0.070	0.262	-0.002	-0.010	0.012	0.034	0.096	0.161	-0.092	0.460		
24	NV (ml)	0.061	-0.133	-0.264	0.022	-0.450	0.499	0.308	0.240	-0.216	-0.084	-0.259	0.543		
25	ND (g·mL ⁻¹)	0.333	0.126	-0.184	-0.152	-0.141	0.078	0.202	0.179	-0.218	-0.254	0.165	-0.270		
26	K% (%)	-0.099	-0.168	0.233	-0.207	0.202	-0.248	-0.087	-0.126	-0.125	-0.001	-0.172	-0.214		
27	ShWt:NV	0.412	0.299	-0.440	0.079	-0.377	0.369	0.303	0.332	-0.070	-0.232	0.343	0.001		
		1	2	3	4	5	6	7	8	9	10	11	12		
14	NL:NWth	-0.519													
15	NH (mm)	0.725	-0.432												
16	NL:NH	-0.445	0.881	-0.694											
17	NW (g)	0.712	-0.031	0.770	-0.212										
18	NB (g)	0.553	0.067	0.421	0.032	0.373									
19	KC	0.080	0.003	-0.064	0.077	0.123	-0.209								
20	KW (g)	0.552	-0.025	0.615	-0.177	0.909	0.122	0.135							
21	DGP% (%)	-0.235	0.179	-0.198	0.164	-0.046	-0.230	0.088	0.024						
22	VGP% (%)	-0.062	-0.291	-0.037	-0.252	-0.222	-0.281	0.043	-0.198	-0.032					
23	Fz% (%)	0.048	0.378	-0.002	0.348	0.037	0.604	0.016	-0.086	-0.128	-0.376				
24	NV (mL)	0.776	0.005	0.764	-0.147	0.910	0.724	-0.009	0.731	-0.139	-0.292	0.296			
25	ND (g·mL ⁻¹)	-0.200	-0.118	-0.039	-0.169	0.132	-0.855	0.258	0.345	0.241	0.179	-0.633	-0.284		
26	K% (%)	-0.274	-0.041	-0.261	0.011	-0.084	-0.560	0.040	0.330	0.181	0.054	-0.357	-0.313		
27	ShWt:NV	0.159	-0.075	0.283	-0.182	0.263	-0.168	0.230	-0.008	0.029	0.124	-0.226	0.120		
		13	14	15	16	17	18	19	20	21	22	23	24	25	26

relationships between the ratios of nut length to width (NL:NWth) and nut length to height (NL:NH) also indicate that as these ratios increase, percent complete halves increase. The ratios would be less as nut width and height increase.

As kernel weight (KW) or nut density (ND) increased, percent complete halves (CH%) decreased and the other size classes increased. This was unexpected, and may emphasize the importance of adequate air spaces within the nuts, as discussed above. The overall high nut quality of these samples probably influenced this result.

Proportion of damaged shoulders (ShDSh%) was related to proportion of chips (Chips%), as expected. This parameter was also associated with increased packing material retained in the dorsal grooves (ShDGP%). Longer nuts were heavier, more buoyant, and had heavier kernels, as expected (Table 4). These nuts also had less ventral groove packing (ShVGP%), but greater percentages of fuzz (Fz%). Higher nut buoyancy (NB) was also related to higher percent fuzz, both characteristics being indicative of low quality.

Overall, we were impressed with the accuracy of the quick visual rating made by Mr.

Fangue. His rating was closely correlated with the major nut evaluation characteristics that objectively measure cracking and shelling efficiency, such as percent kernel of kernel fraction out of sheller, time required to hand-clean kernel samples, degree of kernel breakup during shelling, and kernel color. Other characteristics, such as retention of packing material in dorsal and ventral grooves, seem to have little bearing on overall shelling efficiency, but this may be due to successful selection prior to this shelling evaluation. Many of the above routine measurements performed in the standard USDA pecan breeding program require tremendous effort and time. These results indicate that many of these evaluations are of limited value and do not merit the effort required. However, the calculation of the shell weight per nut volume is an excellent predictor of shelling performance. That parameter requires several direct measurements for its calculation, but out performs each of those measurements in its correlation to shelling performance. These results should help to refine and improve the USDA pecan breeding program, as well as provide insight for shelling plant operators in determining nut and kernel characteristics of prime importance in predicting shellability and nut value.

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