Gross Composition of Coarse and Fine Fractions of Small Corn Samples Ground on the Stenvert Hardness Tester[1]

Y. POMERANZ,[2] Z. CZUCHAJOWSKA,[3] and F. S. LAI[2]

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ABSTRACT

Corn from each of three hybrids differing in kernel hardness was separated into seven classes based on sphericity. Kernels from the separated corn classes were ground with a Stenvert hardness tester, and the ground material was sieved to obtain two main fractions: coarse (>0.710 mm in diameter) and fine (<0.500 mm in diameter). Oil, protein, and ash were determined for the ground corn kernels and the sieved coarse and fine fractions. In addition, the sieved corn fractions were examined, before and after defatting, by near-infrared reflectance spectroscopy at 1,680 nm. The amount of hand-dissected germ, expressed as a percentage of kernel weight, was unaffected by kernel size; germ size was directly proportional to kernel size. The germ oil content varied among the three hybrids. Whole corn from the three hybrids varied in oil content for the classes separated according to sphericity. For the three hybrids, there was no consistent correlation between percent of germ and percent of oil in the whole kernel. The oil content of the ground and sieved coarse and fine fractions differed widely for the three hybrids and among the kernels separated by sphericity. The coarse fraction was low in ash and the fine fraction was high in ash. Corn sphericity was highly correlated with the oil content of the ground coarse fraction. Generally, there were high positive linear correlations between oil and ash and negative correlations between near-infrared reflectance and oil or ash of the ground coarse fraction. The effects of corn hardness on particle size and oil or ash content of the coarse fraction were confirmed for eight corn hybrids dried under various commercial conditions. It is concluded that the Stenvert hardness tester has potential for predictive determination of yields of products and their gross composition in dry-milled corn.

The production of large amounts of corn grits that are low in oil and have good shelf life is of great interest to the dry-corn-milling industry (Hopkins et al 1903, Earle et al 1946, Brekke 1970, Brockington 1970). The routine determination on small samples of the potential for the production of corn grits is of particular interest to plant breeders and the grain trade. As most of the oil in the dry-milled products originates in the germ, there is interest in determining the size and the oil content of the germ (Hopkins et al 1903; Earle et al 1946). We have recently reported on the use of the Stenvert tester to determine corn hardness (Pomeranz et al 1985) and hardness of commercially dried corn equilibrated to about 12.3% and 16.3% moisture (Pomeranz et al 1986). We report here on the use of the Stenvert hardness tester as a rapid and simple predictive test for potential yield of coarse and fine fractions and the gross composition of dry-milled 20-g samples of corn.

MATERIALS AND METHODS

Materials

The three yellow-dent corn hybrids of differing hardness and the seven classes separated according to sphericity (size and shape), have been described previously (Pomeranz et al 1985). Stauffer 8500 was hardest, Bo Jac softest, and Stauffer 8100 intermediate among the three hybrids. Sphericity is expressed according to Mohsenin (1970) as:

$$\left(\frac{\text{volume}}{\text{volume of circumscribed sphere}}\right)^{1/3} = \frac{(abc)^{1/3}}{a}.$$

where a = longest intercept, b = longest intercept normal to a, and c = longest intercept normal to a and b. Eight additional samples of

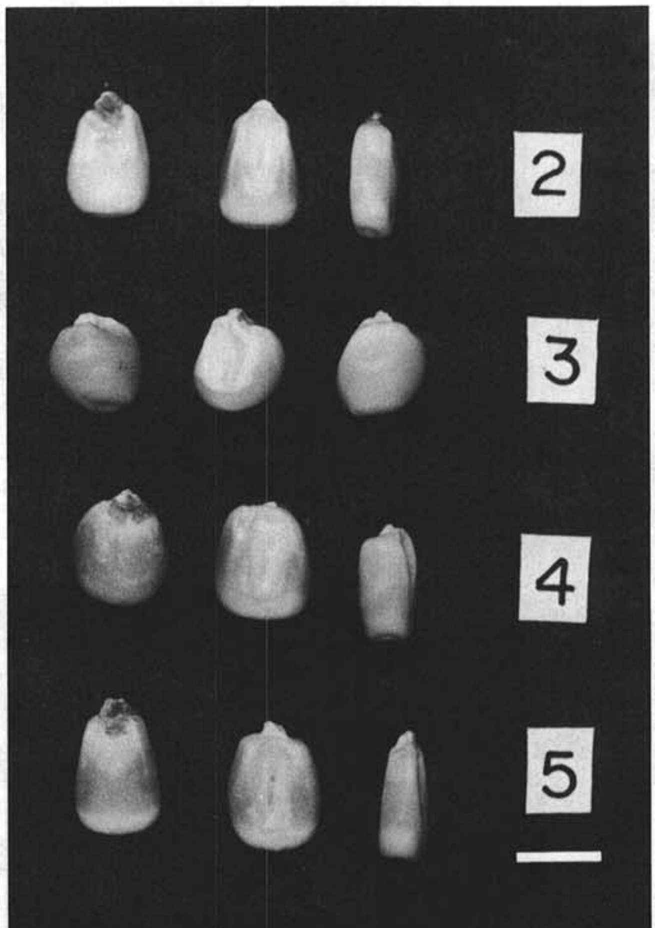

Fig. 1. Corn kernels of Stauffer 8500 with kernel weights and shape factors of 251.8 mg and 0.654 (**2**), 371.3 mg and 0.853 (**3**), 358.2 mg and 0.741 (**4**), and 324.3 mg and 0.652 (**5**). Bar = 7.5 mm.

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[2]Research chemist and research chemical engineer, U.S. Grain Marketing Research Laboratory, 1515 College Avenue, Manhattan, KS 66502.

[3]Research assistant, Department of Chemical Engineering, Kansas State University, Manhattan, KS 66506.

TABLE I
Coarse and Fine Fractions, Each from Seven Classes of Three Corn Hybrids at Two Moisture Levels

Corn	Coarse and Fine Fractions (as % of Total)					
	Stauffer 8500		Stauffer 8100		Bo Jac	
	>0.710 mm	<0.500 mm	>0.710 mm	<0.500 mm	>0.710 mm	<0.500 mm
12.5% Moisture						
Range	47.4–50.3	34.2–36.4	41.2–47.6	36.0–41.7	39.9–44.7	38.9–42.7
Average	49.2a[a]	35.0A	45.5b	38.4B	41.7c	40.9C
15% Moisture						
Range	48.7–50.6	34.2–36.1	42.4–48.5	35.8–40.4	42.0–46.1	38.0–41.4
Average	49.8a	35.1A	46.6b	37.2B	43.3c	39.6C

[a] Means with different letters denote statistically significant differences at the 0.05 level.

TABLE II
Germ and Germ Oil Contents in Three Corn Hybrids Separated According to Kernel Size and Shape

Kernel Wt (mg) and Sphericity Factor	Corn Class	Germ Shape Factor (length/width)	Germs (as % of kernel wt)	Dry Matter per 10 Kernels (g)	Dry Matter per 10 Isolated Germs (g)	Lipids (% in germ)
Stauffer 8500						
371.3/0.853	I	1.7	11.0	3.26	0.360	31.2
283.9/0.775	II	2.1	10.7	2.66	0.285	33.5
358.2/0.741	III	2.3	11.3	3.17	0.359	32.5
288.0/0.662	IV	2.1	11.2	2.60	0.298	34.6
324.3/0.652	V	2.5	10.7	2.84	0.303	33.8
251.8/0.654	VI	2.5	11.1	2.28	0.254	32.2
169.6/0.674	VII	2.6	10.9	1.57	0.171	30.5
Mean						
292.4/0.716			11.0a[a]	2.63a	0.290a	32.6a
Stauffer 8100						
373.0/0.843	I	1.9	10.4	3.23	0.336	30.8
291.0/0.789	II	2.3	10.5	2.54	0.268	31.1
369.2/0.768	III	2.1	10.6	3.17	0.334	31.4
281.2/0.656	IV	2.6	11.5	2.57	0.295	31.4
320.1/0.659	V	2.6	10.8	2.87	0.310	29.9
250.5/0.628	VI	2.7	11.1	2.25	0.250	29.1
171.2/0.662	VII	2.8	10.1	1.59	0.161	30.1
Mean						
292.30.715			10.7b	2.60a	0.279b	30.6b
Bo Jac						
356.0/0.817	I	2.0	10.7	3.11	0.331	29.7
282.3/0.716	II	2.1	10.1	2.49	0.252	30.2
342.5/0.750	III	2.4	11.0	2.90	0.320	29.1
268.0/0.641	IV	2.6	11.3	2.42	0.274	30.1
309.0/0.624	V	3.0	11.3	2.68	0.303	29.6
247.6/0.607	VI	3.1	11.4	2.14	0.242	28.7
168.2/0.664	VII	2.9	10.5	1.61	0.169	28.9
Mean						
281.9/0.688			10.9a,b	2.48b	0.270b	29.5c

[a] Means with different letters denote statistically significant differences at the 0.05 level.

TABLE III
Oil Content (%) of Three Corn Hybrids (separated according to size and shape) and in their Stenvert-Milled Size Fractions[a]

Corn Class[b]	Whole Corn			Fraction >0.710 mm			Fraction <0.500 mm		
	Stauffer 8500	Stauffer 8100	Bo Jac	Stauffer 8500	Stauffer 8100	Bo Jac	Stauffer 8500	Stauffer 8100	Bo Jac
I	4.04	3.61	3.59	1.24	1.50	1.54	7.13	6.04	5.50
II	4.09	3.78	3.65	1.34	1.68	2.05	7.74	6.41	5.07
III	4.17	3.61	3.54	1.43	1.63	1.94	7.85	5.65	5.35
IV	4.17	3.85	3.63	1.60	1.69	2.52	7.96	6.59	4.96
V	4.16	3.50	3.72	1.56	2.16	2.42	8.06	5.14	4.98
VI	3.95	3.85	3.66	1.51	2.00	2.39	7.62	5.82	4.87
VII	3.84	3.64	3.34	1.46	2.00	2.42	7.00	5.64	4.17
Overall mean	4.05a[c]	3.69b	3.59c	1.45a	1.81b	2.18c	7.62a	5.90b	4.98c

[a] 14% moisture basis.
[b] For description, see Table II.
[c] Means with different letters denote statistically significant differences at the 0.05 level.

TABLE IV
Protein and Ash Contents of Three Corn Hybrids and of their Stenvert-Milled and Sieved Fractions

Protein and Ash Range and Mean	Whole Corn			Fraction >0.710 mm			Fraction <0.500 mm		
	Stauffer 8500	Stauffer 8100	Bo Jac	Stauffer 8500	Stauffer 8100	Bo Jac	Stauffer 8500	Stauffer 8100	Bo Jac
Protein (%) (N × 6.25)									
Range	8.3–9.0	7.9–8.6	7.9–8.4	7.9–9.0	7.7–8.4	8.1–8.9	10.0–10.7	8.8–9.4	8.2–9.2
Mean	8.65a[a]	8.15b	8.13b	8.41a	8.05b	8.54a	10.37a	9.06b	8.74c
Ash (%)									
Range	1.20–1.25	1.11–1.24	1.17–1.23	0.40–0.44	0.52–0.70	0.56–0.92	2.20–2.45	1.68–2.12	1.55–1.93
Mean	1.22a	1.16c	1.20b	0.42a	0.59b	0.77c	2.35a	1.94b	1.72c

[a] Means with different letters denote statistically significant differences at the 0.05 level.

TABLE V
Correlation Coefficients[a] Between Shape Factor (SF), Lipids (L) in Coarse Fraction, Ash (A) in Coarse Fraction, and NIR Reflectance at 1,680 nm of Corn

Factors	Stauffer 8500	Stauffer 8100	Bo Jac	Combined
SF × L	−0.948**	−0.806*	−0.956**	−0.635**
SF × A	0.004	−0.655	−0.800*	−0.411
SF × NIR	0.433	0.570	0.631	0.459*
L × A	0.026	0.943**	0.933**	0.953**
L × NIR	−0.187	−0.748	−0.740	−0.862**
A × NIR	−0.406	−0.865*	−0.854*	−0.910**

[a] Correlation coefficients of 0.754 and 0.874 are required for the individual hybrids and of 0.433 and 0.549 for the combined samples, at the 0.05 and 0.01 levels, respectively.

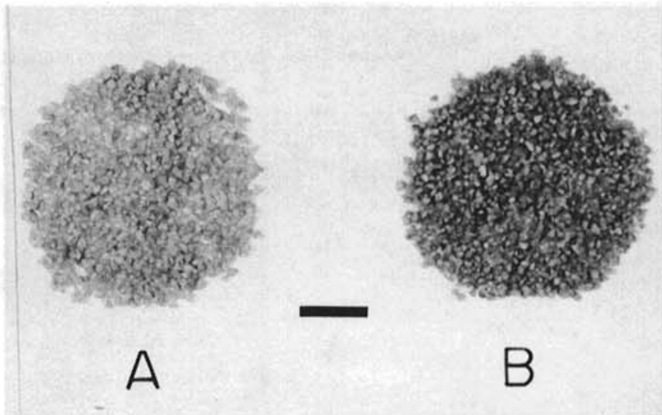

Fig. 3. Fraction >0.710 mm after grinding on the Stenvert hardness tester. Note the substantially higher proportion of floury fine particles and lighter color in Bo Jac (A) than in Stauffer 8500 (B). Bar = 5.0 mm.

Fig. 2. Top (left) and side (right) views of germ isolated from Stauffer 8500 corn kernels with shape factors of 0.654 (**2**), 0.853 (**3**), 0.741 (**4**), and 0.652 (**5**). Bar = 7.5 mm.

corn dried under commercial conditions at various temperatures, as described by Pomeranz et al (1986), were used.

Germ was separated from the corn kernels by hand in four replicates of 10 kernels, after soaking in cold water for about 6 hr. Typical corn kernels of Stauffer 8500 and of its isolated germ are shown in Figures 1 and 2. The figures compare kernels that vary in sphericity and germs that were isolated from those kernels. Similar results were obtained for kernels corresponding in sphericity from Stauffer 8100 and Bo Jac.

Analytical Methods

Whole kernels were analyzed for moisture by the ASAE method (ASAE 1978). Ash, oil, and protein were determined by AACC methods 08-01, 30-20, and 46-10, respectively (1976).

Near-infrared (NIR) reflectance data at 1,680 nm of corn ground on the modified Weber Mill (McGinty et al 1977) at 1.0 mm mesh setting were measured with a Technicon Infralyzer (Pomeranz et al 1984).

Hardness was determined according to the Stenvert method as described by Pomeranz et al (1985). In addition to the time required to collect 17 ml of ground meal (an index of resistance to grinding), the ratio of coarse to fine fractions (wt C/F) was measured. Wt C/F denotes the ratio of sieved fractions after grinding on the tester; fraction C is larger than 0.710 mm in diameter, and fraction F is smaller than 0.500 mm in diameter. All determinations were made at least in duplicate. Unless stated otherwise, all hardness and grinding determinations were made on corn equilibrated to 12.5% moisture (±0.3%). All analytical compositional values are reported on a 14% moisture basis.

RESULTS AND DISCUSSION

The coarse fraction (>0.710 mm) contained a substantially higher proportion of floury fine particles in Bo Jac than in Stauffer

TABLE VI
Ranges of NIR Reflectance (at 1,680 nm) of Ground Corn[a] Before and After Defatting

Hybrid and Treatment	Corn		Coarse Fraction		Fine Fraction	
	Range	Mean[b]	Range	Mean	Range	Mean
Stauffer 8500						
Before defatting	344–368	350A	400–421	408A	258–283	265A
After defatting	216–232	221a[c]	323–347	333a	132–151	141a
Stauffer 8100						
Before defatting	282–349	307B	332–404	363B	216–247	230B
After defatting	189–241	205b	281–347	313b	135–145	139a
Bo Jac						
Before defatting	268–327	278C	312–367	332C	204–222	206C
After defatting	172–204	181c	250–318	271c	126–140	129b

[a] Reground on a Weber mill to pass a sieve with 0.500-mm openings.
[b] Assuming a linear range.
[c] Means with different letters denote statistically significant differences at the 0.05 level.

TABLE VII
Percent of Fine and Coarse Fractions (Reground) Passing Through Sieves After Defatting

Variety	Reground >0.710 mm		<0.500 mm	
	Sieve Opening (mm) 0.250	0.106	Sieve Opening (mm) 0.250	0.106
Stauffer 8500	68.2	26.4	60.0	32.3
Bo Jac	73.7	34.5	66.5	34.9

8500 (Fig. 3). In general, the coarse fraction decreased as corn sphericity decreased (not shown). Stauffer 8500 had the highest and Bo Jac the lowest percentage of the coarse fraction for all seven classes at both moisture levels (Table I). There were no statistically significant differences in the amounts of the coarse and fine fractions at the two moisture levels (12.5 and 15%). The amount of the intermediate fraction (<0.710 mm and >0.500 mm) is small and ranged from 14.7 to 16.9% (average 15.8%) for Stauffer 8500, 15.4–17.1% (16.1%) for Stauffer 8100, and 16.2–19.1% (17.5%) for Bo Jac. The amount of the intermediate fraction was not affected by the moisture content in the 12.5–15.0% range.

In the seven classes separated from the three hybrids according to sphericity and kernel volume, the germ shape factor (ratio of length to width) generally increased as sphericity decreased (Table II). Germ, as a percentage of kernel weight, was affected only slightly and inconsistently by kernel weight. The weights of isolated germs (dry matter per 10 isolated germs) were related to the kernel weight (dry matter per 10 kernels); they were higher in Stauffer 8500 than in Bo Jac or Stauffer 8100. Within a hybrid there was no consistent trend in the fat content of germs isolated from kernels separated according to size and shape. There were, however, consistent differences among the three hybrids: Stauffer 8500 was highest and Bo Jac was lowest in germ fat content.

The oil contents of the whole corn kernels and the two major sieved fractions after grinding on the Stenvert hardness tester for the seven classes of the three hybrids, separated according to size and shape, are given in Table III. For the whole kernels, Stauffer 8500 was consistently the highest in oil, and Stauffer 8100 was higher (with one exception) in oil than Bo Jac. Statistical analysis revealed that whereas in the low-oil hybrid Bo Jac there was a significant linear correlation ($r = 0.791^{**}$) between the germ as percent of kernel weight and percent of oil in whole kernels, no significant correlation could be established for either Stauffer 8500 ($r = 0.146$) or Stauffer 8100 ($r = 0.518$). The oil contents of the coarse and fine fractions after grinding on the Stenvert mill varied widely for the three hybrids and among the seven classes of corn kernels within a hybrid (Table III). For the coarse fraction, the softer Bo Jac was highest and the harder Stauffer 8500 was lowest in oil; the trend was reversed in the fine fraction. Calculation of oil content for the nongerm part of the kernel (the difference between the percentage of oil in the whole kernel and the germ) showed a wide range among the kernels of the seven classes within a hybrid but little difference among the hybrids: Stauffer 8500, 0.38–0.76 (0.56 average); Stauffer 8100, 0.35–0.77 (0.53); Bo Jac, 0.38–0.76 (0.49). The consistent trend for oil content (Table III) in the coarse and fine fractions could not be confirmed for protein contents (Table IV). This is probably due to different distribution patterns of oil and protein in the kernel: the germ contains about 80% of the oil, whereas the distribution of protein is much more even (Earle et al 1946). There were small and inconsistent differences in ash contents of whole kernels for the three hybrids (Table IV). The low-oil coarse fraction was also low in ash, and the high-oil fine fraction was also high in mineral components. Several relationships were calculated and are summarized in Table V. Corn sphericity was highly correlated with oil content of the coarse fraction. Except for Stauffer 8500, there was a high and significant positive linear correlation between oil and ash of the coarse fraction and a negative correlation between NIR reflectance of corn at 1,680 nm and ash in the coarse fraction. The low correlation between ash and oil for Stauffer 8500 probably can be attributed to its very narrow range in ash content.

The grinding pattern and particle size distribution of the ground corn, as determined by NIR reflectance at 1,680 nm, differed among the hybrids and was affected by defatting (Table VI). The higher the NIR reflectance value, the larger the particle size. Removal of oil decreased agglomeration and coherent packing of the particles. In the absence of oil, the particles were more fluffy, and dust formation was enhanced. Average particle size was reduced substantially by defatting; the values were calculated assuming a linear range. The differences persisted even after regrinding the whole corn and coarse fraction to pass through a sieve with 0.500-mm openings. After defatting, both the fine and coarse particles (reground on a Weber mill to pass the 0.500-mm sieve) were sieved (Table VII). All NIR reflectance values were consistently higher for Stauffer 8500 than for Bo Jac (Table VI).

Differences in grinding patterns of samples differing in hardness according to density and the Stenvert method and related to ash and oil content (especially of the >0.710-mm fraction) are further confirmed for eight commercially dried hybrids, as shown in Table VIII. The hard hybrids produced more than the soft hybrids of the coarse fraction, low in oil and ash. When the corn was ground on the Weber mill to pass a 1-mm sieve, the average particle size, as indicated by high NIR reflectance values, was higher in the hard than in the soft corn.

CONCLUSIONS

Results presented here point to the use of the Stenvert hardness tester as means for rapid, simple, predictive determination of the potential yield, particle size, and composition of dry-milled corn. This rapid and simple test conducted on 20-g samples under

TABLE VIII
Oil, Ash, and NIR Reflectance at 1,680 nm
of Eight Corn Hybrids Dried Under Various Conditions

Hybrid	Whole Kernel Density (g/cc)	Stenvert Hardness Tester (sec)	Relative Hardness	Coarse Fraction[a] Yield (%)	Coarse Fraction[a] Oil (%)	Coarse Fraction[a] Ash (%)	Whole Kernel[b] NIR Reflectance at 1,680 nm
A	1.335a[c]	18.0a	Hard	52.2a	1.44g	0.57h	329a
3780/2	1.320b	17.8a		50.5b	1.63f	0.63g	325b
Annex	1.317b,c	17.1b	Intermediate	49.4c	1.82e	0.80c	305d
3780/3	1.314c	16.7c		48.1e	1.90d	0.86a	296e
Brovold	1.300d	17.1b		48.7d	2.00c	0.75e	312c
B	1.285e	15.5d		47.9e	2.14b	0.71f	310c
Franseed	1.263f	14.9e	Soft	47.7e	2.18a	0.78d	286f
Hall	1.284e	15.0e		49.1c,d	2.17a	0.84b	288d

[a]The coarse fraction was reground on a Weber mill for oil and ash determinations to pass a sieve with 0.500-mm openings.
[b]NIR values were obtained on whole kernels ground on the Weber mill to pass a sieve with1.00 mm openings.
[c]Values with different letters denote statistically significant differences at the 0.05 level.

laboratory conditions could be useful for screening large numbers of samples (commercial or plant breeding) for selection of promising and rejection of inferior material. Comparisons of yields and composition of commercially dry-milled and Stenvert-ground corn products are underway in our laboratories. There is also a need to determine the percentage of flint and soft endosperm as they affect yield and shelf life, including oil content and stability, of dry-milled products. The microscopic structure of the coarse and fine fractions from corn hybrids that differ in hardness, and of products in commercial dry corn milling, will be reported elsewhere.

The percentage and gross composition of the coarse and fine fractions were determined on corn ground on the Stenvert hardness tester. Determinations were made on three commercial dent corn hybrids, on their fractions separated according to size and shape, and on eight samples of corn dried on a commercial scale under various conditions. The Stenvert hardness tester was found useful in discriminating among samples that differed in hardness and potential yield of the coarse fraction. The coarse fraction was low and the fine fraction high in oil. The ash and oil contents of the coarse fraction, generally, were highly correlated.

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