Determination of Endosperm Characteristics of 38 Corn Hybrids Using the Stenvert Hardness Test

P. X.-P. LI,[1,2] A. K. HARDACRE,[3] O. H. CAMPANELLA,[1] and K. J. KIRKPATRICK[1]

ABSTRACT

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Grain hardness characteristics for a range of corn hybrids were measured using a modified Stenvert Hardness Test (SHT). A computer-based data logging and analysis system was constructed to obtain the milling time and transient power consumption during the milling process, from which milling energy and peak power demand were calculated. In addition, the time taken to mill 17 ml of flour (resistance time) and the height of the milled 20-g sample in the collection tube were recorded. The SHT measurements were correlated with the ratio of hard to soft endosperm and the bulk density of the grain. Thirty eight hybrid corn cultivars were tested. It was found that the testing system was simple and easy to use and error variation was low. Results indicate that significant variation in the measured parameters occurred among the hybrids. SHT parameters were highly correlated with the ratio of hard to soft endosperm. Statistical analysis using analysis of variance showed that significant differences occurred among the hybrids for the variables measured. Principal component analysis showed that the milling energy and resistance time were the most effective SHT parameters for assessing grain hardness. Both parameters were highly correlated with the ratio of hard to soft endosperm and the bulk density of the grain. Cluster analysis indicated that endosperm characteristics were genetically controlled and associated with germplasm groups.

In the food industry, corn is milled to produce a range of flours and grits that can be further processed for snacks, breakfast cereals, and other cooked or extruded products. Corn grains are viscoelastic in nature and are heterogeneous in structure. Their mechanical properties change with time, temperature, moisture content, chemical composition, and microstructure within the kernel. Grain hardness is related to the protein content and kernel physical properties including kernel density, bulk density, and the ratio of hard to soft endosperm (Watson 1987). Although not widely used by the industry, classification of grain using properties such as milling characteristics and the ratio of hard to soft endosperm have been reported in the literature (Kirleis and Stroshine 1990, Watson 1987). Classification based on these properties could reduce product wastage by varying processing parameters according to grain quality.

A mature corn kernel consists of three major regions: the germ comprising the embryo and the scutellum; the endosperm; and a protective seed coat comprising the aleurone layer and pericarp. The endosperm constitutes 80–85% of the kernel dry weight and is 86–89% starch by weight. Two types of endosperm, floury and hard, are usually present, depending on the structure and amount of the protein matrix that surrounds the starch granules. In the hard endosperm, the protein matrix is thicker and remains intact on drying, binding the starch granules tightly together in a strong structure with a translucent glassy appearance. During drying, the floury endosperm collapses, tearing the thin protein matrix, resulting in loosely bound starch granules (Watson 1987). The endosperm often contains voids and is structurally quite weak (Duvick 1961). The outer region of the kernel tends to comprise hard endosperm while the inner region tends to comprise soft endosperm. In popcorns and flint types of maize, almost all the endosperm is of the hard type, while in the most floury cultivars, almost no hard endosperm is present. Cultivars for the food industry contain a mixture of both types. Generally, a higher proportion of hard endosperm is preferred for milling.

Breeding for improved grain hardness is possible by introgressing flint lines into germplasm with other desirable characteristics such as high yield. Grain hardness can also be increased by improving nitrogen fertilization (Hamilton 1951). The kernel properties vary with hybrid types, planting, environmental variables such as soil type, water, fertility, and climate, and management practices during and after harvesting (Watson 1987).

Despite the importance of corn hardness in industrial applications and the number of studies that have been published on the subject, there is no generally accepted standard for evaluation of corn milling characteristics. Different measurement systems have been applied to investigate the relationship between kernel hardness and other grain variables such as moisture content, drying conditions, the proportion of hard endosperm, and hybrid cultivar. The ratio of cross-sectional area of hard to soft endosperm has been measured (Hamilton 1951, Kirleis 1984) and while it represents the proportions of hard and soft endosperm, it does not necessarily measure endosperm hardness. Jindal and Mohsenin (1978) used a pendulum impact tester to determine dynamic hardness of corn grain and found it to be a function of moisture content. They also found it difficult to obtain a true measure of the energy absorbed by a specimen. As for measurements of the hard and soft endosperm areas, variation among kernels was high, and only one kernel could be tested at a time. The technique was time-consuming and impractical for a large number of samples.

Tran et al (1981) modified and used a Strong-Scott barley pearler to determine corn grain resistance to abrasion and to estimate grain hardness. The grinding energy and grinding index were found to be linear and inversely related to moisture content. Lawton and Faubion (1989) used a tangential abrasive dehulling device to measure kernel hardness. Their results also showed that the moisture content had a large effect on hardness and that care should be taken to develop a repeatable testing method. Significant differences were found between a pop and a dent corn. However, these devices only measure surface properties of the grain. For a representative estimate of grain hardness, the hardness of the entire kernel should be measured.

The Stenvert Hardness Test (SHT) has been reported as a useful approach for measurement of kernel hardness (Pomeranz et al 1985; 1986a,b; Pomeranz and Czuchajowska 1987). In this technique, 20 g of corn kernels at a specific moisture content are milled in a Culatti micro hammer mill. Three parameters were

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[1] Department of Food Technology, Massey University, New Zealand.
[2] Corresponding author. Fax: 06-350-5655.
[3] Crop & Food Research Institute, Palmerston North, New Zealand.

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chosen to define the index of hardness: resistance time (the time required to mill 17 ml of meal); the height of the meal in the collection tube; and the weight ratio of coarse to fine particles in the resulting meal. They found that for three pairs of isogenic maize lines (dent and flint) and three yellow dent hybrids at 12% moisture, resistance time was highly correlated with kernel density and the proportion of coarse particles in the meal. Kirleis and Stroshine (1990) showed that the milling evaluation factor (MEF), a numerical index highly correlated with flaking grit yields, varied significantly among three corn hybrids of varying endosperm hardness. Furthermore, MEF was highly correlated with bulk density, kernel density, and Stenvert hardness measured as resistance time. Kernel hardness decreased as the grain drying temperature was increased between 27 and 93°C. Paulsen and Hill (1985) also showed increases in the yield of large flaking grits by selecting hybrids with low breakage susceptibility and high bulk density.

Mestres et al (1991) summarized the dry-milling properties of 18 corn landraces from Africa using a range of techniques and concluded that the ratio of hard to soft endosperm (vitreousness) was correlated with kernel density but not with protein content or dry milling properties including semolina recovery.

To the best of our knowledge, there is little information on the use of the micro hammer mill or any other techniques to systematically study the endosperm properties and milling characteristics of a wide range of corn hybrids. However, it does appear from the literature that the proportion of grits, and hence grain quality for processing, is correlated with the results of SHT and the ratio of hard to soft endosperm.

The objectives of this study were to systematically evaluate a number of parameters obtained from the SHT as a method of rapidly and reliably estimating grain hardness and to determine whether this is correlated with the ratio of hard to soft endosperm and bulk density for a wide range of hybrid cultivars. It was also aimed at determining whether variation for all the measured parameters occurred in commercially available hybrids and hybrids from New Zealand's maize breeding program.

MATERIALS AND METHODS

Corn

Thirty-five corn hybrids were machine-harvested from a research farm in the Manawatu region of New Zealand in June

TABLE I
Experiment Data for all Hybrids, Ranked for Bulk Density

Sample[a]	Sample Name	Origin[b]	Moisture Content (%)	Bulk Density (kg/hl)	Peak Power (watts)	Mill Time (sec)	Total Energy (J)	Sample Height (mm)	Resistance Time (sec)	Hard/Soft Endosperm Ratio
20	PF1×BS22-78	EF×HT	10.95	80.0	169	28.9	2,391	98.0	8.9	5.0
5	PF1×AS3-94	EF×HT	10.55	79.7	178	27.0	2,408	96.7	10.6	3.6
9	PF1×BS22-39a	EF×HT	10.10	79.2	180	26.4	2,223	94.7	7.9	4.5
27	PF1×BS22-39b	EF×HT	10.38	78.5	175	24.3	2,029	97.3	8.3	5.0
31	P3162	US Com Hard	11.20	78.2	172	26.4	2,373	100.0	8.5	7.4
6	PF1×NZS1-141	EF×HT	10.70	77.9	171	28.1	2,253	100.0	9.3	4.1
28	Hmv5313×PF1	HD×EF	9.85	77.9	156	30.4	2,802	100.0	9.8	3.9
21	PF2×NZ40	EF×HT	10.55	77.5	176	29.3	2,397	95.7	11.6	4.3
30	D1275×M378-80	ED×HT	11.25	77.3	179	25.7	1,936	100.0	7.9	1.8
1	PF2×NZ56	EF×HT	10.25	76.7	182	26.7	2,258	94.3	10.8	3.2
3	PF2×NZ56	EF×HT	10.65	76.7	175	28.7	2,251	96.7	9.2	2.4
23	PF1×NZS3-32	EF×HT	10.50	76.5	161	28.1	2,302	98.3	8.0	3.1
38	Dea	E.Com Flint	12.40	76.2	163	30.8	2,660	100.0	9.8	4.0
2	A676×NZ56	US×HT	10.20	75.7	173	25.2	1,962	99.3	8.1	2.8
29	N190×NZ2	US×HT	10.90	75.6	175	24.9	1,909	98.7	8.6	2.5
22	D1275×NZ84	ED×HT	10.90	75.3	177	24.5	1,738	98.0	7.6	1.8
10	WGI207×BS22-22	US×US(NZ)	11.18	75.3	176	22.0	1,784	100.3	7.4	1.6
4	E1873×NZ3	EF×HT	10.30	75.2	178	25.8	2,113	97.0	8.6	2.2
12	WGI207×M396-14	US×HT	10.85	74.7	178	24.6	1,989	95.7	9.1	2.3
35	P3902	US Com Med-Hard	11.05	74.5	177	25.7	1,922	102.0	7.7	2.4
14	A665×M396-14	US×HT	11.15	74.4	176	23.7	1,848	100.7	7.1	1.8
13	WGI29×PF1	US×EF	9.65	74.2	169	26.3	1,956	96.3	8.7	3.0
8	P3787	US Com Med.	10.90	73.5	174	23.7	1,751	102.0	6.8	0.9
11	WGI207×M378-80	US×HT	10.50	73.4	173	24.8	1,863	98.3	8.7	1.7
19	A82-8×NZ84	US×HT	10.10	73.1	167	24.8	1,739	108.7	6.6	2.0
26	D1260×BS22-22	ED×HT	10.40	72.4	169	26.5	1,802	103.3	7.0	1.5
25	Furio	E Com Dent	10.25	72.2	162	26.5	1,778	95.3	7.0	2.0
33	P3751b	US Com Med.	10.45	71.2	174	26.2	1,793	99.3	6.4	1.7
36	PAC42	US Com Med.	10.35	70.9	166	25.6	1,723	107.3	6.8	1.4
16	P3514	US Com Hard	10.55	70.8	167	25.9	1,671	102.7	6.2	0.7
24	A82-8×MBS847	US×US	10.40	70.4	170	22.2	1,608	99.7	6.5	1.3
7	MBS847×NZS3-59	EF×HT	10.15	70.2	152	30.4	1,750	104.0	7.2	1.4
34	P3901	US Com Med.	10.00	70.2	163	23.9	1,830	104.3	7.6	1.3
17	P3515	US Com Hard	10.15	69.6	162	25.3	1,625	104.0	5.6	0.7
18	P3751a	US Com Med.	10.40	69.2	167	22.0	1,726	102.3	7.5	0.6
15	P3394	US Com Med.	10.35	69.1	168	24.2	1,607	103.0	6.0	0.9
32	P3585	US Com Med.	9.60	69.0	173	21.6	1,539	101.7	5.9	0.8
37	PX74	US Com Soft	10.60	68.6	171	25.5	1,332	103.3	4.2	0.2
	Test Statistic(*F* value)				3.8	3.4	21.6	2.0	18.2	34.9
	Probability > *F*				0.0001	0.0001	0.0001	0.0067	0.0001	0.0001
	Coefficient of variation (%)				3.5	8.4	6.1	4.2	7.9	18.7

[a] Samples 31 and 37 were produced in Gisborne region of New Zealand, sample 38 was produced in a southern New Zealand site; all other samples were produced in Manawatu region of New Zealand.

[b] EF = European flints, HD = Hungarian dents, ED = European dents, HT = highland tropical sources, US = United States Corn Belt Dent, Com = commercial. All the US commercial hybrids are dent types, while the European commercial hybrids are either flint or dent types.

1993. To this set, samples of DeKalb brand PX74 and Pioneer brand P3162 produced in the Gisborne region of New Zealand were added along with a sample of Pioneer brand Dea produced in a southern New Zealand site. Immediately following harvest, the grain was slowly dried to ≈14% moisture and stored in a cool room at 7°C and 30% rh until required. During storage, the grain equilibrated with the air in the cool room resulting in a mean moisture content (MC) of 10.5% (range 9.6 to 12.4%) when tested. Before the testing, all samples were equilibrated to room temperature (25°C) in heavy paper bags.

The corn hybrids used are listed in Table I. They represented germplasm from several diverse sources. The highland tropical (HT) source originates from the CIMMYT (International Center for Maize and Wheat Improvement) maize breeding program and in this article refers to lines containing both highland tropical and corn belt dent germplasm (Eagles and Hardacre 1985). This material generally confers medium hardness properties to the endosperm. The lines of U.S. origins used can be of soft or medium hard endosperm, while the European dents (ED) and Hungarian dents (HD) are of medium hardness. The European flints (EF) have very hard endosperm. The commercial hybrids are of unknown origin although it is suspected that those labeled soft share similar parentage.

Analytical Methods

Moisture content and bulk density. Moisture content and bulk density (test weight) of the stored and dried corn samples were determined by Dickey-John GAC2000 grain analysis meter using a supplied program. Calibration for moisture was checked using oven drying techniques. Bulk density was recorded as kg/hectoliter and moisture as percent wet weight.

Hard to soft endosperm ratios. The hard to soft endosperm ratios in the samples were estimated by sectioning the kernels and measuring the areas of hard and soft endosperm presented at the cut surface (Kirleis et al 1984). Dried kernels were sectioned just above the top of the embryo region using a pair of secateurs. The hard to soft endosperm ratios for 10 kernels of each hybrid were calculated by measuring the average width and depth of the cut surface and the soft endosperm region using a pair of vernier calipers. From the approximate areas measured, the ratio of hard to soft endosperm was calculated. The method was time consuming and not practical for a very large number of samples, although it is the most direct measurement of the proportion of hard endosperm available. For this reason, it was used as the measurement of kernel hardness to which the other indirect measurements were compared.

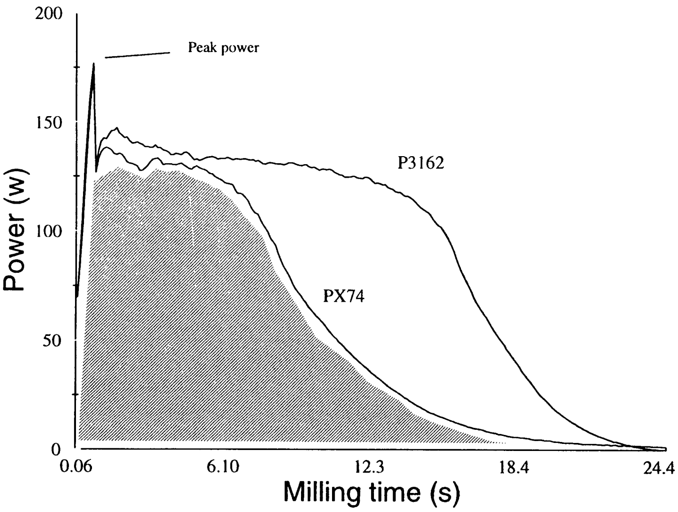

Fig. 1. True transient power changes of two typical hybrids.

Milling. The Stenvert Hardness Test was based on the method described by Stenvert (1974) and Pomeranz et al (1985). A 20-g sample of grain was ground using a Glen Creston micro hammer mill fitted with a 2-mm aperture particle screen. The mill speed was set to 7,500 rpm at empty but slowed substantially under load. This speed was considerably higher than recommended, but as the unit used was not fitted with a tachometer and as none was available at the time, a convenient setting was used. In future work, a purpose-built mill, Glen Creston micro hammer mill No5 equipped with a tachometer, will be used. The mill used in this work was equipped with a computerized data logging system to log the instantaneous electric power consumption during the milling test. From these data the transient peak energy and milling energy were determined.

Before collecting data, the mill was switched on and allowed to warm up by milling a set of five dummy grain samples. The set of test samples was then milled and the data logged. Data acquisition began automatically as soon as the power load increased above the unloaded power demand and continued until power consumption decreased to within 0.3 watts of the initial unloaded condition. In addition to these two measurements, resistance time, the time taken to mill 17 ml of meal, and the meal height in the collection tube at the completion of milling the 20-g grain sample were recorded. All data except the transient power curves were analyzed statistically using three to five replicates depending on the variable measured. Analysis of variance using the SAS procedure GLM (SAS 1988) generated *F* values and coefficients of variation (CV) appropriate for determining differences among the hybrids. The multivariate analysis of variance procedure for principal component analysis (SAS Princom) and cluster analysis (SAS Cluster) were applied to all data. Multivariate techniques were used to determine which of the variables, when considered together, contributed to variability among the hybrids, and how these variables, considered together, separated the hybrids into groups.

RESULTS AND DISCUSSION

The transient power consumption for two hybrids with either predominantly hard (P3162) or soft (PX74) endosperm during the SHT are presented in Figure 1. After the sample was dropped into

TABLE II
Correlation Matrix Using Stenvert Hardness Test Parameters[a] and Moisture Content (MC)

	MC	BD	PeakP	MT	E	H	RT	H/S
MC	1.00							
BD	0.33	1.00						
PeakP	0.18	0.32	1.00					
MT	0.13	0.36	−0.26	1.00				
E	0.25	0.79	0.01	0.63	1.00			
H	−0.05	−0.43	−0.31	−0.17	−0.34	1.00		
RT	0.18	0.73	0.23	0.40	0.79	−0.50	1.00	
H/S	0.23	0.81	0.11	0.38	0.74	−0.32	0.62	1.00

[a] BD = bulk density, Peak P = peak power, MT = milling time, E = milling energy, H = height, RT resistance time, H/S = ratio of hard to soft endosperm.

the grinding chamber, the power consumption of the mill climbed rapidly to its peak value as a result of the sudden load. As the milling process progressed, more grits and flour were swept out through the particle screen, and the power consumption decreased. After 20–40 sec of milling, the grinding chamber was empty and the test was automatically terminated when the power consumption by the mill decreased to within 0.3 watts of the initial unloaded level. The duration of the test was highly dependent on the time required to eliminate the last of the grain from the milling chamber, although this had little impact on the milling energy. It is clear that the softer kernels of PX74 were more rapidly and easily reduced to a size that could pass through the screen than were the harder P3162 kernels. This resulted in higher total power consumption for milling the P3162 when compared to the PX74. This can be seen graphically from the area underneath the plots. Peak power consumption did not differ between the two hybrids.

CV within hybrids were low for most variables (Table I). For the hard to soft ratio, the CV was 18.7%, suggesting that for this variable, differences among hybrids will be harder to resolve. From the *F* values (Table I) and their probabilities at the 5% level, it is evident that significant differences occurred among the hybrids for all variables. *F* values were lower for sample height, peak power, and milling duration as were CV, suggesting that overall variability for these variables was low and that they may be less useful in separating the hybrids for milling characteristics. As moisture content and bulk density measurements were unreplicated for these variables due to small available sample sizes, statistical tests could not be conducted. However, experience with these measurements has proven that errors are inherently very low (CV < 4%) and therefore, differences in bulk density >3kg/hl are probably significant. The reason for differences in moisture content are unknown as all samples were equilibrated under the same conditions. We suggest that differences in endosperm chemistry may be involved. Although, moisture content has a significant effect on hardness measurements (Tran et al 1981) the differences found (Table I) are probably too small to have a significant effect.

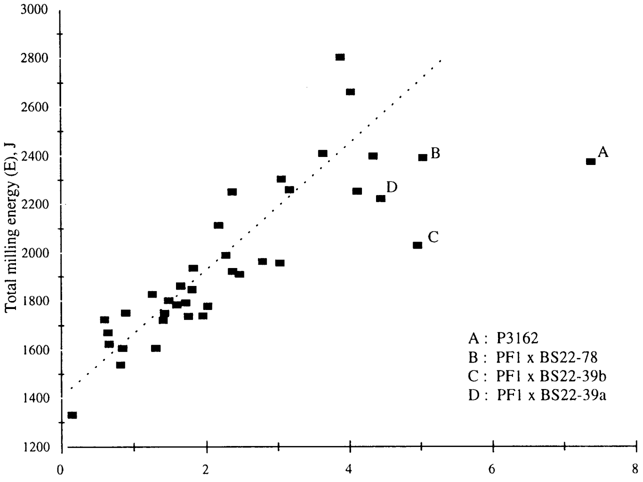

Fig. 2. Relation between the hard to soft endosperm ratio and the milling energy of the 38 hybrids. (Points represent 38 hybrids listed in Table II.)

From the data in Table I, it can be seen that some trends exist. Higher bulk densities are associated with hybrids with higher milling energies (E), greater resistance times (RT), and higher hard to soft endosperm ratios. Rankings on bulk density of entries that are repeated but sourced from different areas of the field, P3751 and PF1×BS22-39, are similar, as are other measured parameters for these pairs of hybrids.

Since one of the objectives of this work was to determine whether the ratio of hard to soft endosperm was correlated with indirect but faster measurement techniques for grain hardness, considerable emphasis was placed on SHT parameters and bulk density which have high correlation coefficients with the ratio of hard to soft endosperm areas (H/S).

The Stenvert properties, milling energy and resistance time were highly correlated with H/S (Table II); therefore these properties are likely to be good estimators of grain hardness. However, H/S had a higher correlation coefficient with milling energy (E) (0.74) than with resistance time (0.62) suggesting that E was a better predictor of the proportion of hard endosperm. In previous publications (Pomeranz et al 1985; 1986a,b), only resistance time was measured. Bulk density was also highly correlated with milling energy (0.79), resistance time (0.73), and H/S (0.81). It is therefore a simple estimator of grain hardness. Correlation coefficients for peak power, milling time and the height of the meal in the collection tube with H/S were ≤0.5 and are therefore less useful estimators of grain hardness.

A plot of E against H/S reveals some anomalies (Fig. 2) that also occurred for resistance time and bulk density with H/S (plots not presented). The hybrids, P3162, PF1×BS22-78, and both entries of PF1×BS22-39 had high H/S ratios, but their milling energies, bulk densities, and resistance times were lower than expected. Deviations from the expected correlation may be due to these hybrids having softer kernel texture. This may be caused by differences in the properties of endosperm from different hybrids. An alternative explanation is that the proportion of hard endosperm at the measured section of the kernel is not an accurate estimate of the volumes of hard and soft endosperm. If this is true, we suggest that the SHT is a more accurate assessment of kernel hardness than the ratio of hard to soft endosperm.

SAS PCA is a multivariate technique used to reduce the number of variables in a dataset (SAS 1988). Therefore, this technique produces new variables called principle components (PC) from correlated variables that account for the total variation in the data. Typically, most of the variation is accounted for by the first one or two PC. The eigenvectors generated by PCA indicate the contribution of the original variables to the variation accounted for by each of the PC. Due to the high correlation among some of the variables obtained in this study, it was considered appropriate to apply PCA to combine the correlated variables to more accurately express a trait, in this case kernel hardness.

PCA revealed that 52% of the variability in the data could be accounted for by the first principal component (PC1) and only 22% by PC2. PC2 and the other principal components are therefore ignored. From PCA, bulk density, milling energy, and resistance time had the larger eigenvectors and are, therefore, the ma-

TABLE III
Correlation Matrix of Stenvert Hardness Test Parameters[a] and Principal Component (PC1)

	PC1	BD	E	RT	H/S
PC1	1.00000				
BD	0.91387	1.00000			
E	0.91218	0.78920	1.00000		
RT	0.86538	0.73254	0.78775	1.00000	
H/S	0.83847	0.80877	0.74099	0.61823	1.00000

[a] BD = bulk density, E = milling energy, RT resistance time, H/S = ratio of hard to soft endosperm.

TABLE IV
Rankings of Principal Component PC1 and Other Parameters[a]

Sample Names	PC1	Ranking				
		PC1	BD	E	RT	H/S
PF2×NZ40	3.38	1	8	4	1	5
Dea	3.07	2	13	2	5	7
PF1×AS3-94	2.99	3	2	3	3	9
PF2×NZ56	2.59	4	10	8	2	10
PF1×BS22-78	2.54	5	1	5	9	2
Hmv5313×PF1	2.39	6	7	1	4	8
PF2×NZ56	2.10	7	11	10	7	15
PF1×BS22-39a	1.82	8	3	11	18	4
PF1×NZS1-141	1.76	9	6	9	6	6
P3162	1.71	10	5	6	14	1
PF1×NZS3-32	1.09	11	12	7	17	11
WGI207×M396-14	1.06	12	19	14	8	17
E1873×NZ3	0.97	13	18	12	13	18
E1386×BS22-39b	0.97	14	4	13	15	3
D1275×M378-80	0.83	15	9	17	19	21
N190×NZ2	0.56	16	15	19	12	14
WGI29×PF1	0.34	17	22	16	10	12
A676×NZ56	0.18	18	14	15	16	13
WGI207×M378-80	0.06	19	24	20	11	25
D1275×NZ84	0.05	20	16	30	21	23
P3902	0.02	21	20	18	20	16
A665×M396-14	–0.43	22	21	21	26	22
WGI207×BS22-22	–0.51	23	17	25	24	26
Furio	–0.55	24	27	26	28	19
P3751b	–1.01	25	28	24	33	24
P3787	–1.09	26	23	27	29	32
D1260×BS22-22	–1.15	27	26	23	27	27
MBS847×NZS3-59	–1.52	28	32	28	25	28
P3514	–1.83	29	30	33	34	36
P3901	–2.01	30	33	22	22	31
A82-8×MBS847	–2.06	31	31	35	32	30
P3751a	–2.15	32	35	31	23	37
PAC42	–2.23	33	29	32	30	29
A82-8×NZ84	–2.27	34	25	29	31	20
P3394	–2.56	35	36	36	35	33
P3515	–2.76	36	34	34	37	35
P3585	–3.08	37	37	37	36	34
PX74	–3.28	38	38	38	38	38

[a] BD = bulk density, E = milling energy, RT resistance time, H/S = ratio of hard to soft endosperm.

jor contributors to the variability accounted for by PC1. Moisture content, milling time, peak power, and sample height contributed less to the variation accounted for by PC1.

Table III shows that PC1 is highly correlated with bulk density, milling energy, resistance time, and the ratio of hard to soft endosperm. In all cases, the correlation of these variables with PC1 are higher than the correlation of the variables with each other. It can therefore be concluded that PC1 is a better estimate of grain hardness than the variables considered separately. The rankings associated with PC1 in Table IV are considered to be the best estimators of kernel hardness.

Cluster analysis (SAS 1988) was then applied to separate the hybrids into groups based on all the variables (analysis not presented). Two major groups were revealed, one with hard endosperm, which includes the first 12 hybrids in Table IV, and a softer group comprising the remaining 26 hybrids. The group with hard endosperm comprises hybrids which are known to contain a high proportion of flint germplasm, either from the inbreds PF1 and PF2 or of unknown origin for the commercial hybrids P3162 and DEA. It is interesting to note that most of the hybrids occurring in this group are based on crosses between flint and highland tropical germplasm. The crosses of highland tropical germplasm with nonflint lines are intermediate in hardness, suggesting that highland tropical germplasm may be a useful source of grain hardness. These hybrid combinations also have good grain yield potential in the cool temperate New Zealand climate (Eagles and Hardacre 1985). The hybrids with softer grain often contain the inbreds MBS847 and A82-8 as one, or are the commercial hybrids which are commonly used for grain production in New Zealand. It therefore appears possible to improve kernel hardness by choosing the kernel properties of the parents of the hybrids.

CONCLUSIONS

From the data presented here, it is possible to see that significant and quite large differences in the hard to soft endosperm ratio in the maize hybrids studied was closely correlated with grain hardness measured by the modified Stenvert Hardness Test and bulk density. The SHT is, therefore, proven to be a quick and simple method of comparing the endosperm hardness of diverse maize hybrids at constant moisture content. In addition, the test has the benefit of measuring a large number of kernels in each test so providing a better estimate than tests based on single kernels.

The presence of outliers in the correlation between milling energy and the ratio of hard to soft endosperm suggests that all measurements of kernel hardness should be based on a mechanical milling test such as that described here and not on a visual assessment of the ratio of hard to soft endosperm area.

In New Zealand, commercially available hybrids are capable of high yields. However, the grain tends to be soft and less suitable for milling for grit production. The challenge has been to discover germplasm combinations that result in commercially acceptable yields with good milling quality. Table IV shows that hybrids in which one of the parents was from the flint group, or to a lesser extent of highland tropical origins, had higher values for PC1 and had a higher proportion of hard endosperm.

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