# Corn Hardness Determination

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**ABSTRACT**

Breakage susceptibility and kernel hardness as measured by density, near-infrared reflectance, and average particle size of ground material were determined for four groups of corn samples. The groups were isogenic pairs with regard to hardness (dent and flint), commercial dent hybrids, dent corn heat-dried under various conditions, and a group that varied in starch composition (waxy, regular, high amylose) and in protein, oil, and ash contents. Density, near-infrared reflectance, and average particle size values were highly, linearly, and positively correlated provided homogenous groups were analyzed and evaluated. In samples that were highly susceptible to breakage, correlation coefficients of hardness determination increased when calculations were made on the basis of constant breakage susceptibility. The three methods of hardness determination were equally sensitive and useful in routine analyses.

Corn hardness is of great significance to producers, processors, and workers in the grain trade. Hardness is related to kernel density, bulk density, storability, attack by storage insects, breakage susceptibility caused by drying, storage, handling, or processing (milling characteristics, power requirements, dry and wet milling yields), production of special foods, and classification (Thompson and Isaacs 1967, Freeman 1973, Stroshine et al 1981, Emam et al 1981). Bennett (1950a) devised an electric machine for the determination of grain hardness. Indexes of hardness were obtained by a hydraulic piston-regulated recorder unit driven by a rotating crushing wheel. In a subsequent publication (Bennett 1950b), microscopic structure of corn kernels and hardness were closely correlated, as measured with the machine. More recently, Tran et al (1981) studied the effects of moisture on corn hardness. A Strong-Scott barley pearler and a disk grinding mill were modified, and electromechanical sensors were installed to record torque and energy during pearling and grinding. Additional measurements included determination of compression resistance, stiffness, pearling index, breakage index, and percentage of grits larger than 1.7 mm produced by grinding (termed *grinding index*). As moisture contents increased, corn endosperm softened and corn bran became more plastic. There was a linear, inverse relation between grinding energy and grinding index. Sensitivity values of corn hardness determination were highest from dividing the grinding index by grinding energy.

We recently completed a series of studies on wheat hardness, using four methods of evaluation: work to grind; time to grind; particle size resulting from grind, average particle size (APS); and near-infrared reflectance (NIR) of ground wheat (Miller et al 1981a, 1981b, 1982). The determination of work to grind requires expensive equipment. As in wheat, results of hardness determination in corn are affected by kernel size and shape, so any method selected should minimize those factors. The effects of moisture or temperature on measurements should be either eliminated (by equilibration) or accounted for (by calibration). Preliminary studies (unpublished data) have shown that determination of time to grind is not feasible for corn, probably because of the high oil content, which clogs the instrument. Therefore, to evaluate the hardness of corn we used the other two methods: particle size resulting from grind and near-infrared reflectance of ground corn. We supplemented these methods with density determinations.

There are several complications, however, in using particle size and NIR to determine corn hardness. The relatively high oil content may cause agglomeration and conceal differences in particle size. The floury and flinty parts of the corn kernel contain sharp gradients, and caution must be exercised to properly grind and prevent segregation of the ground material. In addition, results can be affected by increased susceptibility of corn to breakage due to drying at elevated temperatures. Such drying "softens" flint corn by causing the formation of cracks and fissures. This, in turn, lowers kernel density and increases breakage, and affects the particle size of ground material. Consequently, methods of determining corn hardness must also take into account susceptibility to breakage or must express final hardness values on the basis of breakage susceptibility.

## MATERIALS AND METHODS

Four groups of samples were selected for this study. They included: a series of isogenic pairs (dent and flint) based on hardness; a series of commercial dent corn hybrids (largest acreage in the United States); dent corn dried under various commercial conditions; and a series that varied in starch composition (waxy, regular, and high amylose).

### Pairs of Isogenic Lines

Three pairs of isogenic lines (dent and flint) were obtained from the breeding program of Cargill, Inc., Minneapolis, MN. These pairs are considered to differ primarily or only in kernel hardness. The samples are described in Table I. The flint corn kernels were smaller and had higher density, higher particle size, and (generally) higher NIR values than their dent corn isogenic counterparts. Breakage susceptibility of the hand-harvested samples was low.

### Commercial Hybrid Dent Corn

Twenty samples of commercial hybrid dent corn were obtained from DeKalb Co., DeKalb, IL. The samples were hand-harvested from a demonstration plot at approximately 20–25% moisture (at various times appropriate to their maturity), dried overnight at 105°C, and hand-shelled in a mechanized Black Beauty Sheller. The samples ranged in 1,000-kernel weight from 270.1 to 391.8 g (average 338.0), density from 1.274 to 1.332 g/ml (1.303), breakage susceptibility from 0.51 to 1.52% (0.99), NIR at 1.680 $\mu$m of ground material from 421 to 570 $\mu$m (497), and APS of ground material from 577 to 720 $\mu$m (650).

### Commercially Dried Corn

Six samples of corn were dried experimentally under a wide range of conditions, including commercially unacceptable high temperatures. The samples were prepared by Anderson Co., Maumee, OH. They are described in Table II. The samples varied relatively little in kernel weight, were low in density, NIR, and APS, but were very high in breakage susceptibility.

### Waxy, Common Dent, and Amylose Corn

Five waxy maize, four common dent, and four high-amylose corn samples were obtained from American Maize Products Company, Hammond, IN. The samples are described in Tables III

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Reference to a company or product does not imply approval or recommendation of the product by the USDA to the exclusion of others that also may be suitable.

and IV. The hand-harvested samples varied widely in kernel weight and APS and were low in breakage susceptibility. The waxy kernels (except for the high-lysine sample) were low in protein and ash and intermediate in oil; the high-amylose kernels were high in protein, ash, and oil.

### Analytical Methods

Oil (petroleum ether extract), ash, and protein (N × 6.25) were determined by AACC methods 30-20, 08-01, and 46-10, respectively (AACC 1961). Whole kernels were analyzed for moisture (72 hr at 103°C in a forced-air oven) by ASAE Method S352 (Agricultural Engineers Yearbook 1978). Breakage susceptibility, density, NIR, and APS were determined on moisture-equilibrated samples (12.5% ± 0.5%).

Breakage susceptibility was determined by the $CK_2$ Stein breakage tester as described by Miller et al (1981c, 1981d).

### Corn Density

Density determinations were made with an air-comparison pycnometer as described by Thompson and Isaacs (1967). Approximately 50 cc of whole, sound corn kernels were manually selected and weighed to within 1 mg. The volume of each sample was then measured with a model 200 Beckman air-comparison pycnometer. Density of each sample was calculated after dividing the weight by the volume.

### Sieving Time

Two samples were selected to determine the effect of sieving time on particle size analysis. Each 25-g sample was ground on a Falling Number mill (Falling Number AB, Stockholm, Sweden) at a no. 3 setting. Preliminary trials proved that this setting gave the best differentiation. One of the ground corn samples used in preliminary determinations had a large NIR value, and the other had a small one. The ground sample with the small NIR value (fine particles) was sieved for 2, 4, 8, 10, 12, and 16 min on a set of Tyler 32-, 35-, 65-, and 100-mesh sieves. Results of these various sieving time analyses were plotted on a log-normal distribution graph (Fig. 1) that plots, in microns, the percent that was smaller than the sieve opening versus log of the sieve opening. This graph shows that a sieving time longer than 8 min but shorter than 10 min would cause a particle separation approximated by a straight line connecting the size ranges between 150 μm (100-mesh sieve) and 410 μm (35-mesh sieve).

Similar sieving time analyses were made with the ground sample having the high NIR value (coarse particles) using 2-, 4-, and 8-min

**TABLE I**
**Kernel Weight, Density, Near-Infrared Reflectance, Particle Size Index, and Breakage Susceptibility of Isogenic Pairs of Corn**

| Corn Description | 1,000 Kernel Weight (g) | Breakage Susceptibility (%) | Density (g/cc) | NIR at 1.680 μm | Average Particle Size (μm) |
|---|---|---|---|---|---|
| Dent I | 315.9 | 3.49 | 1.306 | 556 | 682 |
| Flint I | 267.9 | 4.01 | 1.318 | 542 | 717 |
| Dent II | 313.6 | 2.18 | 1.280 | 459 | 597 |
| Flint II | 256.5 | 1.25 | 1.324 | 540 | 682 |
| Dent III | 325.6 | 1.27 | 1.302 | 530 | 632 |
| Flint III | 269.4 | 1.13 | 1.345 | 626 | 745 |

**TABLE II**
**Kernel Weight, Density, Near-Infrared Reflectance, Particle Size Index, and Breakage Susceptibility of Commercially Dried Corn**

| Corn Sample | 1,000 Kernel Weight (g) | Breakage Susceptibility (%) | Density (g/cc) | NIR at 1.680 μm | Average Particle Size (μm) |
|---|---|---|---|---|---|
| 1 | 332.0 | 12.6 | 1.272 | 430 | 617 |
| 2 | 302.6 | 24.4 | 1.247 | 364 | 524 |
| 3 | 319.8 | 26.4 | 1.283 | 452 | 657 |
| 4 | 306.1 | 27.5 | 1.191 | 371 | 521 |
| 5 | 312.3 | 35.2 | 1.188 | 359 | 521 |
| 6 | 319.1 | 37.8 | 1.279 | 390 | 552 |

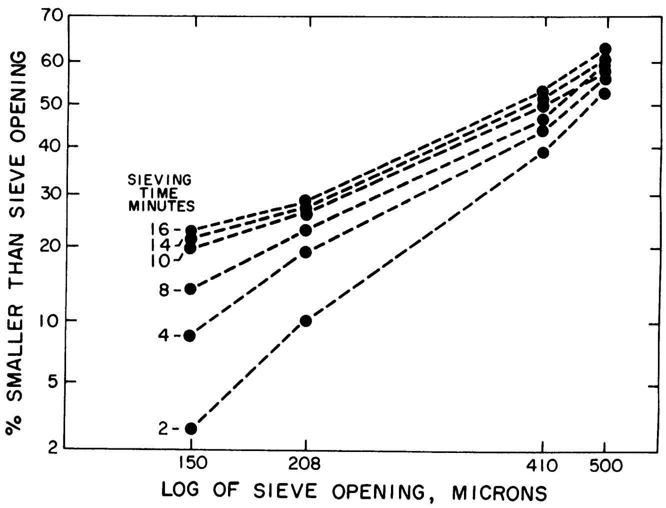


**Fig. 1.** Particle size distribution of low near-infrared reflectance ground corn at different sieving times.

**TABLE III**
**Kernel Weight, Density, Near-Infrared Reflectance, Particle Size Index, and Breakage Susceptibility of Waxy, Dent, and Amylose Corn**

| Corn Description | 1,000 Kernel Weight (g) | Breakage Susceptibility (%) | Density (g/cc) | NIR at 1.680 μm | Average Particle Size (μm) |
|---|---|---|---|---|---|
| Waxy maize | | | | | |
| HNYRCO 255 | 317 | 1.38 | 1.315 | 541 | 655 |
| HNYRCO 411 | 300 | 1.09 | 1.325 | 590 | 697 |
| MOEWS Hy Lysine | 301 | 1.14 | 1.280 | 558 | 627 |
| MOEWS 320 | 221 | 0.84 | 1.306 | 494 | 601 |
| Pioneer 3780 | 278 | 1.08 | 1.310 | 519 | 598 |
| Common Dent | | | | | |
| MOEWS 3020 | 366 | 4.65 | 1.294 | 526 | 616 |
| Pioneer 3382 | 302 | 1.43 | 1.310 | 567 | 632 |
| Pioneer 3535 | 329 | 0.65 | 1.332 | 616 | 718 |
| Pioneer 3780 | 284 | 1.39 | 1.293 | 516 | 665 |
| Amylose V | | | | | |
| A-540 | 280 | 0.64 | 1.303 | 556 | 824 |
| A-591 | 303 | 0.83 | 1.288 | 593 | 777 |
| AE-5800 | 293 | 0.48 | 1.285 | 596 | 749 |
| Amylose VII | | | | | |
| A-792-B | 327 | 1.14 | 1.290 | 612 | 841 |

**TABLE IV**
**Protein, Ash, and Oil Contents of Waxy, Dent, and Amylose Corn**

| Corn Description | Protein (N × 6.25, %) | Ash (%) | Oil (%) |
|---|---|---|---|
| Waxy | | | |
| HNYRCO 255 | 8.7 | 1.17 | 4.1 |
| HNYRCO 411 | 9.2 | 1.17 | 4.1 |
| MOEWS Hy Lysine | 10.3 | 1.50 | 4.6 |
| MOEWS 320 | 8.6 | 1.25 | 4.1 |
| Pioneer 3780 | 8.7 | 1.25 | 3.6 |
| Common Dent | | | |
| MOEWS 3020 | 9.3 | 1.15 | 3.7 |
| Pioneer 3382 | 9.7 | 1.15 | 4.2 |
| Pioneer 3535 | 10.4 | 1.33 | 3.8 |
| Pioneer 3780 | 10.3 | 1.40 | 3.8 |
| Amylose V | | | |
| A-540 | 11.3 | 1.52 | 5.0 |
| A-591 | 10.9 | 1.43 | 4.9 |
| AE-5800 | 11.7 | 1.51 | 5.2 |
| Amylose VII | | | |
| A-792-B | 11.1 | 1.56 | 5.0 |

time periods. Figure 2 shows the results of coarse particle analyses compared to the results of fine particle analyses from the same sieving times. At a sieving time of 8 min, the particle size distribution of both fine and coarse particles are approximated by a straight line in the sieve opening range between 150 and 410 $\mu$m. These two 8-min lines have similar slopes but very different median particles sizes. A time of 10 min for APS was selected for more consistent separation. The spread between the 2- and 8-min lines was wider in the low-NIR sample than in the high-NIR sample (Fig. 2). This is consistent with a higher proportion of fine particles and longer time requirement for particle separation by sieving of the low-NIR sample rather than the high-NIR sample.

**Particle Size Analysis**

Sieved fractions were obtained from replicated samples after 10 min of sieving on a Ro-Tap sieve shaker, using a set of Tyler 32-, 35-, 65-, and 100-mesh sieves. The geometric medians were calculated from the log-normal distribution function (Stockham and Fochtman 1977), using sieve fractions obtained from the Tyler 35-, 65-, and 100-mesh sieves. These geometric medians were used to determine the APS.

**TABLE V**
**Average, Ranges (D), Standard Deviation (S), and Differences in Sensitivity D/S of Hardness Determination in Groups of Corn Samples**

| Group and Test | Number of Samples | Average | Range (D) | Standard Deviation (S) | D/S |
|---|---|---|---|---|---|
| Isogenic pairs | 6 | | | | |
| Breakage susceptibility (%) | | 2.22 | 2.88 | 1.25 | 2.30 |
| Density (g/cc) | | 1.313 | 0.065 | 0.0220 | 2.95 |
| NIR[a] at 1.680 $\mu$m | | 533 | 176 | 56.9 | 3.09 |
| Average particle size ($\mu$m) | | 676 | 148 | 54.2 | 2.73 |
| Hybrid dent | 20 | | | | |
| Breakage susceptibility (%) | | 0.99 | 1.01 | .312 | 3.24 |
| Density (g/cc) | | 1.303 | 0.058 | 0.0148 | 3.92 |
| NIR[a] at 1.680 $\mu$m | | 497 | 149 | 33.8 | 4.41 |
| Average particle size ($\mu$m) | | 650 | 165 | 45.3 | 3.64 |
| Commercial dried corn | 6 | | | | |
| Breakage susceptibility (%) | | 27.3 | 25.2 | 8.92 | 2.83 |
| Density (g/cc) | | 1.243 | 0.095 | 0.0436 | 2.18 |
| NIR[a] at 1.680 $\mu$m | | 394 | 93 | 38.2 | 2.43 |
| Average particle size ($\mu$m) | | 565 | 153 | 61.4 | 2.38 |
| Waxy-dent-amylose | 13 | | | | |
| Breakage susceptibility (%) | | 1.29 | 4.17 | 1.06 | 3.94 |
| Density (g/cc) | | 1.302 | 0.045 | 0.0158 | 2.84 |
| NIR[a] at 1.680 $\mu$m | | 560 | 122 | 39.5 | 3.09 |
| Average particle size ($\mu$m) | | 691 | 240 | 83.5 | 2.88 |

[a]Near-infrared reflectance.

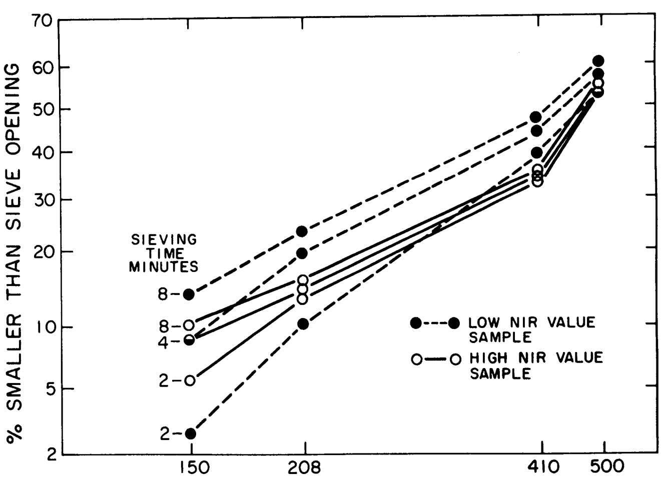


**Fig. 2.** Particle size distribution of low- and high near-infrared reflectance ground corn samples at different sieving times.

**NIR Reflectance**

NIR reflectance data at 1.680 $\mu$m of corn ground in the Falling Number mill, with a no. 3 setting were measured with a Technicon InfraAlyzer. The reflectance values at 1.680 $\mu$m for wheat have been shown to change as particle size distribution of the samples changed. Limited studies have shown that better differentiation was produced from the Falling Number mill at the no. 3 setting than from either the mill set at a coarser grind or the UDY mill at a 1-mm mesh setting, which yielded very fine particles.

Moisture, ash, protein, breakage susceptibility, APS, and NIR determinations were made in duplicate; density determinations were made in triplicate. All results given in this report represent the averages of two or three determinations.

## RESULTS AND DISCUSSION

Averages, ranges, standard deviations, and sensitivity (range/standard deviation) of breakage susceptibility and three hardness measurements (density, NIR at 1.680 $\mu$m, and APS) of the four groups of samples are summarized in Table V. Breakage susceptibility of the commercially dried corn samples was substantially higher than susceptibility of samples in the other three groups. High breakage susceptibility significantly reduced density, NIR, and APS values of the commercially dried corn. The commercially dried samples had the widest range of breakage susceptibility and density. Differences in sensitivity for the three methods of hardness determination (within and among groups) of corn samples were relatively small and inconsistent. The three methods are, therefore, equally powerful in determining hardness.

Correlation coefficients, linear regression equations, and standard errors of estimate of breakage susceptibility and hardness are given in Table VI. The high correlation coefficients for hardness determination among the isogenic pairs are accompanied by relatively low coefficients between breakage susceptibility and any of the hardness parameters. High correlation coefficients for the three methods of hardness determination were obtained for the relatively homogenous group of 20-hybrid dent corn samples; there were somewhat higher correlations between breakage susceptibility and hardness than in the isogenic pairs.

For the group of commercially dried samples, a similar situation was noted; the highest correlation for the three correlation coefficients was between NIR and APS, both measures of particle size of ground grain.

For the three small subgroups of corn samples that varied in starch composition (waxy, regular, and high amylose), correlation coefficients were erratic. In the subgroup of waxy corn, however, correlation coefficients of 0.164, 0.510, and 0.877 (Table VI), increased to 0.999, 0.966, and 0.949, respectively, when the high-lysine sample was excluded from the calculation. Similarly, correlation coefficients of 0.079, 0.172, and 0.702 (Table VI) increased to 0.815, 0.649, and 0.829 for the whole group when the high-lysine corn and high-amylose samples were excluded. The high-lysine and high-amylose samples have shrunken endosperm and larger proportions of germ than the other corn samples. The high-amylose samples differed from the other samples in the group, not only in their starch composition, but also in their higher protein, mineral matter (ash), and oil contents (Table IV). Those compositional differences no doubt affect physical properties, such as grain hardness and breakage susceptibility, as well as agglomeration of particles in ground corn. It is obvious, therefore, that corn-hardness determinations (density, NIR, and APS) can be interpreted properly only if the history of the grain (ie, heat treatment) is considered. The methods are most useful for routine testing and for comparing large numbers of samples from homogenous populations that vary little in composition.

The results may be affected by breakage susceptibility, as measured by the Stein breakage tester. This method can be used to

TABLE VI
Correlation Coefficients, Linear Regression Equations, and Standard Error of Estimates of Corn Hardness Determination

| Groups | Density (y) vs NIR[a] (x) | Density (y) vs APS[b] (x) | Density (y) vs APS[b] (x) | Density (y) vs Breakage (x) | Breakage (y) vs NIR[a] (x) | Breakage (y) vs APS[b] (x) |
|---|---|---|---|---|---|---|
| | | | Correlation Coefficients | | | |
| Isogenic pairs | .924 | .926 | .892 | .244 | .174 | .132 |
| Hybrid dent | .926 | .821 | .811 | .525 | .430 | .405 |
| Commercial dried | .746 | .718 | .995 | .279 | .480 | .425 |
| Waxy, dent, amylose | .079 | .172 | .702 | .146 | .345 | .338 |
| Waxy | .164 | .510 | .877 | .091 | .456 | .447 |
| Dent | .995 | .758 | .698 | .629 | .585 | .754 |
| Amylose | .838 | .623 | .098 | .056 | .546 | .708 |
| | | | Linear Regression Equations | | | |
| Isogenic pairs | 1.12 + 0.00036x | 1.06 + 0.00038x | 100 + 0.94x | 1.32 − 0.0043x | 4.26 − 0.0038x | 0.15 + 0.0031x |
| Hybrid dent | 1.10 + 0.00042x | 1.12 + 0.00028x | 102 + 0.61x | 1.33 − 0.026x | 3.00 − 0.0040x | 2.84 − 0.0028x |
| Commercial dried | 0.908 + 0.00084x | 0.969 + 0.00048x | 47 + 0.61x | 1.28 − 0.0013x | 71.4 − 0.111x | 62.0 − 0.061x |
| Waxy, dent, amylose | 1.28 + 0.000032x | 1.32 − 0.000033x | 330 + 0.33x | 1.31 − 0.0021x | 6.45 − 0.009x | 4.69 − 0.0049x |
| Waxy | 1.27 + 0.000029x | 1.18 + 0.00021x | 45 + 0.78x | 1.30 + 0.0079x | 0.19 + 0.0024x | 0.22 + 0.0021x |
| Dent | 1.09 + 0.00040x | 1.11 + 0.00031x | 92 + 0.71x | 1.32 − 0.0064x | 14.7 − 0.023x | 21.6 − 0.030x |
| Amylose | 1.46 − 0.00028x | 1.20 + 0.00012x | 633 − 0.055x | 1.29 − 0.0016x | −3.08 + 0.006 × 5 | −3.02 + 0.0047x |
| | | | Standard Error of Estimate | | | |
| Isogenic pairs | 0.009 | 0.009 | 28.86 | 0.024 | 1.38 | 1.39 |
| Hybrid dent | 0.006 | 0.009 | 20.36 | 0.013 | 0.29 | 0.30 |
| Commercial dried | 0.032 | 0.035 | 5.94 | 0.646 | 8.77 | 9.04 |
| Waxy, dent, amylose | 0.016 | 0.016 | 29.37 | 0.016 | 1.03 | 1.02 |
| Waxy | 0.019 | 0.017 | 20.38 | 0.019 | 0.20 | 0.20 |
| Dent | 0.002 | 0.015 | 39.95 | 0.017 | 1.77 | 1.43 |
| Amylose | 0.005 | 0.008 | 28.87 | 0.010 | 0.29 | 0.25 |

[a]Near-infrared reflectance.
[b]Average particle size.

TABLE VII
Simple and Partial Correlation Coefficients[a] Between Three Methods of Hardness Determination

| Corn Group | Simple Correlation | | | Partial Correlation | | |
|---|---|---|---|---|---|---|
| | Density vs NIR[b] | Density vs APS[c] | NIR vs APS[c] | Density vs NIR[b] | Density vs APS[c] | NIR vs APS[c] |
| Isogenic pairs | .924 | .926 | .892 | .924 | .926 | .894 |
| Hybrid dent | .926 | .821 | .811 | .934 | .834 | .811 |
| Commercially dried | .746 | .718 | .995 | .915 | .850 | .990 |
| Waxy, dent, amylose | .079 | .172 | .702 | .079 | .172 | .702 |

[a]Keeping breakage susceptibility constant.
[b]Near-infrared reflectance.
[c]Average particle size.

account, in part, for the effect of drying at high temperatures, which, as severity of drying increases, causes stress cracks to form in the endosperm and softness to increase (Thompson and Foster 1963). To account for breakage susceptibility, simple correlation coefficients among hardness parameters were compared with partial correlation coefficients (keeping breakage susceptibility constant) (Table VII). No significant difference was noted for the groups of isogenic pairs, hybrid dent, or waxy-dent-amylose, all of which were harvested manually and dried at a low temperature. In the group of commercially dried samples, however, simple correlations of 0.746, 0.718, and 0.995 were changed to partial correlations of 0.915, 0.850, and 0.990.

Theoretically, density, NIR, and APS reflect differences in inherent hardness; in practice, breakage susceptibility of commercial dent corn is affected by harvest and by heat treatment. Corn varieties vary genetically in breakage susceptibility, and measurements of "true hardness" are affected by breakage susceptibility. Because breakage susceptibility and hardness are related and affect utilization of corn, both must be considered in its evaluation.

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