Properties of Corn Screenings

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Abstract
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Keywords
Particle-size distribution, Corn, BCFM

Disciplines
Agriculture | Bioresource and Agricultural Engineering

Comments
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ABSTRACT. Inspection data from 1988 to 1990 validated a previous prediction equation for corn particle size distribution and showed the relative distribution to be independent of market location, BCFM level, and other grade factor data. Samples (62) of corn screenings obtained from country elevators were size-separated in 2/64-in. increments, from 4.5/64 in. to 16/64 in. Smaller particles had lower bulk density, higher particle density, more mycotoxins, higher protein, and lower starch than larger particles. About 17% of the material was larger than 12/64-in., which means it would not have been classed as broken corn-foreign material in the grades. Removal efficiency for commercial cleaners was estimated, by size increment, as a function of removal efficiency for BCFM.

The elevators sending samples provided data on handling rates, cleaning parameters, and volume handled. No elevator parameter except screen size influenced the properties or size distribution of screenings.

Keywords. Particle-size distribution, Corn, BCFM.

The particle-size distribution of market corn is important because any change in corn particle-size standards will affect the amount of material classed as discountable. The current particle-size factors are broken corn-foreign material (BCFM), broken corn (BC), and foreign material (FM). BCFM is all material passing through a 12/64-in. (4.8-mm), round-hole screen, plus large non-grain material remaining atop the screen. BC is material passing through the 12/64-in., round-hole screen, but not a 6/64-in. (2.4-mm), round-hole screen. FM is material passing through the 6/64-in. screen plus the non-grain material atop the 12/64-in. screen. The definitions and test procedures are contained in the Federal Grain Inspection Service procedure manual (FGIS, 1990).

There have been several studies of particle-size distribution in market corn, summarized by Bern and Hurburgh (1992). Concentrations of various particle sizes can be determined as a percentage of BCFM concentration. The relative distribution of sizes remains constant through the market chain. Their equation relating percentage of any particle size to BCFM percentage was:

\[ P_{i,c} = e^{0.2625 s_i + 1.455} \]  

where

- \( P_{i,c} \) = material passing through the \( i^{th} \) screen, as a percent of weight classed as BCFM
- \( s_i \) = hole diameter of size \( i \) (64th in.)

This leads to:

\[ p_i = 0.01 B e^{0.2625 s_i + 1.455} \]  

where

- \( p_i \) = percentage of sample weight passing through screen size \( s_i \)
- \( B \) = percent BCFM in sample

The incremental amount (percentage of material in size range) between size \( i \) and \( i-1 \), is:

\[ \Delta p_{i,i-1} = p_i - p_{i-1} = 0.01 B e^{0.2625 s_i + 1.455} - e^{0.2625 s_{i-1} + 1.455} \]  

The essential issue is whether equations 1, 2, and 3 will hold for market corn inspection data. If so, then the equations can be used to estimate quantities of discountable material and cleanings under various particle-size standards alternatives. If not, then market location and/or other quality factor influences need to be included in the estimates.

Particle-size analysis of corn samples provides a theoretical estimate of screenings removable by various sized screens. Estimation of screenings quantities and/or size distribution from laboratory-cleaned corn samples assumes 100% cleaning efficiency for all sizes. Actual cleaning efficiency is less than 100% and declines as particle size approaches the opening size. Production cleaners normally have square, rather than round, screen openings.
Hurburgh et al. (1989) studied on-farm rotary grain cleaners equipped with 0.225-in. (5.7-mm), square-opening screens, and concluded the BCFM was removed at approximately 75% efficiency and that material greater than 12/64-in. diameter but less than 16/64-in. (6.4-mm) diameter was removed at about 25% efficiency. The latter material is important because it could have been sold for full value as corn. About 1% of total grain weight was removed as larger than 12/64-in. diameter particles.

Quality of corn screenings is most often measured by test weight and moisture (Hill et al., 1991a). Screenings are usually discounted or rejected by users if test weight is below 40 lb/bu (51.2 kg/hl). The quart-cup test-weight apparatus (FGIS, 1986) is normally used to determine test weight of screenings. Screenings that consistently weigh less than 40 lb/bu are difficult to merchandise and occupy proportionately more storage volume per unit of weight.

Composition is important to determine feeding and market value of corn screenings. The traditional index of screenings value, test weight, does not necessarily measure composition, except that fiber has inherently lower density than starch or protein. The extent to which bulk or particle density can be used to predict composition is not known.

Bern and Hurburgh (1992) reported previous studies measuring composition of fines removed from corn. In general, protein increased with decreasing particle size, but so did fiber and ash. These reports were for laboratory-cleaned samples, not for actual screenings samples.

Mycotoxins are another concern to users of corn screenings. The most common mycotoxins found in corn screenings are aflatoxin (Hill et al., 1982) and, most recently, fumonisin (Ross et al., 1991).

Elevator configuration and cleaner operating practices probably contribute to variability in screenings properties, although the extent of influence is not known. Greater emphasis on corn cleaning will create a need to manage the properties of cleanings for maximum salability and minimum economic loss.

Published data on the properties of production screenings are not available. These data are important to establish both quantities and qualities of actual screenings removed, should more cleaning be done in response to Standards changes.

**OBJECTIVES**

The objectives of this research were to:

- Validate the Bern-Hurburgh predictive equation for particle size distribution of corn as applicable at all market points and as insensitive to other quality factors.
- Estimate particle-size distribution, bulk density, particle density, composition, and mycotoxin levels of corn screenings from country elevators.
- Estimate an aggregate cleaning efficiency, by particle size, of cleaners in use at country elevators.
- Relate elevator design and operating parameters to the properties of corn screenings.

Data collected by Federal Grain Inspection Service in domestic and export inspections from September 1988 to August 1990, samples of corn screenings collected in 1989, and survey information from 62 country elevators were used for this analysis.

**MATERIALS AND METHODS**

**INSPECTION DATA**

Federal Grain Inspection Service provided data from both export and domestic inspections. All inspection data were collected according to approved procedures for corn inspections (FGIS, 1990). Test results for all grade and condition factors, plus classification information, were available.

Export data were taken from the Export Grain Inspection System (EGIS) database. Interior inspection data were obtained from the Grain Inspection Monitoring System (GIMS) database. Two types of inspections are recorded in the GIMS database: (1) appeals of interagency original inspections to FGIS field offices, and (2) field-office supervisory monitoring on 0.5% of interagency inspections. Appeal data were not used in this analysis because appealed inspections might not be representative of inspections as a whole. Supervisory samples are drawn randomly.

Percentages of FM and BCFM were measured directly by inspectors. BC was calculated by subtracting FM percentage from BCFM percentage. The coarse FM (large hand-picked nongrain material) was included with FM. Any nongrain material falling through the BCFM screen but not the FM screen was included in the BC fraction. The FM ratio, percent FM divided by percent BCFM, was calculated for each observation. Predicted FM ratio is the solution of equation 1, with $s_1 = 6$. Federal inspectors only determined FM and BCFM, not the full range of particle sizes. This analysis assumes that if equation 1 predicts FM-sized particles accurately, then the equation is valid for other particle sizes as well.

For export corn, averages and standard deviations for all grade factors and the FM ratio were calculated by year and grade. Paired t-tests were used to determine if the FM ratio was significantly different between grades ($P = 0.05$), and if the measured FM ratios were different from those predicted by equation 1. Mean values of all numeric variables, by grade, for the two years were tested for significant differences.

The domestic inspection data were sorted by year, carrier, and grade. Only samples where the carrier was designated were used, which eliminated submitted samples. Statistical comparisons were made among carriers and years.

A simple correlation matrix was formed with all the grade factor variables and the FM ratio, by year. Export and domestic data were combined. The purpose was to determine if quality factors affect the relative amounts of BCFM and FM in corn lots.

**ELEVATOR SCREENINGS AND SURVEY**

Questionnaires and requests for screenings samples were sent to 500 elevators across the United States. This was a subset of a larger 2000-elevator group receiving surveys only. Details of the questionnaires and survey protocol are given by Hill et al., 1991b. Elevators were asked to send about 2000 g of screenings in a plastic grain sample bag. Table 1 summarizes the origins of the 62 screenings samples received.
LABORATORY PROCEDURES

Screenings samples were weighed, then separated into eight particle-size fractions with the following round-hole screens, progressively placed in the top rack of a Carter Dockage tester: 4.5/64 in., 6/64 in., 8/64 in., 10/64 in., 12/64 in., 14/64 in., and 16/64 in. (1.8, 2.4, 3.2, 4.0, 4.8, 5.6, and 6.4 mm). The sized portions were analyzed separately. All material larger than 16/64 in. was classed as 18/64 in. in equations.

The weights of each fraction (through one screen size but not the next smaller size) were measured to calculate the percentage distribution. Bulk density (test weight) of each fraction was measured with a test weight apparatus (FGIS, 1986). Particle density was measured with an air-comparison pycnometer (Dorsey-Redding et al., 1991).

Some fractions were too small to fill the quart cup on the test-weight apparatus. For these, a smaller (156 cc) plastic cup was used. This cup was filled from the test-weight apparatus, at the same 2-in. drop height used for the comparison pycnometer (Dorsey-Redding et al., 1991). A correction equation, based on 60 samples, 39 elevators sent both a survey and a sample. Not all size-sample combinations were analyzed. All material larger than 16/64 in. was classed as 18/64 in. in equations.

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Some fractions were too small to fill the quart cup on the test-weight apparatus. For these, a smaller (156 cc) plastic cup was used. This cup was filled from the test-weight apparatus, at the same 2-in. drop height used for the quart cup. A correction equation, based on 60 samples tested in both cups, was:

\[ T_q = 1.014T_s - 2.3 \]

\[ R^2 = 96.0, \text{ std. dev.} = 1.3 \]

where

\[ T_q = \text{test weight from quart cup (lb/bu)} \]
\[ T_s = \text{test weight from small cup (lb/bu)} \]

This equation was used to convert all 156-cc test weights to quart-cup equivalents. The pycnometer required only 20 to 25 g, so fraction weight was not a concern in the particle density test.

Six samples were measured for bulk density (test weight) as received, before separation. The composite test weight was 2.0 lb/bu (s = 0.5 lb/bu) higher than the size-weighted average because the smaller particles fit in spaces between the larger ones. The weighted average test weight plus 2.0 lb/bu was used to estimate the test weight of mixtures.

Particle density was measured for samples of each size. The pycnometer test was more time consuming, which is why not all size-sample combinations were analyzed. Particle density of mixtures can be calculated as a size-weighted average.

A 20-g subsample for each size-sample combination was ground in a Magic Mill III+ home flow mill, analysis for protein, oil, and starch content (basis 15.5% moisture) in a Dickey-john Instalab 800 near-infrared reflectance analyzer. For sized samples of sufficient weight, approximately 30 to 50 g was divided out for mycotoxin analysis. Aflatoxin assays were done by the Iowa State University Veterinary Diagnostic Laboratory. Fumonisin assays were done by the National Animal Disease Center, Ames, Iowa.

SURVEY DATA

The following elevator design and operating parameters were established as potentially important in determining amounts and properties of screenings.

- Storage volume (bu)
- Volume of corn handled (bu/yr)
- Volume of all grains handled (bu/yr)
- Turnover ratio (c/a)
- Cleaner rated capacity (bu/h)
- Cleaner operating capacity (bu/h)
- Cleaner operation as a percentage of capacity \((f/e \cdot 100)\)
- Cleaner age (yr)
- Percentage of corn cleaned
- Percentage points of screenings removed
- Volume of screenings handled (bu/yr)
- Cleaner type
- Screen opening type and dimensions
- Scalping

Parameters a through k are continuous-scale variables.

Parameters m, n, and o are categorization variables. Eleven were included in the survey; the other two (d and g) were calculated.

Volume of screenings (k) was reported and also was calculated from b, i, and j. While 62 elevators sent samples, 39 elevators sent both a survey and a sample. Not all surveys were fully completed.

DATA ANALYSIS

The particle-size distribution of each sample was computed as a percentage distribution based on total weight, and as a percentage distribution based on percent BCFM (material through the 12/64 in. screen). The distributions were both cumulative (all material through a given size) and incremental (material between any two adjacent sizes).

The mean-particle-size distribution was determined for the 62 samples. A regression curve was fitted through the individual-sample data points. The curve for the cumulative distribution, as a percent of BCFM, was analogous to the Bern and Hurburgh (1992) equation for corn sample particle-size distribution. The equations for particle-size distribution in screenings and corn were
combined to estimate cleaning efficiency at U.S. country elevators.

Bulk and particle densities were averaged by particle-size increment and estimated by cumulative size. The latter predicts the density of screenings removed by various screen sizes. A correlation matrix was formed between incremental bulk and particle densities and the percentage of sample weight in each size increment.

Composition and mycotoxin data were first averaged by particle size. An analysis of variance was used to test size categories for statistical significance and to determine least significant differences (LSD).

A simple correlation matrix was then formed, including composition, mycotoxins, density, and size. This was done to identify any potential for predicting intrinsic quality factors from physical properties information. The current 40 lb/bu trading limit for screenings test weight was evaluated against actual compositional and mycotoxin data.

Values for elevator parameters were summarized. Parameters were correlated to describe operating patterns of elevators. Then, screenings properties were correlated with those elevator parameters measured on a continuous scale. Averages by category were computed for parameters not on a continuous scale.

RESULTS AND DISCUSSION

SIZE DISTRIBUTION OF CORN SAMPLES

Table 2 gives the averages for grade factors along with the number of samples. The data was divided by carrier (vessel, barge, hopper car, and truck) and grade (1-5 and Sample). Grades deteriorated from predominantly 1YC and 2YC at inland points to 3YC at export locations. This decline was almost exclusively due to BCFM increases, not to reduction in test weight or increase in damage.

Trucks were the only carrier significantly different in FM Ratio. This is logical because truck grain is handled less, blended less, and therefore is of quality closer to field run than grain in any of the other carriers. Truck corn samples were not as close, in BCFM, to their respective grade limits as samples from the other carriers.

As would be expected, shiplot samples were the closest to the grade limits, followed by barge samples, hopper car samples, and truck samples. BCFM was the only factor that changed noticeably by carrier, and was the only factor that consistently approached grade limits. The point is that, however the corn particle size factors are structured, exporters will feel the most pressure.

FM ratio increased slightly with BCFM concentration for three of the four carrier types, but the slopes (rates of change of FM ratio) were not large, averaging 1.4 percentage units/% BCFM. One percentage unit of FM ratio means only 0.03 to 0.04 percentage points of actual FM. The R² values of linear regressions by carrier were very low (<5%), which indicates that the regression equations were not very useful for predicting individual situations.

Equation 1 underestimated the FM ratio by about two percentage points (22.5% actual vs. 20.7% predicted). This is probably not large enough to cause concern about use of equation 1 to estimate particle-size distributions in market corn. Figure 1 shows the scatter of deviations (actual FM vs. predicted -- equation 1).

Figure 1—Actual FM ratio compared to Bern-Hurburgh equation predictions.

Table 2. Corn quality data, by carrier

<table>
<thead>
<tr>
<th>Carrier</th>
<th>Vessel (export)</th>
<th>Barge (interior)</th>
<th>Hopper Car (interior)</th>
<th>Truck (interior)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of lots</td>
<td>1819, 2049</td>
<td>2479, 2213</td>
<td>7836, 8231</td>
<td>1110, 1402</td>
</tr>
<tr>
<td>(1989, 1990)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% distribution</td>
<td>1-22-85-1-1-0</td>
<td>18-42-29-7-3-1</td>
<td>25-42-21-8-3-1</td>
<td>56-18-10-8-5-3</td>
</tr>
<tr>
<td>by grade (1-2-3-4-5-S)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moisture (%)</td>
<td>13.9</td>
<td>13.8</td>
<td>13.9</td>
<td>13.8</td>
</tr>
<tr>
<td>Test weight (lb/bu)</td>
<td>57.0</td>
<td>57.1</td>
<td>57.1</td>
<td>57.7</td>
</tr>
<tr>
<td>Total damage (%)</td>
<td>3.7</td>
<td>3.8</td>
<td>3.6</td>
<td>3.8</td>
</tr>
<tr>
<td>BCFM (%)</td>
<td>3.3</td>
<td>2.9</td>
<td>2.6</td>
<td>2.6</td>
</tr>
<tr>
<td>FM ratio* (BCFM)</td>
<td>22.8</td>
<td>24.3</td>
<td>22.1</td>
<td>17.8</td>
</tr>
</tbody>
</table>

* The overall average FM ratio was 22.5%.
ratio-predicted FM ratio), by carrier, in increments of 1% BCFM. Equation 1 was derived by Bern and Hurburgh (1992) using totally different data.

The only significant correlations among the factors listed in table 2 were FM-BCFM (r = 0.85) and FM Ratio-FM (r = 0.61). This was somewhat unexpected. Low test weight is often considered indicative of breakage prone and/or moldy corn and thus ought to be related to BCFM and damage (DKT) levels. Evidently blending and cleaning cause BCFM and DKT to be independent of other factors.

Because equation 1 is valid, equations 2 and 3 can be used to determine the incremental (between any two screen sizes) distribution of sizes. This is the particle-size distribution within samples of com, not within samples of screenings. Cleaner efficiency, which is a function of interior (country) elevators are low, less than 0.5%. A larger screen size for FM would increase measured test weight of particles through 6/64 in. would be estimated at 33.6 lb/bu.

**Screenings Properties**

The cumulative (C) and incremental (I) screenings properties are summarized in table 3. Cumulative values are calculated as shown, and estimate properties of screenings removed by various possible screen sizes. For example, the test weight of particles through 6/64 in. would be estimated at 33.6 lb/bu.

**Particle-Size Distribution**

A cumulative distribution equation was generated from regression on the individual sample data:

\[ p_{i,s} = -0.387s_i^2 + 15.54 s_i - 52.7 \]  

\[ R^2 = 90.0\%, \text{ std. dev.} = 10.5 \text{ percentage points} \]

---

**Table 3. Incremental (I) and calculated cumulative (C) corn screenings properties, by particle size**

<table>
<thead>
<tr>
<th>Property</th>
<th>Size Increment (64th-in.)</th>
<th>Size Increment (64th-in.)</th>
<th>Size Increment (64th-in.)</th>
<th>Size Increment (64th-in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;-------FM--------&gt;</td>
<td>&lt;--------BC----------&gt;</td>
<td>&lt;--------Corn--------&gt;</td>
<td></td>
</tr>
<tr>
<td>Size distribution*</td>
<td>I 12.4</td>
<td>14.3</td>
<td>13.6</td>
<td>22.3</td>
</tr>
<tr>
<td>(% of weight) C</td>
<td>12.4</td>
<td>26.7</td>
<td>40.3</td>
<td>62.6</td>
</tr>
<tr>
<td>FM, Loss ratios</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(% of BCFM)</td>
<td>I</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test weight</td>
<td>I</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(lb / bu)</td>
<td>32.4</td>
<td>30.9</td>
<td>35.4</td>
<td>39.3</td>
</tr>
<tr>
<td>C</td>
<td>32.4</td>
<td>33.6</td>
<td>34.9</td>
<td>37.2</td>
</tr>
<tr>
<td>Density‡</td>
<td>I</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(g / cc)</td>
<td>1.424</td>
<td>1.380</td>
<td>1.385</td>
<td>1.378</td>
</tr>
<tr>
<td>C</td>
<td>1.424</td>
<td>1.400</td>
<td>1.395</td>
<td>1.389</td>
</tr>
<tr>
<td>Protein§</td>
<td>I</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(%)</td>
<td>8.7</td>
<td>8.3</td>
<td>8.1</td>
<td>7.9</td>
</tr>
<tr>
<td>C</td>
<td>8.7</td>
<td>8.5</td>
<td>8.4</td>
<td>8.2</td>
</tr>
<tr>
<td>Oil§</td>
<td>I</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(%)</td>
<td>1.9</td>
<td>1.8</td>
<td>1.7</td>
<td>2.4</td>
</tr>
<tr>
<td>C</td>
<td>1.9</td>
<td>1.8</td>
<td>1.8</td>
<td>2.0</td>
</tr>
<tr>
<td>Starch§</td>
<td>I</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(%)</td>
<td>58.6</td>
<td>59.2</td>
<td>60.2</td>
<td>60.0</td>
</tr>
<tr>
<td>C</td>
<td>58.6</td>
<td>58.9</td>
<td>59.4</td>
<td>59.7</td>
</tr>
<tr>
<td>Cleaning Efficiency</td>
<td>I</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>1.23</td>
<td>2.28</td>
<td>1.81</td>
<td>0.91</td>
</tr>
<tr>
<td>Multiplier (Cf)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fumonsin (ppm)‡‡</td>
<td>I 49.7</td>
<td>34.3</td>
<td>28.1</td>
<td>27.7</td>
</tr>
<tr>
<td>C</td>
<td>49.7</td>
<td>41.5</td>
<td>37.0</td>
<td>33.7</td>
</tr>
<tr>
<td>Aflatoxin (ppb)‡‡</td>
<td>I 36</td>
<td>61</td>
<td>36</td>
<td>41</td>
</tr>
</tbody>
</table>

* Cumulative distribution = sum of increments.
‡ Cumulative test weight = weighted average + 2.0 lb / bu.
§§ Cumulative composition = weighted average; protein, oil, starch basis 15.5% moisture.
# Cumulative CEM.

\[ C_i = -0.00496s_i^2 + 0.199s_i - 0.67 \]  

\[ e^{0.2625s_i + 1.455} \]

** Only one sample positive for aflatoxin (337).
Ratios for the 62 screenings samples. Loss Ratio is the concentration in smaller sizes than were com samples. This percentage of BCFM is given in figure 2, with comparison estimator of potential discounts. In screenings, the FM percentage of oversize material relative to BCFM. means that commercial corn cleaners produce a smaller margin. Production cleaners with square-mesh screens do not “cut off” at a particle size defined by round-hole screens. Particle-size distribution of screenings as a percentage of BCFM is given in figure 2, with comparison to corn samples. The screenings samples were more concentrated in smaller sizes than were corn samples. This means that commercial corn cleaners produce a smaller particle-sized product than laboratory cleaning of corn samples would predict. Table 4 shows the FM and Loss Ratios for the 62 screenings samples. Loss Ratio is the percentage of oversize material relative to BCFM.

In corn, the FM Ratio has economic significance as an estimator of potential discounts. In screenings, the FM Ratio measures size distribution and therefore is an indicator of quality, assuming smaller sized screenings to be of lesser quality than larger sized screenings. The Loss Ratio does not apply to whole corn but is of economic importance in screenings. Each 0.1% of economic loss represents about 0.2¢/bu, at current corn prices.

BULK AND PARTICLE DENSITY

The cumulative test weights were calculated as a weighted average of the individual sizes, plus 2.0 lb/bu. Sizes smaller than 8/64 in. have a significant chance of weighing less than 40 lb/bu, the usual trading standard for corn screenings. There was considerable variability in the test weight data in all sizes. The standard deviations were 10 to 15% of the mean values.

The higher particle densities for the smaller sizes probably reflect higher ash content and less entrained air. Obviously density can be a very confusing measure of screenings quality. Particle and bulk density are inversely correlated, and the advantages or disadvantages of higher bulk density are not clear.

Samples with more small particles had lower cumulative test weights and higher cumulative particle densities. Within a size, density measures were independent of the relative concentration of that size.

Over all the particle sizes, test weight and particle density were inversely related. However, within a given size increment, the opposite was true. The simple correlation coefficient between test weight and particle density within size increments ranged from 0.32 to 0.74. Over all sizes, the correlation between test weight and particle density was −0.51. This is further evidence of the difficulty in using density measurements as indicators of screenings quality.

For screenings of mixed sizes to weigh more than 40 lb/bu, material up to or larger than 12/64 in. must be included. This is not to say that 40 lb/bu screenings are automatically valuable as feed, or that lighter screenings are not valuable. If smaller-sized screenings were made available, however, adjustments in marketing practices would be needed.

COMPOSITION

Sized particles varied significantly in protein, oil, and starch content. Overall, the screenings were approximately the same as corn in all factors except oil, which was lower in screenings. If anything, screenings were slightly higher in protein than corn (which is normally about 8.0% protein). The trend of protein being high at the larger and smaller sizes is consistent with Al-Yahya et al. (1991). Hill et al. (1982) reported higher protein in the smaller sizes but did not find the dip in protein in the middle sizes. The lower starch in the small sizes supports earlier work showing an increase of 1 to 2% fiber and ash in small fines (Hill et al., 1982).

Within a size, protein and starch were inversely related (r = −0.29 to −0.80) as expected. Protein and oil were positively correlated (r = 0.29 to 0.42), probably because of germ parts. Higher test weight samples generally had higher amounts of starch, but not necessarily more protein. Only one sample contained measurable aflatoxin (avg.
33 ppb) in any of its fractions. The smaller sizes generally contained more aflatoxin, but the striking point is that only one sample was affected. Screenings are generally thought to have greater aflatoxin risk than is whole corn, and cleaning is sometimes cited as a method to reduce aflatoxin levels. Hill et al. (1982), however, also reported low correlation between particle size and aflatoxin levels.

Most samples contained fumonisin in one or more fractions. Only three were negative in all fractions. There was a generally declining trend of fumonisin levels as size increased. This means smaller fines, if removed as a separate product, would be of even greater risk than screenings currently marketed. Within a size, higher test weight was accompanied by lower fumonisin (r = 0.46 to −0.77), which means that screenings test weight can be a risk indicator.

**DERIVATION OF CLEANER EFFICIENCY**

The distribution of particle sizes in the 62 screenings samples (eq. 5) was combined with the estimated size distribution of market corn (eq. 1) to estimate cleaner efficiency at country elevators. A mass balance on the entire grain weight, and on each particle size, describes efficiency in cleaning.

\[
W_{co} = W_s + W_{cf} \tag{6}
\]

where

- \(W_{co}\) = initial corn weight
- \(W_s\) = weight of screenings removed
- \(W_{cf}\) = weight of cleaned corn

and

\[
\frac{p_{i,o} W_{co}}{100} = \frac{p_{i,s} W_s}{100} + \frac{p_{i,f} W_{cf}}{100} \tag{7}
\]

where

- \(p_{i,o}\), \(p_{i,f}\) = percentage of total corn weight in size \(i\)

\[
E_i = \frac{p_{i,s} W_s}{p_{i,o} W_{co}} \tag{8}
\]

where

\(E_i\) = efficiency of removal for particles of size \(i\) and smaller

\[
p_{i,s} = \frac{p_{i,s} B_s}{100} \tag{9}
\]

where

\(B_s\) = BCFM percentage of screenings

\[
p_{i,o} = \frac{p_{i,c} B_c}{100} \tag{10}
\]

where

\(B_c\) = BCFM percentage of corn

A special case of \(E_i\) is \(E_g\), equation 8 solved for \(s_i = 12\). Combination of equations 6 through 10 yields:

\[
E_{i,s} = \frac{P_{i,s}}{E_B} + \frac{P_{i,s}}{P_{i,c}} \tag{11}
\]

and, for particles in size range \(i\) to \(i - \Delta i\)

\[
E_{i,i-\Delta i} = \frac{p_{i,s}}{E_B} = \frac{p_{i,s}}{p_{i,c}} \tag{12}
\]

Define two efficiency multipliers \(C_t\) and \(C_i\)

\[
C_t = \frac{E_i}{E_B} = \frac{p_{i,s}}{p_{i,c}} \tag{13}
\]

\[
C_i = \frac{E_{i,i-\Delta i}}{E_B} = \frac{p_{i,s}}{p_{i,c}} \tag{14}
\]

This means that individual size efficiencies are calculated as functions of \(E_B\). Rearrangement of 13 and 14 will give \(E_{i,i-\Delta i}\), if \(E_B\) is known.

The removal efficiency, \(E_B\), for BCFM can be calculated as:

\[
E_B = \frac{B_{co} - B_{cf}}{B_{co}} \tag{15}
\]

where

\(B_{co}\), \(B_{cf}\) = initial, final percentages of BCFM

If we assume that \(B_{cf} = 3.0\%\) (No. 2 yellow corn), and \(B_{co}\) ranges from 4\% to 8\%, then \(E_B\) ranges from 25\% to 63\% in normal practice. The exact value for a given situation can be calculated from samples of cleaned and uncleaned corn. The average removal for the 62 elevators returning screenings samples was 2.0 percentage points, with a target (cleaned) BCFM of 3.0\%. In this case, \(E_B = 0.40\) (40\%). The cleaners were being operated at 70\% of rated capacity.

**ELEVATOR PARAMETERS**

Table 5 gives a description of the 39 elevators that returned both a survey and a screenings sample. Not all elevators completed all parts of the survey, which accounts for the unequal observation numbers for the various parameters.

All the elevators were country elevators, buying from farmers. This is why the turnover ratio was relatively low. Storage contributes a major portion of country elevator income. The elevators did not push their cleaners to full capacity. Most of the cleaners were older, gravity flow models purchased in the more profitable marketing years of the late 1970s. Hill et al. (1991b) reported that the average age of export cleaners was a similar 14.6 years.
Table 5. Description of elevators returning screenings samples and surveys (n = 39)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>n</th>
<th>Average</th>
<th>Range</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Storage volume (106 bu)</td>
<td>39</td>
<td>3.0</td>
<td>0.3 - 20.0</td>
<td>3.2</td>
</tr>
<tr>
<td>b. Corn handled (106 bu / yr)</td>
<td>39</td>
<td>3.0</td>
<td>0.1 - 20.5</td>
<td>3.4</td>
</tr>
<tr>
<td>c. Grain handled (106 bu / yr)</td>
<td>39</td>
<td>4.1</td>
<td>0.5 - 24.6</td>
<td>4.3</td>
</tr>
<tr>
<td>d. Turnover ratio (c / a)</td>
<td>39</td>
<td>1.47</td>
<td>0.38 - 4.72</td>
<td>0.94</td>
</tr>
<tr>
<td>e. Cleaner rated cap. (bu / h)</td>
<td>34</td>
<td>11,000</td>
<td>3,000 - 43,000</td>
<td>9,600</td>
</tr>
<tr>
<td>f. Cleaner operating cap. (bu / h)</td>
<td>34</td>
<td>7,800</td>
<td>2,000 - 40,000</td>
<td>8,500</td>
</tr>
<tr>
<td>g. Percent operation (100 t / e)</td>
<td>34</td>
<td>67</td>
<td>30 - 100</td>
<td>20</td>
</tr>
<tr>
<td>h. Cleaner age (yrs)</td>
<td>27</td>
<td>13.0</td>
<td>6.0 - 20.0</td>
<td>4.0</td>
</tr>
<tr>
<td>i. Percent of corn cleaned</td>
<td>35</td>
<td>68.7</td>
<td>15.0 - 100.0</td>
<td>30.5</td>
</tr>
<tr>
<td>j. Screening removed (% points)</td>
<td>32</td>
<td>2.0</td>
<td>0.2 - 3.0</td>
<td>1.0</td>
</tr>
<tr>
<td>k. Screenings removed (bu)</td>
<td>32</td>
<td>2.0</td>
<td>0.2 - 3.0</td>
<td>1.0</td>
</tr>
<tr>
<td>-- Calculated (b_ij / 10,000)</td>
<td>32</td>
<td>52,000</td>
<td>400 - 430,500</td>
<td>87,700</td>
</tr>
<tr>
<td>-- Reported</td>
<td>34</td>
<td>32,100</td>
<td>2,100 - 232,100</td>
<td>53,200</td>
</tr>
</tbody>
</table>

Interestingly, more than 60% of the corn was cleaned, with an average of 2.0 percentage points of BCFM removed. This suggests that there is more corn breakage in elevators than tabulations of graded quality at various points would indicate. The additional breakage is being removed as screenings. Country elevator operators have traditionally estimated that BCFM increased 2 to 3 percentage points in their elevators. However, the operators did not differentiate between cleaning to remove screenings and cleaning to reblend for more precise quality control.

According to Hill et al. (1991b), 97% of export elevators reported cleaning some corn, removing 3.5 percentage points of BCFM from the corn that was cleaned, at an average flowrate of 19,000 bu/h (72% of rated capacity). Exporters cleaned faster and removed more screenings but did not push their cleaners any harder than interior operators. Hill et al. (1991b) also reported that exporters sold only 1% of total volume as screenings, the same percentage as interior operators. Removal/reblending operations are more sophisticated at export, allowing exporters to approach grade limits more closely than interior operators.

The reported screenings volumes did not equal the predicted screenings volume (calculated from points removed and corn volume). There are two explanations: (1) some screenings were rebled with cleaner corn, and (2) some screenings were used by the elevators themselves for livestock feed, and thus were not sold. Again, this is consistent with the Hill study that reported 1% of total corn volume actually sold as screenings.

The cheaper gravity cleaners were most common. Most of the cleaners had screen openings larger in equivalent area than the 0.188-in., round-hole screen used for BCFM analysis. This virtually assures that some oversize material will be removed in the screenings.

Some of the elevator parameters were related to one another. Table 6 gives the parameter-pairs that had correlation coefficients with |r| ≥ 0.40 and significance at or beyond the 0.05 probability level. The volume variables (storage, annual corn, annual total, screenings) are obviously interrelated. There were few relationships between the cleaner variables and other parameters. Elevators removing more screenings tended to have larger capacity cleaners.

Of more interest were the relationships that did not exist. Size of elevator had no impact on the turnover ratio, or on the percentage points of screenings removed. This suggests that factors other than sheer size account for differences in the need to clean corn. The traditional view is that larger elevators, because they move grain faster, create more broken kernels. An emphasis on fewer broken kernels is thought to be incompatible with increased needs for speed in handling. Data from these surveys did not support this theory.

A summary of elevator parameters, categorized by cleaner variables, is given in table 7. The “shaker” type cleaners were owned by larger elevators. Shaker cleaners are inherently more efficient; thus the higher throughput as a percentage of maximum. Export elevators use “shaker” cleaners almost exclusively (Hill et al., 1991b).

Screenings properties were compared with the elevator parameters. As more screenings were removed per bushel, or the cleaners were operated closer to rated capacity, the FM Ratio declined (less smaller material relative to larger) (r = -0.42, -0.40, respectively). Conversely, economic loss (from large particles in cleanings) increased with operating capacity and screenings removal (r = 0.51, 0.47, respectively). The chemical and physical properties of screenings were not consistently related to any cleaner parameter. At higher flowrates, elevators used larger screens which put more “corn” in the screenings and therefore relatively less FM. Hill et al. (1991b) also reported that export elevator screenings contained more oversize material, on a percentage basis, as flow rate increased. This is important because more cleaning initiated by Standards changes will necessitate not only more cleaners but higher flowrates with more removal through existing cleaners. The screenings will be richer in larger, more dense particles, but more cost will be generated from corn loss in screenings. The FM Ratio and...

Table 6. Correlation coefficients * (r) among elevator parameters†

<table>
<thead>
<tr>
<th>Variable</th>
<th>Storage</th>
<th>Corn Volume</th>
<th>Total Volume</th>
<th>Screenings Removed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Predicted</td>
</tr>
<tr>
<td>Corn volume</td>
<td>0.92</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total volume</td>
<td>0.89</td>
<td>0.98</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Predicted screenings</td>
<td>0.89</td>
<td>0.90</td>
<td>0.89</td>
<td>1.00</td>
</tr>
<tr>
<td>Reported screenings</td>
<td>0.89</td>
<td>0.66</td>
<td>0.73</td>
<td>0.90</td>
</tr>
<tr>
<td>Points removed</td>
<td>--</td>
<td>--</td>
<td>0.51</td>
<td>0.45</td>
</tr>
<tr>
<td>Cleaner operating</td>
<td>--</td>
<td>--</td>
<td>0.47</td>
<td>--</td>
</tr>
</tbody>
</table>

* Significant (P = 0.05) and |r| ≥ 0.40.
† All combinations not listed had P > 0.05 or |r| ≤ 0.40.
CONCLUSIONS

1. The Bern-Hurburgh equation was valid based on actual inspection data, for estimating concentrations of corn particle sizes at any market location. Corn particle-size distribution or concentration did not influence any other official grade factor.

2. The corn screenings samples contained an average 55.8% BC (between the 12/64 in. and the 6/64 in.), 26.7% FM (6/64 in. and below), and 17.5% “corn” (greater than 12/64 in. diameter). The corn loss represented about 0.2% weight loss (0.12% of corn value). There was more FM than was predicted from laboratory analysis of corn samples.

3. Smaller particle sizes had lower test weights, down to 33.5 lb/bu for pure FM.

4. Particle density decreased with increasing particle size. If particle size was held constant, particle density increased with increasing test weight.

5. Overall, the corn screenings had approximately the same nutritional composition as corn. The smallest sizes (below 6/64-in. diameter), however, were about 0.5% higher in protein and 1 to 2% lower in starch than the weighted average of all sizes.

6. Only one sample (of 62) contained measurable aflatoxin, but nearly all samples contained fumonisin, with the smaller sizes having more. The weighted average fumonisin content was 30 ppm.

7. In any particle size, high test weight was negatively correlated with fumonisin and positively correlated with starch content. In any size, protein and oil content were positively correlated; protein and starch were negatively correlated.

8. Size distribution and cleaner parameters were not related to any physical or chemical property of screenings.

9. Country elevators reported that more than 60% of corn handled was cleaned, with an average removal of 2.0 percentage points of BCFM. More screenings were removed than indicated by tabulations of corn inspection data. Elevator size was not related to percentage points of removal.

10. Elevators removing the most screenings operated their cleaners at higher throughputs, with larger-sized screens.

REFERENCES


