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Shrinkage and Other Corn-Quality Changes From Drying at Commercial Elevators

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Abstract
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Disciplines
Agriculture | Bioresource and Agricultural Engineering

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Shrinkage and Other Corn-Quality Changes from Drying at Commercial Elevators

Charles R. Hurburgh, Jr., Bruce W. Moechnig
ASSOC. MEMBER ASSOC. MEMBER
ASAE ASAE

ABSTRACT

WEIGHT losses and corn-quality changes from drying and handling were measured at two modern country elevators. In addition to moisture losses, material handling losses averaged 0.88% of initial weight, with a range of 0.64% to 1.33% of initial weight. There was a fourfold increase in breakage susceptibility and a twofold increase in physical kernel damage after drying. Load-to-load variations in moisture content and test weight decreased after drying while load-to-load variations in BCFM, breakage susceptibility and harvest damage increased after drying.

INTRODUCTION

Weight reductions and quality changes are major concerns to any grain handler. To the extent that these changes result in economic loss, their value is reflected in prices and discounts somewhere in the grain market. An advance prediction of weight and quality losses enable a grain merchant to determine costs of operations and to explain those costs more clearly to grain sellers.

Weight Reductions - Shrinkage

Moisture loss can be calculated from the following formula, provided that the initial and final moisture contents are accurately measured:

\[ W_o - W_f = \left( \frac{1}{100 - M_f} \right) (M_o - M_f)(W_o) \]  \[1\]

where:

- \( W_o, W_f \) = initial and final weights, in mass units
- \( M_o, M_f \) = initial and final moisture contents, percent wet basis

Of a more elusive and unpredictable nature is the dry-matter loss that occurs in drying and transfer operations. This dry matter loss or “handling loss” includes dust emissions, loss of fine particles, spillage, and any discarded screenings. Shrinkage can be calculated from equation [1] with the addition of a handling loss allowance, \( h \), as a percentage of \( W_o \).

The traditional assumption for \( h \) (handling in and out of a dryer) has been 0.005 (0.5%), the Minary Tables, Series D (Minary, 1947). Until the early 1970’s, grain dealers normally used the Series D Minary Tables to calculate shrinkage of wet grain. A revision of the Series D Tables, in which \( h \) is set to the value of 0.02 (2.0%), has recently been published as the Minary Combination (Series C) Tables (Minary, 1977). The stated difference between the Series D and Series C tables is that the Series C tables include moisture loss plus handling loss in all operations, whereas the Series D tables cover only moisture loss plus handling loss in the dryer.

Moisture loss and handling loss are, under current practice, combined and calculated through the use of a shrinkage factor. The shrinkage factor is the percentage of weight loss per point of moisture removed that is charged to the seller for drying and handling. This factor is not universal because elevators are not universal in design or operating practice. Instead, each elevator establishes the shrink factor that it will use based on past records, experience, and pressure from competitors. In Iowa, shrink factors normally range from 1.25% to 1.50% per point of moisture removed (IGFA, 1979). In shrink-factor calculation the factor is substituted for the \(1/100 - M_f\) term in equation [1].

The shrink factor will provide a given amount of handling loss, \( h \), as a percentage of wet weight, when the following condition is met:

\[ f = \frac{1}{100 - M_f} + \frac{h}{100 (M_o - M_f)} \]  \[2\]

Given a value of \( h \), the equivalent shrink factor increases as initial moisture content decreases.

In equation [1], \((1/100 - M)\) represents the fraction of water-weight loss per point of moisture removed. When drying to 15.5% moisture (base moisture for Number 2 corn), 1.183% of wet weight is lost per point of moisture removed.

Quality changes

In an economic sense, changes in corn quality are just as relevant to grain merchants as are actual weight losses. Of major interest are the increases in broken corn and foreign material (BCFM) which occur continuously (Hill et al., 1979) as grain is handled. The BCFM problem is complicated because very little wet grain is delivered with BCFM percentages over 1.5% (Hurburgh et al., 1979). The quality characteristics breakage susceptibility (brittleness) is indicative of future increases in BCFM (Herum and Hamdy, 1981). Presumably grain with a high potential for breakage will also experience a greater amount of handling loss from dust and fines. Foster and Holman (1973) demonstrated that the grain temperature within a dryer is a key determinant of increases in breakage susceptibility. While several researchers have developed methods to reduce breakage susceptibility increases in continuous-flow dryers, there is a shortage of data describing the performance of typical systems as operated at commercial elevators.
The recurrent difficulty of sampling and testing grain lots compounds the problem of measuring quality changes during drying. A grain merchant buys and sells on the basis of sample analyses. Variability in sampling and testing creates risk for the trade, risk which must be compensated in some way. Probe samples are often not representative, especially if only one probing is taken per load (Hurburgh et al., 1979; Bermingham et al., 1975). Grain moisture meters, fundamental to the calculation of shrink, are accurate only to ±0.8% moisture at 15.5% corn moisture content (Hurburgh et al., 1981).

All economic costs, be they handling losses, quality changes, or measurement errors, figure in the establishment of fees and discounts. A logical plan for the reduction of these costs is to identify them one by one and refine the discount structure such that accurate information is being conveyed to grain sellers.

OBJECTIVES

The objectives were:

1. Measure weight loss as corn is dried and transferred in commercial elevator. Relate the measured weight loss to the present practice of using fixed shrink factors to estimate weight losses.

2. Determine the changes in the following corn-quality characteristics as corn is dried and transferred in commercial elevators:
   - Moisture
   - Test weight
   - Broken corn and foreign material (BCFM)
   - Breakage susceptibility
   - Kernel physical damage

3. Determine the variability of the above quality characteristics among wet corn load and among similar-sized loads of the same (identity-preserved) corn after drying.

MATERIALS AND METHODS

Field testing

For this experiment, both inbound wet corn and dry corn as discharged from the dryer had to be weighed and sampled. Two Cargill elevators met these requirements: Swea City, IA, the site of the 1979 and 1980 tests, and Central City, NE, the side of the 1981 test.

Swea City, 1979 and 1980

Cargill's Swea City elevator is a farm-to-rail operation with permanent, concrete storage for 28,000 m³ (800,000 bu) of grain. Grain, primarily corn and soybeans, is bought from the local producers and shipped by rail to terminal elevators. In addition to the concrete storage tanks, an asphalt pad provides temporary storage room for approximately one million bushels of corn. Drying is done with two Aeroglide continuous-flow dryers, one rated at 50,816 kg (2000 bu)/h and the other at 25,408 kg (1000 bu)/h, both on a 20% to 15% moisture basis. Both dryers are equipped with screen houses to reduce fugitive emission of "bees' wings" and dust. There was no dust control system at the dump pit.

Fig. 1 shows the flow diagram used for the Swea City tests. Both the wet and dry holding bins were "emptied" before the test; that is, corn was allowed to gravity-flow out of the bins through the side drawoff until no further flow occurred. The grain left in the bottom of the bin undoubtedly reduced impact damage from the fall. Grain to the dryers was switched to another wet holding bin when the bin to be used in this test became empty. The corn discharged from the dryer was directed to a bin other than the test bin during this time.

The inbound wet corn was being weighed and sampled even while the drying of the preweighed corn was in progress. A pelican was used to sample wet grain loads at the dump pit, and again to sample dry grain loads after they were hauled from the dry holding bin to the pile. Samples were divided in a Boerner divider and taken half to the Cargill laboratory and half to Iowa State University. In 1979, samples went only to Cargill.

Central City, 1981

The Central City elevator is also a farm-to-rail elevator similar to Swea City. However, the Central City elevator used a Hart-Carter dryer rated at 50,816 kg (2000 bu)/h for 5 points removal. The dryer had a screen-house, but there was no dust control system at the dump pit. Dryeration was used; hot grain from the dryer was tempered overnight in one of the concrete tanks, cooled, and removed to storage in other concrete bins. There was a Howe-Richardson grainer scale in the head house of the Central City elevator. This scale was certified to ± 20 lb by the State of Nebraska. Wet and dry grain were both
weighed on this scale. Wet grain for the test was collected on the day before the test.

Fig. 2 shows the flow diagram for the Central City test. The Hart-Carter dryer is equipped with a low-grain alarm, operated by a pressure switch in the upper garner. Before the test, the dryer was operated until the low-grain alarm sounded. At this point, feed to the dryers was switched to the test grain. Feed from the dryers was switched to an empty dryeration tank.

Therefore, wet grain was weighed in drafts as it was moved into the dryer. Samples were taken at the discharge of the scale. When the low grain alarm on the dryer sounded a second time, the drying of the test corn was completed. The corn was cooled overnight, reweighed, and resampled. All samples were tested for moisture at the elevator, divided, and taken to Cargill and Iowa State University for further analysis.

Laboratory testing

In 1979, the samples were tested for moisture at the Cargill Grain Research Laboratory. The official 72-h, 103 °C whole-grain air-oven method (USDA, 1976) was used, with three replicate determinations per sample.

In 1980 and 1981, the samples were tested at the Cargill laboratory and at the Iowa State University Grain Quality Laboratory, Cargill determined moisture by the air-oven method. At Iowa State University, tests were made as described in Table 1.

After a sample was opened in the Iowa State Laboratory, test weight was determined; and the sample was cleaned for BCFM and LBK (large broken kernels). The cleaned grain was sampled three times by hand for oven moisture, then divided into representative subsamples (with a Boerner sample divider) for moisture meter tests, Stein breakage tests, and fast green dye tests. It was not practical to use a Boerner divider to split samples of several thousand grams down to the 15 g required for oven analyses.

RESULTS AND ANALYSIS

Weight losses

Data from the three years are given in Table 2. Two measures of variability are presented for each quality characteristic (a) the standard deviation, s, and (b) the coefficient of variability, CV. Weight losses alone are analyzed and presented in Table 3. Calculated shrink factors were based on equation [2] solved with the oven moisture contents and the measured handling loss.

The calculated shrink factors ranged from 1.24 to 1.45% weight loss per percent moisture removed. These values do fall within the range of values presently used in Iowa. The average shrink factor, 1.34% per point, should not be interpreted as a statement of what is "right" for an elevator to use. An elevator will use a moisture meter to determine moisture for the wet grain, and will use some preset "base" moisture for the dry grain. The actual oven moisture of the dry grain will not be known. The agreement between the base moisture and the actual dry grain moisture will have a great impact on the accuracy of a particular shrink calculation. The important point is that elevators and crop years are not uniform in handling loss. This data should be interpreted as a case study of handling loss and other changes.

In all three cases, handling losses exceeded the 0.5% included in the Series D Minary Table. The measured values ranged from 0.64 to 1.33%, with an average of 0.88%. There was no indication that handling losses are related to initial moisture content. Handling losses were not higher in the year when initial moisture was high (1979). The characteristics and operation of an individual elevator probably are more critical in causing

<table>
<thead>
<tr>
<th>Test</th>
<th>Replicate tests per sample</th>
<th>Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture, %</td>
<td>3</td>
<td>Air-oven; whole grain heated 72 h at 103 °C (USDA, 1976)</td>
</tr>
<tr>
<td>Broken corn and foreign material, %</td>
<td>1</td>
<td>4.8-mm (12/64-in.) screen, handpicking of FM (USDA, 1976)</td>
</tr>
<tr>
<td>Large brokens, %</td>
<td>1</td>
<td>6.4-mm (16/64 in.) screen</td>
</tr>
<tr>
<td>Test weight, kg/m³ (Measured as lb/bu)</td>
<td>3</td>
<td>Quart kettle struck-off level (USDA, 1976)</td>
</tr>
<tr>
<td>Breakage susceptibility, %</td>
<td>3</td>
<td>Stein breakage tester; 100 g, conditioned to 12.8% moisture, 4.0 minute test (Miller et al., 1979)</td>
</tr>
<tr>
<td>Kernel physical damage</td>
<td>3</td>
<td>MC T-1100 damage meter; 100 g, (Chowdhury, 1978)</td>
</tr>
</tbody>
</table>
### TABLE 2. DATA FROM THE 1979, 1980 AND 1981 GRAIN HANDLING TESTS

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of loads</th>
<th>Net weight, kg</th>
<th>On-site moisture, %</th>
<th>Oven moisture, %</th>
<th>Moisture error, points</th>
<th>Test weight, kg/m³</th>
<th>BCFM, %</th>
<th>Stein breakage, %</th>
<th>Fast green dye index</th>
</tr>
</thead>
<tbody>
<tr>
<td>1979, Swea City</td>
<td>54</td>
<td>506,352</td>
<td>26.16</td>
<td>26.75</td>
<td>-0.50**</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>s 2.33</td>
<td>2.38</td>
<td>0.81</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dry corn</td>
<td>53</td>
<td>435,799</td>
<td>15.52</td>
<td></td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>CV, % 8.9</td>
<td>8.9</td>
<td></td>
<td></td>
<td></td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dry-wet</td>
<td>-70,553</td>
<td>-11.23</td>
<td></td>
<td></td>
<td></td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1980, Swea City</td>
<td>35</td>
<td>370,068</td>
<td>19.50</td>
<td>19.41</td>
<td>0.09</td>
<td>731.0</td>
<td>0.96</td>
<td>7.11</td>
<td>12.91</td>
</tr>
<tr>
<td></td>
<td>CV, % 0.18</td>
<td>0.17</td>
<td>0.41</td>
<td>9.25</td>
<td>0.53</td>
<td>0.47</td>
<td>5.56</td>
<td>3.91</td>
<td>8.16</td>
</tr>
<tr>
<td>dry corn</td>
<td>35</td>
<td>344,474</td>
<td>15.18</td>
<td>14.64</td>
<td>0.54**</td>
<td>743.0</td>
<td>1.42</td>
<td>27.60</td>
<td>22.85</td>
</tr>
<tr>
<td></td>
<td>CV, % 0.41</td>
<td>0.12</td>
<td>0.41</td>
<td>0.77</td>
<td>1.01</td>
<td>5.33</td>
<td>8.16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>dry-wet</td>
<td>-25,594</td>
<td>-4.32</td>
<td>-4.77</td>
<td>0.43**</td>
<td>0.93**</td>
<td>0.46**</td>
<td>19.89**</td>
<td>9.94**</td>
<td></td>
</tr>
<tr>
<td>1981, Central City</td>
<td>12</td>
<td>300,100</td>
<td>19.54</td>
<td>19.70</td>
<td>-0.16</td>
<td>721.7</td>
<td>0.86</td>
<td>8.23</td>
<td>9.72**</td>
</tr>
<tr>
<td></td>
<td>CV, % 0.63</td>
<td>0.63</td>
<td>0.48</td>
<td>4.38</td>
<td>0.38</td>
<td>2.42</td>
<td>3.50</td>
<td>29.5</td>
<td>36.0</td>
</tr>
<tr>
<td>dry corn</td>
<td>13</td>
<td>281,338</td>
<td>14.30</td>
<td>14.95</td>
<td>0.65**</td>
<td>723.7</td>
<td>1.92</td>
<td>37.84</td>
<td>20.88</td>
</tr>
<tr>
<td></td>
<td>CV, % 0.57</td>
<td>0.54</td>
<td>0.25</td>
<td>2.83</td>
<td>0.83</td>
<td>5.64</td>
<td>3.88</td>
<td></td>
<td></td>
</tr>
<tr>
<td>dry-wet</td>
<td>-18,762</td>
<td>-5.24</td>
<td>-4.75</td>
<td>0.49**</td>
<td>2.0</td>
<td>1.06**</td>
<td>29.61**</td>
<td>11.16**</td>
<td></td>
</tr>
</tbody>
</table>

*Includes adjustments for dryer and garner bin level
†Includes adjustments for tare weights taken every five loads
‡Includes extra 9887 kg load accidentally mixed in the measured wet corn
§Excluding extra load
**Significantly different than 0.00 at the 95% level of confidence

handling losses.

**Corn-quality changes**

Both the 1980 and 1981 tests showed an increase in BCFM during drying and handling. There was a concurrent increase in breakage susceptibility. In 1980, brittleness increased 3.6 to 1; in 1981, brittleness increased 4.6 to 1, despite the use of dryeration. The test with higher breakage susceptibility (1981) did produce a larger increase in BCFM. In neither case did the BCFM exceed the 3.0% limit of Number 2 yellow corn.

The northern Iowa corn sampled in 1980 was not significantly different in initial breakage susceptibility or initial BCFM (before drying) than the central Nebraska corn of 1981.

There also was an increase in kernel damage (as measured by the fast green dye test) during drying and handling. The increases were in the ratio of 1.8:1 and 2.1:1 for 1980 and 1981, respectively. The initial kernel damage was significantly greater for the 1980 corn than for the 1981 corn, despite the fact that the initial breakage susceptibility was slightly lower in 1980. Thus, there is not always a strong correlation between kernel damage and breakage susceptibility, especially in freshly harvested corn. The kernel-damage test is indicative of the severity of previous operations, regardless of future potential for breakage.

As a cross reference for the moisture values, the samples from 1980 and 1981 were oven-dried at both Cargill Laboratory and the Iowa State University

### TABLE 3. WEIGHT LOSS ANALYSIS FOR THE CARGILL-ISU GRAIN HANDLING TESTS

<table>
<thead>
<tr>
<th>Year</th>
<th>Weights,* kg</th>
<th>Weight loss, %</th>
<th>Moisture loss, %</th>
<th>Handling loss, %</th>
<th>Equivalent shrink factor, % weight loss per point of moisture†</th>
</tr>
</thead>
<tbody>
<tr>
<td>1979</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dry</td>
<td>435,799</td>
<td>15.52</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>wet</td>
<td>506,352</td>
<td>26.75</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>loss</td>
<td>70,553</td>
<td>11.23</td>
<td>13.93</td>
<td>13.29</td>
<td>0.64</td>
</tr>
<tr>
<td>1980</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dry</td>
<td>344,474</td>
<td>14.64</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>wet</td>
<td>370,968</td>
<td>15.41</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>loss</td>
<td>25,594</td>
<td>4.77</td>
<td>6.92</td>
<td>5.59</td>
<td>1.33</td>
</tr>
<tr>
<td>1981</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dry</td>
<td>281,338</td>
<td>14.95</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>wet</td>
<td>300,100</td>
<td>19.70</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>loss</td>
<td>18,762</td>
<td>4.75</td>
<td>6.25</td>
<td>5.58</td>
<td>0.67</td>
</tr>
<tr>
<td>Average losses</td>
<td></td>
<td>6.92</td>
<td>9.03</td>
<td>8.15</td>
<td>0.88</td>
</tr>
</tbody>
</table>

*Including all adjustments
Laboratory. The average difference of 0.04 percentage points was not statistically significant.

Variability of corn-quality measures

Measurement variability is a constant problem for the grain industry. Producer-deliveries are, by nature, not homogeneous from one to another. One might assume, however, that drying and handling would produce more consistency among lots. A noteworthy exception to this assumption is the well-documented tendency of fines (BCFM) to separate themselves, and to be difficult to measure accurately (Hill et al., 1979; Hurburgh et al., 1979).

Moisture meter measurements with regard to the oven showed less variation among dry loads than among wet loads. Standard deviations were consistently smaller among the dry loads. The moisture meter measurements were only slightly more variable within a sample than were the oven measurements. This would suggest that a significant share of the total variability reported to occur in meter-oven comparisons (Hurburgh et al., 1981; Paulsen et al., 1981) is originating from the oven measure, as opposed to the meter being the only measure subject to among-sample variations. As expected, loads from the wettest corn year (1979) were the least consistent, with respect to oven moisture measurements. This was one of the first opportunities to verify the laboratory data on in-service meters of unknown condition. Table 4 compares the observed variations in meter errors with those predicted from laboratory data. Observed variations were less than predicted. The prediction equation was based on a much wider range of corn varieties, harvest damage levels, and growing regions. These two elevator meters were as precise as like models in our laboratory.

Variations in BCFM among loads increased in the dry corn. This supports the generally held opinion that BCFM is a difficult property to sample and blend.

The Stein breakage and fast green dye values were more variable among the dry loads. Large increases in dye values did cause variations to become a lesser percentage of the measured value. Nonetheless, if these tests are used to determine market value, sampling and measurement problems may occur, especially for handlers beyond the country elevator. Presumably, grain lots would be judged against absolute standards for these characteristics, just as they are so judged for the present grade factors.

In the 1979, 1980, and 1981 tests:
1. An average of 0.88% of initial corn weight was lost as material-handling losses, with a range of 0.64% to 1.33% of initial weight. Handling losses were not greater in the year when initial moisture content was higher.
2. The calculated shrink factors based on measured weight loss and on initial and final oven moisture contents fell within the range of values commonly used in Iowa.
3. The moisture meters owned by the elevators exhibited less random variability with respect to the air-oven than did similar moisture meters in laboratory tests.

In the 1980 and 1981 test:
4. Corn BCFM, breakage susceptibility, and kernel physical damage increased through the continuous-flow dryer and related handling operations.
5. Corn from the test with greater breakage susceptibility incurred a greater increase in BCFM content. There are not enough data, however, to establish a mathematical relationship.
6. Variability among lots of moisture content and test weight decreased after drying, whereas the variability of BCFM, breakage susceptibility and kernel physical damage among lots increased after drying.

References

**Table 4. Comparison of on-site moisture meters with laboratory data**

<table>
<thead>
<tr>
<th>Year</th>
<th>Meter minus oven, percentage points</th>
<th>Standard deviation of meter errors, s, points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cardill ISU data</td>
<td>Predicted from Hurburgh (1981)</td>
</tr>
<tr>
<td>1979</td>
<td>wet -0.59</td>
<td>0.81</td>
</tr>
<tr>
<td></td>
<td>dry -0.09</td>
<td>-</td>
</tr>
<tr>
<td>1980</td>
<td>wet 0.09</td>
<td>0.41</td>
</tr>
<tr>
<td></td>
<td>dry 0.54</td>
<td>0.41</td>
</tr>
<tr>
<td>1981</td>
<td>wet -0.16</td>
<td>0.48</td>
</tr>
<tr>
<td></td>
<td>dry -0.65</td>
<td>0.25</td>
</tr>
</tbody>
</table>