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Abstract
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Shrinkage and Corn Quality Changes in On-Farm Handling Operations

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ABSTRACT

MATERIAL handling losses and corn quality changes were measured in three typical on-farm corn-drying systems. Handling losses averaged 0.78% of initial weight, with a range of 0.40% to 1.71% of initial weight. There was no indication that handling losses were related to initial moisture content. Handling losses were less than would have been assessed in shrink had the corn been delivered wet to a grain buyer. Test weight increased during drying, but the simplified Hall and Hill test weight adjustment table overpredicted these increases.

INTRODUCTION

Weight reductions and quality changes occur when corn is dried and handled. Regardless of where the drying takes place, on-farm or at an elevator, economic value will be affected by both the weight losses and the quality changes. A commercial grain handler will experience direct economic loss in the inventory balance between grain purchased and grain sold. Producers will not normally weigh wet corn; consequently, on-farm drying and handling losses may be undetected. To minimize profits from an on-farm storage system, a producer should minimize these losses.

Data on weight loss in actual working systems are scarce. Hall and Hill (1973) developed a prediction equation for increases in test weight as corn dries. Herum et al. (1981) reported BCFM (broken corn and foreign material) increases as corn was handled in a small elevator. These increases were related to breakage susceptibility (brittleness) as measured by a Stein breakage tester. Breakage susceptibility increased as moisture decreased. The amount of increase in breakage susceptibility was related to drying-air temperature (Foster and Holman, 1973), higher temperatures producing more brittle grain.

Shrinkage in grain passing through dryers (and other handling equipment) can be divided into two components, moisture loss and material handling loss. The moisture loss can be calculated by the following formula, assuming that the initial and final moisture contents are measured accurately:

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

where

W_o, W_f = initial and final weights, in any mass units

M_o, M_f = initial and final moisture contents, percent wet basis

Material handling losses include the following components:

1. Dust
2. Stray kernels lost in handling
3. Discarded or lost fines
4. Fugitive emissions of "bees wings"
5. Dry matter loss from insect and mold invasion.

These losses are often termed "invisible" losses by the grain trade. Any operation that creates handling losses is also likely to degrade the quality of the remaining grain (e.g., increase the level of BCFM or of mold-damaged kernels).

If we add handling losses, h, as a percentage of the original weight, to the water-loss formula, it becomes a shrinkage formula:

$$W_o - W_f = \left[\left(\frac{1}{100 - M_f}\right)(M_o - M_f) + \frac{h}{100}\right] W_o \quad [2]$$

Handling losses after delivery by producers are included in discounts for moisture content. For comparison purposes, a producer needs an estimate of handling losses occurring in typical farm grain-handling systems.

Current trade practice is to combine the two types of weight loss into a single shrinkage factor representing the percentage of initial weight that is charged to the seller per point of moisture removed. This factor is not universal because elevators are not uniform in design or operating practice. Instead, each elevator establishes the shrink factor that it will use on the basis of past records, experience, and pressure from competitors. In Iowa, shrink factors normally range from 1.25 to 1.50% per point of moisture removed, with the most commonly used factor being 1.35% per point (IGFA, 1979).

In a shrink-factor calculation, weight loss is calculated as:

$$W_o - W_f = \left(\frac{f}{100}\right)(M_o - M_f) W_o \quad [3]$$

where

f = shrink factor, percent loss per point of moisture removed.

The amount of handling loss, as a percentage of wet weight, that is included in a factor calculation is:

$$h = \left[\frac{f}{100} - \left(\frac{1}{100 - M_f}\right)\right](M_o - M_f)(100) \quad [4]$$

Therefore, given a value of f and M_f, h is a linear function of M_o in a shrink-factor calculation. Conversely, for any value of h, the equivalent factor *increases* as M_o *decreases*.

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TABLE 1. DESCRIPTION OF FARM GRAIN HANDLING SYSTEMS

Location	Type of drying	Drying temperature	Number of handlings: Total	Number of handlings: Of the dry corn	Number of individual tests	Test code
ISU Woodruff farm	In-storage, low temperature	Natural air	2	1	6	LT
ISU Bilsland farm	Batch-in-bin, with stirring	Approx. 38°C	3	2	1	IT
ISU Curtiss farm	Column, continuous flow	Approx. 100°C	4	2	4	HT

OBJECTIVE

The objective of this study was to measure handling losses and quality changes in three typical on-farm grain-conditioning systems.

MATERIALS AND METHODS

Farm Systems Studied

A summary description of the three farm systems is contained in Table 1.

In the LT tests, conducted over the years 1977-1979, wet shelled corn was unloaded from wagons into 105-m^3 (3000-bu) bins and dried with natural air or small heat rises. These bins also were used for solar grain-drying research and were emptied the following spring or summer. Storage losses from respiration of living organisms (fungi, bacteria) were included in handling losses in the LT tests. Low temperature drying is a slow-drying procedure, in which it is impossible to totally eliminate fungal activity.

The IT test, in 1979, involved a 350-m^3 (10,000-bu) drying bin with a stirring device and supplemental propane heater. Batches were dried in this bin overnight and transferred to storage in two bins adjacent to the drying bin. Drying air temperature varied between 32 °C (90 °F) and 38 °C (100 °F). The storage bins were emptied in July of 1980.

The four HT tests, three in 1978 and one in 1979, were conducted on a Behlen continuous-flow dryer, with a rated capacity of 9530 kg (375 bu) per hour, 8% moisture removal. Drying air temperature was set at 100 °C (212 °F), the normal operating practice for the ISU Curtiss Farm. Wet grain was unloaded into a 160-m^3 (4500-bu) wet holding tank, augered into the dryer on demand, then transferred hot to another 160-m^3 (4500-bu) cooling bin. The corn was cooled overnight and transferred to storage.

For all tests, the wet grain was weighed and sampled as it arrived from the field. Sampling was done with a pelican sampler. Weighing of grain loads was done on a platform scale to ± 9.1 kg (20 lb). The dry corn loads for each test were weighed and sampled similarly. The identity of the corn lots was maintained through the dryer and related handling operations. Samples were stored in a walk-in refrigerator maintained at 2 °C.

Laboratory Methods and Procedures

The LT samples were tested for oven moisture content by using the oven procedure (USDA, 1976) only. The IT and HT samples were also part of a moisture meter study (Hurburgh et al., 1981), and were analyzed for test weight and BCFM in addition to oven moisture content.

Oven moisture content was determined by the USDA official method (USDA, 1976). From each sample, representing one load of corn, three subsamples of about 15 g, weighed to the nearest mg, were removed. The subsamples (dishes) were dried for 72 h at 103 °C in a Thelco Model 28 forced-air convection oven. Moisture content was calculated from the difference in weights before and after drying. The three dish results were averaged to obtain the oven moisture assigned to a particular sample.

Test weight was measured on an official apparatus according to the USDA procedure (USDA, 1976). A 946-mL (1-qt) brass measure is filled from a drop height of 5.1 cm (2 in.). The measure is struck-off level and weighed. The measure contains 1/32 of a volume bushel; weight per bushel is calculated from the weight of corn in the measure.

BCFM in the Official Grade is defined as all particles passing through 4.8-mm (12/64-in.) round-hole sieve, plus any nongrain material in the screened sample. Screening was done in a Carter Dockage Tester, as described by USDA (1976).

RESULTS AND ANALYSIS

Low-Temperature Dryer

Table 2 summarizes the weight reductions in the LT tests.

Although the average handling loss was 0.78% of original weight, there was a considerable range of handling losses over the six tests. In-storage respiration losses are included in the handling losses from the LT tests. Low-temperature dryers are designed to allow up to, but not more than the 0.5% dry-matter loss criterion for allowable storage time. The two high values of handling loss, LT 1 and LT 6, involved the highest and, therefore, the riskiest initial moisture contents. Two data points are not sufficient to establish a conclusion, but perhaps there was additional fungal activity in these two bins. In the other four LT tests, there was no indication that handling losses were related to initial moisture content. Over all six LT tests, the correlation of h to M_o was not statistically significant.

Intermediate and High-Temperature Dryers

The data from the IT and HT tests are given in Table 3.

The HT tests created the most handling losses, an average of 0.87%. In similar research, Hurburgh and Moechnig (1982) reported handling losses of 0.88% in commercial elevator high-temperature drying and related handling operations. There was no indication in either the commercial elevator tests or in the HT tests of an on-farm system that handling losses are related to initial moisture content in the moisture range studied. In these tests, h was not significantly correlated with M_o.

TABLE 2. WEIGHT LOSS ANALYSIS FOR LOW-TEMPERATURE (LT) TESTS

Year,	Test	Weight, kg	Oven moisture, %	Moisture loss, % wet weight	Handling loss, % wet weight	Equivalent shrink factor, % loss/point of moisture
1977,	LT 1					
	wet	84,913.6	24.33			
	dry	72,968.2	13.47			
	loss	11,945.4	10.86	12.55	1.52	1.20
1977,	LT 2					
	wet	86,840.9	22.94			
	dry	76,777.2	13.28			
	loss	10,063.6	9.66	11.14	0.45	1.20
1978,	LT 3					
	wet	84,325.0	20.57			
	dry	78,368.2	14.95*			
	loss	5,956.8	5.62	6.61	0.45	1.26
1978,	LT 4					
	wet	87,350.0	23.24			
	dry	78,790.9	15.18			
	loss	8,559.1	8.06	9.50	0.30	1.22
1978,	LT 5					
	wet	90,395.5	22.37			
	dry	82,509.1	15.25			
	loss	7,886.4	7.21	8.51	0.22	1.21
1979,	LT 6					
	wet	86,736.4	23.25			
	dry	75,327.3	13.33			
	loss	11,409.1	9.92	11.45	1.71	1.22
Average losses			8.56	9.96	0.78	1.24
	$s_{\bar{x}}$†				0.27	0.02

* Moisture content measured on a Motomco meter, then adjusted to an equivalent oven moisture content using the correction equation from Hurburgh et al. (1981).
† Standard error of the mean.

TABLE 3. WEIGHT LOSS AND QUALITY CHANGE DATA FOR INTERMEDIATE (IT) AND HIGH TEMPERATURE (HT) TESTS

				Weight loss analysis			Quality changes		
							Test weight		
Year, test	Number of loads	Weight, kg	Oven moisture content, %	Moisture loss, % wet weight	Handling loss, % wet weight	Equivalent shrink factor, %/point of moisture removed	kg/m^3	(lb/bu)	BCFM, %
1978, HT 1									
dry	17	79,131	14.15				707.6	(54.6)	0.63
wet	15	89,081	22.97				677.8	(52.3)	0.50
dry-wet		- 9,950	- 8.82	10.27	0.90	1.27	29.8	(2.2)	0.13
1978, HT 2									
dry	16	76,209	12.39				725.8	(56.0)	0.64
wet	11	81,109	17.00				723.2	(55.8)	0.62
dry-wet		- 4,900	- 4.61	5.26	0.78	1.31	2.6	(0.2)	0.02
1978, HT 3									
dry	14	63,531	13.95				736.1	(56.8)	0.44
wet	10	67,427	17.85				729.5	(55.9)	0.29
dry-wet		- 3,896	- 3.90	4.53	1.25	1.48	11.6	(0.9)	0.15
1979, HT 4									
dry	4	33,163	14.65				755.6	(58.3)	0.56
wet	5	36.622	22.25				719.3	(55.5)	0.39
dry-wet		- 3,459	- 7.60	8.90	0.54	1.24	36.3	(2.8)	0.17
Average HT				7.24	0.87	1.33			
$s_{\bar{x}}$					0.15	0.05			
1979, IT 1									
dry	60	487,763	14.22				754.3	(58.2)	1.05
wet	48	516,009	18.57				737.4	(56.9)	0.55
dry-wet		- 28,246	- 4.35	5.07	0.40	1.26	16.9	(1.4)	0.50

TABLE 4. ANALYSIS OF TEST-WEIGHT INCREASES

Test	Initial moisture, %	Final moisture, %	Actual test weight increase, lb/bu	Predicted test weight increases, lb/bu: Hill and Roush	Hall and Hill: 10% harvest damage	Hall and Hill: 15% harvest damage
IT 1	18.57	14.22	1.4	1.7	1.5	0.9
HT 1	22.97	14.15	2.2	2.8	2.6	2.0
HT 2	17.00	12.39	0.2	1.3	1.0	0.4
HT 3	17.85	13.95	0.9	1.5	1.2	0.7
HT 4	22.25	14.65	2.8	2.6	2.4	1.8
Average			1.5	2.0	1.7	1.2
Average except HT 2			1.8	2.2	1.9	1.4

There were other quality changes in the IT and HT tests. BCFM content generally increased, but even after drying, BCFM was well below the market limit of 3.0% for No. 2 yellow corn. As expected, test weight increased. Table 4 compares the data with the prediction equation developed by Hall and Hill (1973) and the simplified adjustment table developed from that equation (Hill and Roush, 1975). "Damaged" kernels in the Hall and Hill equation are defined as kernels with visually detectable physical damage.

The simplified table generally overpredicted test weight increases. The 10% damaged kernels option of the Hall-Hill equation produced better agreement with the data. Test HT 2 is separated out because the final moisture content, 12.39%, is below the moisture claimed by Hall and Hill to produce maximum test weight. Test weight declines at moistures below 14%, provided drying was done at temperatures higher than 70 °C.

Equivalent Shrink Factors

The shrink factors listed in Tables 2 and 3 were generally within the range of shrink factors used in Iowa and were less than the industry norm of 1.35%/point of moisture removed. The data also illustrate an important point about factor shrinkage; the factor needed to account for a given amount of handling loss varies sharply with initial moisture content. A lower factor may provide a larger handling loss allowance, provided the initial moisture content is high. If initial moisture is not an important variable in determining handling losses, as results of this experiment suggest, then factor shrink calculations will not assess handling losses proportionately among sellers of corn lots with varied initial moisture. Factor shrink will also pose risks to grain buyers because neither the average moisture nor the distribution of moistures in a year's purchases will be known in advance.

If handling loss is not dependent on the points of moisture removed, a more accurate procedure for estimating shrink would be to separate moisture loss and handling loss factors. The moisture loss factor would predict weight changes due to moisture loss only and would have units of percent wet weight per point of moisture removed. The handling loss factor would be a percent of wet weight, the same for all sellers.

CONCLUSIONS

1. In six tests of a low-temperature corn-drying system, handling losses averaged 0.78% of wet weight. In one test of a batch-in-bin intermediate-temperature system, handling loss was 0.40% of wet weight, and in four tests of a continuous-flow, high-temperature corn-drying system, handling losses averaged 0.87% of wet weight. The overall average handling loss for all 11 tests was 0.78% of initial weight, with a range from 0.40% to 1.71% of initial weight.
2. The magnitude of handling losses was not affected by initial moisture content of the wet corn, up to about 24% moisture.
3. When converted to equivalent shrink factors, the weight losses, moisture and handling, for all tests combined, amounted to 1.28% loss per point of moisture removed.
4. Test weight increases during drying were less than predicted by the simplified adjustment table. The Hall and Hill formula for 10% physically damaged kernels fit the data well.
5. BCFM concentration increased slightly (0.19%) in the IT and HT tests. BCFM concentration of the dry corn never exceeded 1.1% however.

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