HANDLING EFFECTS ON COMMINGLING AND RESIDUAL GRAIN IN AN ELEVATOR

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ABSTRACT. *Grain handlers have responded to an increased use of specialty grain and the resulting need for grain segregation without the benefit of experimental data in the literature quantifying the commingling that may occur during grain handling. This study was conducted to evaluate the effects of handling equipment on commingling and residual grain at an average grain flow rate of 47 t h^{-1} (1852 bu h^{-1}) in the research elevator at the USDA-ARS Grain Marketing and Production Research Center in Manhattan, Kansas. Tests were done by first moving white corn through selected pieces of cleaned elevator equipment followed by moving yellow corn through the same equipment without any special clean out between the two operations. Commingling was calculated as the percentage of white kernels mixed in the yellow corn samples collected at selected time intervals during the second operation. Commingling was greater than 1% during no more than the first 38 sec and always decreased to less than 0.5% within the first metric ton of load (76 sec) for all tested equipment. The highest cumulative commingling for tests of one truckload (ca. 7.3 t) was 0.24% for the grain cleaner. Mean cumulative commingling values for the other handling equipment were 0.22%, 0.01%, and 0.18% for the weighing scale, grain scalper, and the combined effect of dump pit and boot, respectively. The residual grain obtained from cleaning the equipment after the test was highest at the elevator boot (120 kg), followed by the receiving pit (20 kg). The amounts of residual grain collected from the weighing scale, grain cleaner, and grain scalper were negligible (<1 kg) by comparison.*

Keywords. *Grain commingling, Grain handling equipment, Grain segregation, Identity preservation, Residual grain.*

Identity preservation (IP) programs in the grain industry are designed to maintain the genetic and physical purity of the grain. The introduction of genetically modified varieties and specialty grain has increased the importance of segregation and IP grain handling.

The Association of Official Seed Certifying Agencies (AOSCA) has designed IP programs to ensure purity levels above 99% for corn and 99.5% for soybean at the farm level (AOSCA, 2000). Included in the programs are specific requirements in farm activities to minimize pollen drift or cross-pollination.

Standard IP programs have not been established in grain elevators. The American Corn Growers Association (ACGA) conducted a survey of more than 700 elevators in the U.S. and found that 91.4% of the elevators did not consider grain segregation as part of their daily operation (New Hope, 1999). In 2001, the same agency conducted another survey of 1,141 elevator facilities and reported that about 26% required segregation and 6% suggested segregation of grain (ACGA, 2001). About 36% of the respondents required and/or suggested that farmers segregate grain before delivery. Recent research has analyzed the economics of on-farm grain segregation. Hurburgh (1994) reported an additional cost of 2 to 3 cents per bushel of soybean for testing and segregation. On-farm segregation can be profitable if grain merchants are offering a premium for IP grain. Herrman et al. (1999) reported an added protein value associated with wheat segregation on a peak harvest day at a country elevator of about $15,000. Grain merchants are reported to be willing to pay from 3 cents to $1 premiums per bushel for identity-preserved and non-genetically modified corn (ACGA, 2001; AgDayta, 2001).

The capability of an elevator to segregate grain depends largely on its design, including configuration and capacity. Facilities with two or more receiving pits and bucket elevators have better segregation capabilities (Herrman et al., 2001). Dedicating grain paths for specialty products, genetically modified (GM) grain, or non-GM grain will minimize or prevent commingling of two or more grain varieties and maintain product identity at levels specified by processors and consumers (Bullock et al., 2000). Export-bound crops have more stringent requirements related to IP and commingling of GM crops. Japan accepts 5% or less of GM corn in non-GM lots (Zinkand, 2000; Spencer, 2001), while Europe sets a maximum threshold of 1% (EU Committee, 2001; Food Standards Agency, 2001). However, neither Japan nor Europe will tolerate commingling of unapproved GM varieties.

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Table 1. Initial quality and characteristics of grain before grain movement—means (and standard deviations).[a]

Corn Load	N	Grade	Impurity[b] (%)	BCFM (%)	Moisture Content (% wet basis)	Test Weight (kg hL^{-1})
Yellow	17	U.S. No. 2	0 to 0.12	3.2 a (0.20)	12.66 a (1.0)	77.4 b (0.5)
White	12	U.S. No. 1	0 to 0.54	1.6 b (0.008)	12.08 a (0.6)	78.0 a (0.4)

[a] Means in the same column followed by the same letter are not significantly different at p = 0.05.
[b] Impurity = white corn in yellow, or yellow corn in white.

Thelen (1999) reported that grain receiving pits, augers and conveyors, elevator legs, dryers, and bins are areas where commingling can occur. Grain segregation would be facilitated by better identification of the different effects of handling equipment on grain commingling in an elevator. This understanding would allow elevator owners and operators to better handle multiple varieties of incoming grain.

The purpose of this study was to obtain fundamental data that would facilitate the design and development of strategies and equipment for better IP and more effective grain segregation and to develop and evaluate procedures to effectively measure such data. The major objectives were to: (1) quantify the level of commingling at a grain elevator for the different grain handling equipment, and (2) characterize the residual grain collected from each piece of handling equipment after every handling operation.

Methodology

Raw Materials

Two types of corn were used for the tests. White corn was obtained from Frankfort, Kansas, and yellow corn was obtained from Manhattan, Kansas. Upon delivery, each load was inspected for moisture content, test weight, foreign material, undesirable odor, and purity based on the amount of corn of different color mixed in the whole lot. The initial quality and characteristics of the grain are shown in table 1.

Representative samples were collected upon receipt of grain following USDA recommendations (USDA-GIPSA, 1995), except for the addition of two sampling points for probe sampling, giving eleven rather than nine probes per truck. For the first replication of the test on the combined effect of pit and boot, the first truckload of white corn was unloaded into the receiving pit immediately after the sampling process. The remaining truckloads of white corn were sampled and combined in one bin before being used. All the loads of yellow corn were dumped directly into the pit from the truck after probe sampling.

Elevator Facility and Handling Equipment

The study was conducted in the elevator facility of the USDA-ARS Grain Marketing and Production Research Center (GMPRC) at Manhattan, Kansas (fig. 1). The facility has a storage capacity of 1,938 m^3 (55,000 bu). It has one receiving pit and two-bucket elevator legs, each with a maximum rate of 1.8 m^3 min^{-1} (3,000 bu h^{-1}). Incoming grain is first unloaded into the receiving pit and moved down to the elevator boot by belt conveyor and spout. Grain is then bucket-elevated and spouted to the upper garner of the weighing scale (Howe Richardson Scale Co., Clifton, N.J.) or cleaned in the grain scalper (Rumba Vibrating Grain Scalper, Hutchinson Mfg. Co., Houston, Texas). Grain samples may be collected at this point using the Strand diverter sampler (Carter-Day Co., Minneapolis, Minn.). After passing through the sampler or the scale, grain may be cleaned in an aspirated cleaner (Eureka Continental Seed Cleaner, S. Howes Co., Silver Creek, N.Y.). The grain then flows into the designated bins using distributors and spouting.

Grain Transfer Process

The grain transfer process simulated the receiving operation of two consecutive grain types or varieties without additional cleaning of equipment between operations. Two hybrids of corn of different colors were used to easily identify the degree of mixing between loads. A schematic diagram of the grain transfer process including sampling is shown in figure 2. The elevator design allowed the tested equipment to be isolated and tested independently, except for the receiving pit and elevator boot combination, which were tested together.

Prior to each test, the elevator was cleaned thoroughly to remove the dust, dirt, and residual grain from previous loading operations. The loading truck, conveyor belts, bins, and spouts were vacuum cleaned.

White corn was dumped first into the receiving pit, either directly from a truck or from a holding bin, and moved to a storage bin. Each load weighed 6.1 to 8.5 t (13,450 to 18,740 lb). All handling equipment was run long enough to

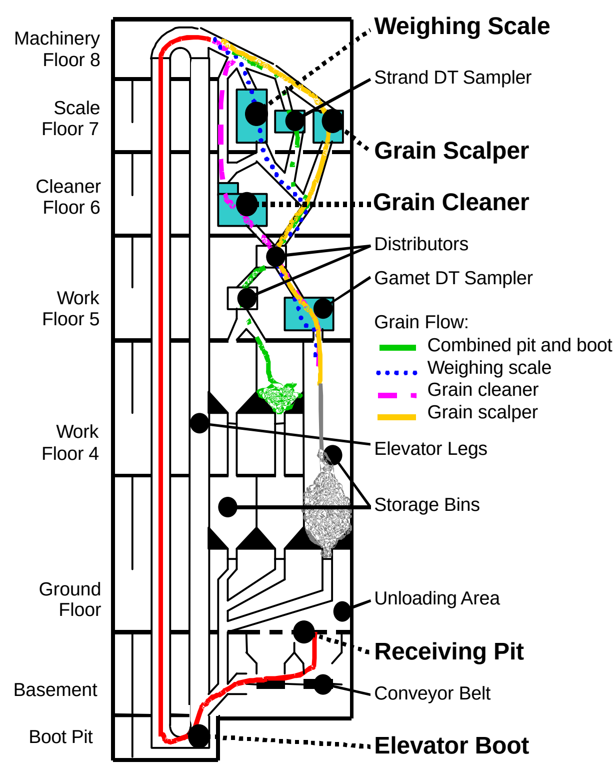

Figure 1. Grain flowchart and location of handling equipment (names in bold indicate equipment tested in this study).

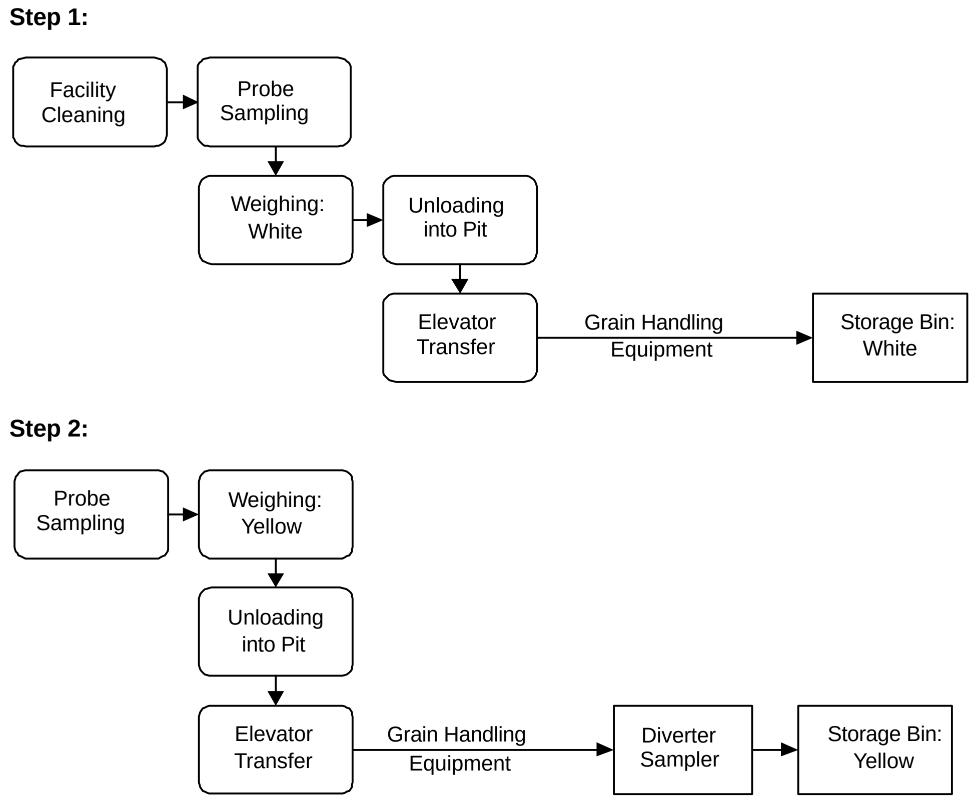

Figure 2. Grain transfer flowcharts.

enable self-cleaning at the conclusion of transferring each corn load. The operation was stopped when the noise from the grain flow in the bucket elevator and spouting ceased. Without additional cleaning, yellow corn was dumped into the receiving pit and moved to a separate storage bin following the same grain flow path as the preceding white corn. Only one piece of tested equipment was in the grain flow path for each test. Each load took about 10 to 12 min. Representative samples were collected while the yellow corn was transferred. Tests were replicated three times with one replication being two truckloads, one of each corn variety. Thorough manual cleaning of the facility and sampler with brooms, vacuum, and air blowers was done before each replication. No cleaning was done between loads of different colors of corn during each replication. The residual grain collected from equipment was kept in plastic bags, sealed, and stored with the other samples for later analysis of composition, moisture, and purity.

Sampling Process

During grain transfer, representative samples were collected using diverter-type (DT) samplers. The Strand DT sampler (Seedburo Equipment Co., Chicago, Ill.) was used for the receiving pit and elevator boot, and the Gamet DT sampler (Seedburo Equipment Co., Chicago, Ill.) was used for the weighing scale, grain cleaner, and grain scalper. Samples were obtained at intervals of 15 sec for the first 2 min of grain movement, 30 sec for the next 3 min, 45 sec for the next 3 min, and 60 sec for the rest of the operation. A larger number of samples were taken during the first set of tests (the pit and boot), where a sampling interval of 15 sec was used throughout the test. Each sample was stored in a separate resealable plastic bag, labeled, and stored at 10°C for later analysis.

Sorting and Grain Analysis

The samples were analyzed for moisture content, test weight, broken corn and foreign material (BCFM), and degree of commingling. Moisture content of the grain samples was measured with a Motomco 919 Automatic Moisture Meter (Seedburo Equipment Co., Chicago, Ill.). Test weight was determined based on the weight per Winchester bushel (USDA-GIPSA, 1997). Moisture content, test weight, and BCFM were determined immediately after sample collection, before the samples were stored.

BCFM were separated by passing the samples and residual grain through a Carter-Day Dockage Tester (Seedburo Equipment Co., Chicago, Ill.) using a 4.8 mm (3/16 in.) diameter screen. The dried leaves, foreign seeds, chaff, and all grain components passing through the screen were classified as BCFM, while corn kernels collected above the screen were classified as mechanically cleaned corn kernels. The dockage tester was allowed to run empty for about 5 min before the next sample. This was done to ensure that no residue of the previous sample was left in the machine and to prevent commingling of samples during the cleaning process.

The mechanically cleaned corn kernels for each test were sorted manually to separate the white from the yellow corn kernels. For the dump pit and the elevator boot, the amounts of residual grain were quite large for manual sorting. Thus, the residual grain from the pit and boot was first passed through a Satake Automatic Color Sorter (Satake USA, Houston, Texas) to assist with the separation of the white corn from the yellow corn. A final manual sorting was done on the color-classified fractions.

Data Analysis

Commingling tests were conducted separately for each piece of equipment with three replications of each test. The facility design allowed the grain flow to bypass other equipment and flow only through the individual equipment being tested, with the exception of the dump pit and elevator boot, which were tested as one unit. Commingling associated with each piece of equipment was determined based on the amount of white corn found in the representative samples collected with diverter-type samplers. Instantaneous commingling was defined as the amount of white corn in the collected samples (eq. 1), and cumulative commingling was the weighted average of the instantaneous measurements (eq. 2):

$$\text{Instantaneous commingling} = \frac{\text{mass of white kernels}}{\text{total sample mass}} \times 100\% \tag{1}$$

$$\text{Cumulative commingling} = \sum \left\{ \frac{\left(\text{feed rate} \times \text{sampling interval} \times \text{instantaneous commingling} \right)}{\text{total mass of load}} - \left(\text{initial impurity} \right) \right\} \tag{2}$$

The calculated values of cumulative commingling were adjusted based on the initial purity of the corn load. No adjustments were done to the instantaneous values since that can result in inappropriate negative values of commingling due to the variation present in the sampling.

Basic descriptive statistics (i.e., mean and standard deviation) were determined for the parameters evaluated. Statistical analysis techniques were used to determine variability between corn varieties and among handling equipment. In the presence of significant differences in the variances between tests and unequal sample sizes, homogeneity of variances was first tested using Hartley's test (Ott, 1993) before the means were compared. In cases where equality of variances was not established, data were first transformed to their logarithmic or inverse forms, as appropriate, to stabilize the variances before proceeding to the analysis of variance (ANOVA). Comparison among pieces of grain handling equipment was done using Fisher's least square differences (LSD).

Results and Discussion

Grain Quality and Sample Composition

The two varieties did not significantly differ ($p > 0.05$) in moisture content; however, there were significant differences ($p < 0.05$) in BCFM and test weight (table 1). The two varieties graded differently; the white corn was classified as U.S. No. 1, whereas the yellow corn, because of its high BCFM content, was U.S. No. 2 (USDA-GIPSA, 1997). Sample mass ranged from 0.35 kg for the grain scalper to 0.74 kg for the scale. There was no significant difference ($p > 0.05$) between the mean values of the total load, feed rate, and sample mass for the different equipment, although some differences were observed in the levels of initial and final purity (table 2).

Instantaneous Commingling

The instantaneous commingling for the pit and boot, expressed as the percentage of white kernels mixed in yellow, was approximately 4% during the first 15 sec of grain transfer (0.2 t) and dropped to 0.5% within the first metric ton (1.3 min) of grain load (fig. 3). It declined to 0.2% after 2.5 min (2.0 t). Instantaneous commingling for the weighing scale was initially 1.1% and dropped to 0.2% during the first metric ton of grain load. While this initial level of commingling was lower than that for the combined pit and boot or for the grain cleaner, the scale commingling was comparable to that from the combined pit and boot after this low initial value. The lowest level of instantaneous commingling from the scale (0.026%) was observed after 6 t of load (7 min grain transfer). For the grain cleaner, instantaneous commingling began at 3% and decreased to less than 0.5% within the first metric ton of grain transfer (fig. 3). Similar to the scale, instantaneous commingling was very low (approximately 0.05%) after 6 min of grain transfer. However, commingling from the scale increased again later in the test, indicating that the self-cleaning process was not yet complete when the first low readings were obtained at 6 min.

The scalper had the least instantaneous commingling, starting at 1.2% (0.2 t) and dropping to a level of 0.02% within 4 min of the start of grain transfer (3 t). This indicates that the scalper was more effective at self-cleaning than the other equipment in this handling system. The scalper showed noticeably lower levels of commingling than the other equipment throughout the test (fig. 3). As a rule, commingling data from the other equipment overlapped throughout the test period.

The measured commingling values can be normalized with the grain transfer rate by dividing the amount of grain above a specified level of commingling (e.g., 1%) by the amount of grain transferred in a specified time, such as the metric tons transferred in one hour from column 3 of table 2. For example, for the equipment with the highest level of instantaneous commingling (the cleaner), only the first 0.52 t of grain (1.1% of the feed rate per hour, which was 48.4 t h^{-1} in this test) were contaminated at levels greater than 1%. Only the first 0.74 t of grain (1.5% of the feed rate per hour) were contaminated at levels greater than 0.5%. Such normal-

Table 2. Average mass and cumulative commingling for grain handling equipment—means (and standard deviations).[a]

Elevator Equipment	Total Load (t)	Feed Rate (t h^{-1})	Number of Samples	Sample Mass (kg)	Initial Impurity (%)	Cumulative Commingling (%)
Pit and boot	8.5 a (0.4)	47.3 a (0.6)	79	0.61 a (0.10)	0.092 a (0.001)	0.18 a (0.04)
Weighing scale	8.3 a (0.5)	49.6 a (2.8)	37	0.74 a (0.28)	0.023 b (0.02)	0.22 a (0.02)
Grain cleaner	6.9 a (2.0)	48.4 a (1.7)	40	0.45 a (0.05)	0.036 b (0.02)	0.24 a (0.03)
Grain scalper	6.1 a (2.5)	43.3 a (3.7)	38	0.35 a (0.05)	0.093 a (0.03)	0.01 b (0.03)

[a] Means in the same column followed by the same letter are not significantly different at $p = 0.05$.

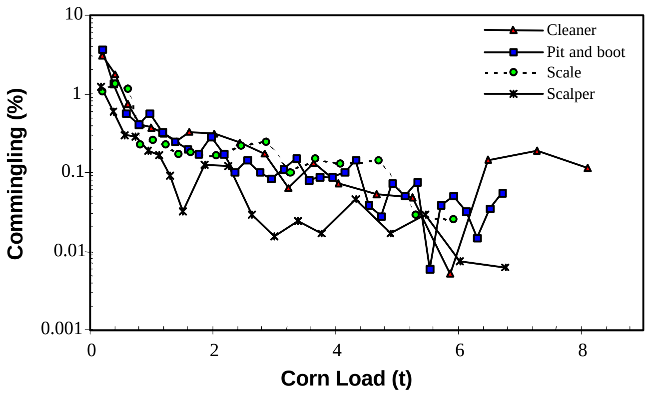

Figure 3. Instantaneous commingling of white corn in yellow corn as yellow corn passed through the handling equipment.

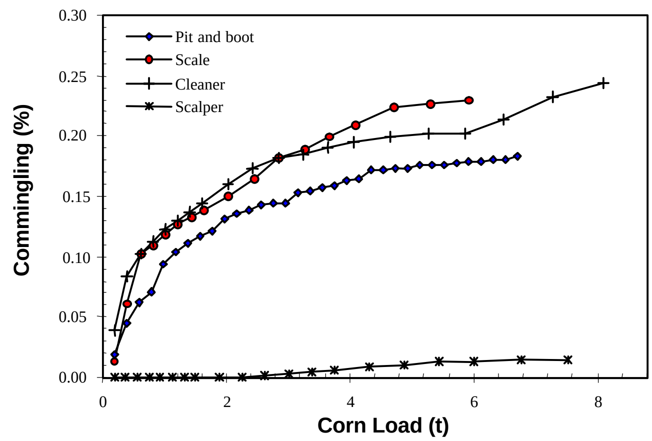

Figure 4. Incremental cumulative commingling for tested handling equipment.

ization could be done with any commingling values, based on the feed rates in table 2. For the reported values of instantaneous commingling, the initial impurity (table 2, column 6) must first be subtracted, since this has not been done as it has been with the reported cumulative values. The reported cumulative values are already normalized to the total mass of the truckload; that normalization would first have to be removed, based on equation 2, before normalizing with the feed rate.

Cumulative Commingling

Mean cumulative commingling for the pit and boot, scale, cleaner, and scalper were 0.18%, 0.22%, 0.24%, and 0.01%, respectively (table 2, fig. 4). These mean cumulative commingling values were not significantly different ($p > 0.05$) except for the grain scalper. Grain transfer through this elevator (fig. 1) could result in a maximum overall cumulative commingling of approximately 0.65% if values for the pit and boot, scale, and cleaner were combined. An elevator facility of this design and equipment with grain conditions similar to those of the tests is expected to ensure IP and maintain grain purity at levels above 99%. Elevators with different handling equipment may use the same methods to measure commingling but may be expected to obtain different values.

For small loads of corn ranging from 6.1 to 8.5 t, most of the tested equipment added 0.18% to 0.24% of commingling to the grain. Typical operations would involve the receiving pit, elevator leg, and at least one other piece of equipment, which may result in a cumulative commingling of 0.5% to 0.6%. For larger grain loads, the cumulative commingling would be proportionally less, since the instantaneous commingling dropped to near zero by the end of the loads that were tested.

Of the handling equipment, the scalper had the lowest cumulative commingling and was significantly different from the other equipment (table 2). Although the initial impurity of the grain used for the cleaner test was low (0.036%), the degree of commingling in the samples collected all through the grain transfer process was higher compared to the other tests (fig. 3). The same trend of relatively high commingling was observed for the scale. The cumulative commingling for the scale and cleaner were similar to each other and higher than for the other equipment. Commingling for the scale was higher at the end of the load, which was completed at 6 t, but commingling for the cleaner ended slightly higher after it continued for 8 t total. The pit and boot showed slightly less cumulative commingling than either the scale or cleaner throughout the test. The ANOVA showed that the differences were not significant for the pit and boot, but the grain scalper did have significantly less commingling than the other equipment. These variations may be influenced most by differences in the design of the equipment, although the configuration of the spouting or grain flow path could also have an effect.

Residual Grain

Most grain handling equipment is designed to be self-cleaning to a certain degree. Residual grain was expected in pits, boots, conveyors, and other equipment after each grain transfer operation. The grain collected from each piece of equipment after each replication constituted the residual grain that may affect the overall commingling. The largest amount of residual grain was collected from the elevator boot with an average mass of 120 kg, followed by the grain collected from the receiving pit (20 kg). The weighing scale, grain cleaner, and grain scalper displayed self-cleaning properties, evident from the negligible amounts of residual grain after grain transfer. The least amount (0.3 kg) was collected from the grain cleaner, followed by the grain scalper and weighing scale (both 0.5 kg, table 3).

Sorting of the residual grain showed that the elevator boot had the highest amount of white corn (88 kg, or 73.6% of the residual grain mass). This can be explained by the characteristics of grain flow in the boot. White corn was handled first, when the boot was clean and empty, so a considerable amount of white corn filled the bottom of the boot (fig. 5). The amount of residual grain in the boot was large, but much of that grain may make little contribution to commingling because the residual grain at the bottom of the boot could not be reached by the scooping action of the leg's buckets. The amount of white corn in the residual grain from the pit was 19.6% (table 3). While it was significantly lower ($p < 0.05$) than that for the boot, it may have a greater influence on the level of commingling because it could readily mix with the subsequent load.

Although the percentage of cleaned corn was largest in the scalper, it contained the lowest level of white kernels and BCFM, while the residual grain collected from the elevator boot had the highest amount of white kernels. The values

Table 3. Average amount and characteristics of residual grain collected from each piece of equipment—means (and standard deviations).[a]

Elevator Equipment	Mass (kg)	Whole Kernels (%)	BCFM (%)	White Corn (%)
Dump pit	20.5 b (1.8)	84.2 b (2.8)	15.8 b (2.8)	19.6 b (2.8)
Elevator boot	120.1 a (5.4)	85.2 b (0.5)	11.5 c (0.5)	73.6 a (6.3)
Weighing scale	0.5 c (0.4)	23.4 c (1.7)	76.6 a (1.7)	2.1 c (0.4)
Grain cleaner	0.3 c (0.1)	97.1 a (0.1)	2.8 d (0.2)	0.9 d (0.2)
Grain scalper	0.5 c (0.1)	97.6 a (<0.1)	2.2 e (<0.1)	0.5 e (<0.01)

[a] Means in the same column followed by the same letter are not significantly different at p = 0.05.

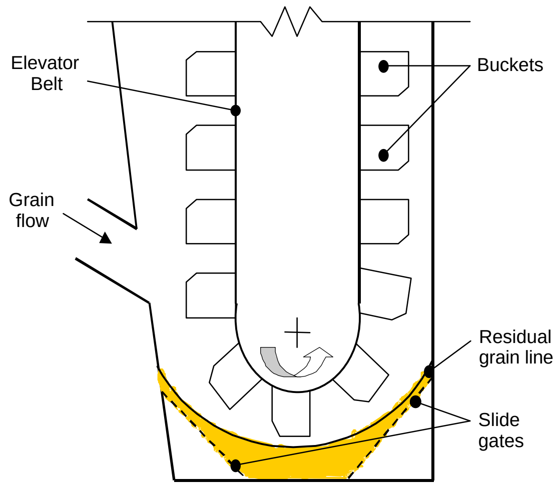

Figure 5. Schematic diagram of the boot portion of the bucket elevator of the USDA-ARS Grain Marketing and Production Research Center (GMPRC) elevator facility.

obtained indicated the self-cleaning capabilities of the equipment used and emphasized the areas where further design improvement and modification are needed to reduce the residual grain and allow better IP during handling operations.

Summary and Conclusion

The procedures used for thoroughly cleaning the facility and handling equipment after each run and the procedures used in sampling and color sorting were used to assess commingling potential in this research elevator and should be useful for additional studies of other equipment or elevators. The commingling trends (figs. 3 and 4) point out that instantaneous commingling was highest during the first few minutes of loading and decreased to nearly zero as grain transfer progressed. It is anticipated that loads larger than were used in these tests (table 2) would result in lesser cumulative commingling values with the same sampling and clean-out procedures.

This study quantified the effects of handling equipment on the percent commingling and amount of residual grain during grain transfer operations in a research elevator. For this elevator facility:

- At grain flow rates of 43 to 50 t h^{-1}, commingling started at levels above 1% during the first 38 sec or less and declined to levels below 0.5% after the first metric ton of grain transfer.
- The grain cleaner had the highest cumulative commingling at 0.24%, followed by the weighing scale at 0.22%, the pit and boot at 0.18%, and the grain scalper at 0.01%.
- For grain transfer with the pit and boot, scale, and cleaner in the grain path, the total possible commingling was 0.64%. This elevator could then ensure identity preservation above 99% for corn of individual truckload-size quantities (6 to 8 t), when considering only commingling that occurs during equipment operation with initially cleaned equipment, but without residual grain clean-out between different types of grain.
- The largest amount of residual grain was from the elevator boot (120 kg, about 1.4% of the total load).

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