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Influence of Storage Bin Design and Feed Characteristics on Flowability of Pig Diets Containing Maize Distillers Dried Grains with Solubles

Abstract

Maize dried distillers grains with solubles (DDGS) is a valuable ingredient in the swine industry but when incorporated into diets at high levels (40%) poor flowability of the feed often results. Researchers have investigated the physical properties of DDGS and use of anti-caking agents to determine their influence on flowability but few studies have evaluated effects of feed storage structures on flowability. Thus, two experiments were designed to evaluate the effects of feed bin design and passive agitator use on flowability of a commercial swine finishing diet containing 40% DDGS. Six bins of three different designs were used, which included: a galvanized steel, seamless bin with a 60° cone (Steel60; Dealers Livestock, Glenwood, Minn.); a galvanized, corrugated steel bin with a 67° cone (Steel67; PigTek, Milford, Ind.); and a white, polyethylene bin with a 60° (Poly60; Prairie Pride, Winnipeg, MB). In Experiment 1, rate of feed flow from each bin was assessed on days 3, 7, and 21 post-feed delivery. Feed flow from Poly60 (736.8 kg/min) was faster than Steel60 (602.9 kg/min), with Steel67 having intermediate flow (663.3 kg/min). In Experiment 2, passive feed flow agitators (Sure Flo Agitator, Farmer Boy Ag Supply, Myerstown, Pa.) were installed in one bin of each design. Feed flow was evaluated on days 2, 3, 6, 7, 20, and 21 post-feed delivery. Feed flow from Poly60 (900.7 kg/min) was greater than flow from either Steel60 (826.7 kg/min) or Steel67 (843.8 kg/min). The passive agitator increased flow in Poly60 (970.0 vs. 831.4 kg/min), tended to improve feed flow in Steel67 (880.2 vs. 807.4 kg/min), but had no effect in Steel60 (826.8 vs. 826.7 kg/min). Results indicate feed bin design can influence flowability of feed containing 40% DDGS. Of the bins tested, the passive agitator appeared to improve feed flow in some, but not all bin designs.

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INFLUENCE OF STORAGE BIN DESIGN AND FEED CHARACTERISTICS ON FLOWABILITY OF PIG DIETS CONTAINING MAIZE DISTILLERS DRIED GRAINS WITH SOLUBLES

A. M. Hilbrands, K. A. Rosentrater, G. C. Shurson, L. J. Johnston

ABSTRACT. *Maize dried distillers grains with solubles (DDGS) is a valuable ingredient in the swine industry but when incorporated into diets at high levels (40%) poor flowability of the feed often results. Researchers have investigated the physical properties of DDGS and use of anti-caking agents to determine their influence on flowability but few studies have evaluated effects of feed storage structures on flowability. Thus, two experiments were designed to evaluate the effects of feed bin design and passive agitator use on flowability of a commercial swine finishing diet containing 40% DDGS. Six bins of three different designs were used, which included: a galvanized steel, seamless bin with a 60° cone (Steel60; Dealers Livestock, Glenwood, Minn.); a galvanized, corrugated steel bin with a 67° cone (Steel67; PigTek, Milford, Ind.); and a white, polyethylene bin with a 60° cone (Poly60; Prairie Pride, Winnipeg, MB). In Experiment 1, rate of feed flow from each bin was assessed on days 3, 7, and 21 post-feed delivery. Feed flow from Poly60 (736.8 kg/min) was faster than Steel60 (602.9 kg/min), with Steel67 having intermediate flow (663.3 kg/min). In Experiment 2, passive feed flow agitators (Sure Flo Agitator, Farmer Boy Ag Supply, Myerstown, Pa.) were installed in one bin of each design. Feed flow was evaluated on days 2, 3, 6, 7, 20, and 21 post-feed delivery. Feed flow from Poly60 (900.7 kg/min) was greater than flow from either Steel60 (826.7 kg/min) or Steel67 (843.8 kg/min). The passive agitator increased flow in Poly60 (970.0 vs. 831.4 kg/min), tended to improve feed flow in Steel67 (880.2 vs. 807.4 kg/min), but had no effect in Steel60 (826.8 vs. 826.7 kg/min). Results indicate feed bin design can influence flowability of feed containing 40% DDGS. Of the bins tested, the passive agitator appeared to improve feed flow in some, but not all bin designs.*

Keywords. Distillers dried grains with solubles, Feed bin, Flowability, Maize, Passive agitator.

Poor flowability of feed is a continual source of frustration for many commercial pork producers. Poor flowability often reduces the rate of feed delivery to feeders or bridging of feed in the storage bin prevents feed from reaching pigs. Consequently, poor feed flowability can lead to out-of-feed events which increases stress of pigs, increases the likelihood of gut health problems, and reduces growth performance. Usually, manual intervention by pounding or beating on the bin by the barn workers is needed to re-establish feed flow. Consequently, this can lead to significant damage to bins and create water leaks leading to feed spoilage. In addition, workers often need to leave the barn to correct the feed flow problem, which may lead to violating the farm's biosecurity standards by not showering or changing clothes and footwear prior to re-entering the pig space. Therefore, consistent feed flow is an essential component to assure high quality pig performance, uncompromised pig welfare, and effective biosecurity practices.

Flow of a bulk material, such as pig feed, is defined as "the relative movement of a bulk of particles among neighboring particles or along the container wall surface" and many factors affect flowability of a bulk material (Peleg, 1977). Diet composition, particle size and shape, moisture level, ambient temperature and humidity, pressure leading to compaction, and addition of anti-caking agents include some of the characteristics that may influence flowability of feed (Ganesan et al., 2008b). Despite this long list of factors, very few of these can be controlled in commercial pork production systems. Maize-dried distillers grains with solubles (DDGS) are notorious for poor flowability under conditions commonly experienced in commercial pork production systems (Bhadra et al., 2009; Johnston et al., 2009). Anecdotal reports from pork producers are consistent and indicate that inclusion of high levels of maize DDGS (30% or greater on an as-fed basis)

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in swine diets significantly reduces flowability of feed. However, during times of high maize prices, pork producers often use high levels of maize DDGS in diets to reduce feed costs, regardless of its negative effect on flowability of the diet. One might expect that the use of anti-caking agents could provide a simple solution to poor flowability, but previous research with DDGS suggests common anti-caking agents are not effective in improving flow rate (Ganesan et al., 2008a; Johnston et al., 2009).

The economic realities of modern pork production systems dictate that producers use finely ground diets to improve feed conversion in addition to adding high levels of bioenergy co-products (i.e., DDGS and similar maize co-products) that further contribute to poor feed flowability. Given this reality, it appears that the industry should abandon attempts to alter the feed to improve flowability in favor of focusing on the feed handling equipment to improve feed flowability. Many design characteristics of feed storage bins such as, slope and shape of the discharge cone, material used to construct the bin, and presence of mechanical aids could potentially influence flowability of feed. However, there is little diversity among designs and features of storage bins currently being marketed to pork producers. Historically, pork producers have spent little time and effort in selecting feed storage bins. The primary questions asked by producers are: "How much feed will the bin hold?" and "What does the bin cost?" Seldom do producers consider the flow characteristics of the bin. If feed flowability problems are to be corrected, storage bin design, as it relates to feed flowability under the economic realities of modern feed formulation and manufacturing practices, merits investigation.

The primary objective of this study was to determine the effects of selected commercially-manufactured feed storage bins on flowability of feed containing 40% maize DDGS. The secondary objectives were to determine if the installation of a passive agitator within the bin is effective for improving feed flow from these commercially-manufactured feed storage bins, and to determine characteristics of feed and environmental conditions of storage that are predictive of feed flowability.

MATERIALS AND METHODS

FEED BINS AND DESIGN

The research site consisted of six feed storage bins arranged in a single row on a concrete pad oriented in a north-south direction at the West Central Research and Outreach Center, Morris, Minnesota. There were six total bins representing three different designs and manufacturers (two bins per design). The three bin designs were: 1. A galvanized steel, smooth-sided, seamless bin with a 60° round discharge cone (Steel60; Dealers Livestock, Glenwood, Minn.); 2. A galvanized, corrugated steel bin with a 67° round discharge cone (Steel67; PigTek, Milford, Ind.); and 3. A white, polyethylene bin with a 60° round discharge cone (Poly60; Prairie Pride, Winnipeg, MB). All bin models used are commercially available to pork producers in the United States (fig. 1). All bins had a sealed

Figure 1. Bin flowability research site, West Central Research and Outreach Center, Morris, Minn. Feed bin designs were: Steel67 (two bins on left), Poly60 (two center bins), and Steel60 (two bins on right).

top and were non-vented. Hopper angles are defined from the horizontal plane which passes through the hopper discharge outlet and bins were designed for mass flow under ideal conditions. Each bin was equipped with a standard straight boot for transition to the unload auger, but bins were not equipped with augers so that feed flow from the bin was not dictated by the speed and capacity of the auger. Instead, feed flow was measured by opening the boot slide completely and allowing feed to flow directly into a tractor-powered grain auger with sufficient capacity to prevent feed buildup at the bin outlet. The size of the boot outlet with the discharge slide fully extended was 15 × 24 cm for all bins. Bin styles were selected to represent different slopes to the sides of the discharge cone or different materials on the inner wall of the bin. Steel67 and Poly60 bins had a capacity of about 2,700 kg, but Steel60 bins had an approximate capacity of 2,300 kg. Bins with larger capacity (14 to 18 metric tonnes) would have been more indicative of typical storage conditions in the United States, but logistical challenges of handling such a large amount of feed (108 metric tonnes at once), and desire for maintaining uniformity of feed added to each of the 6 bins forced the use of bins with less storage capacity. We assumed that the relative differences in feed flowability among the lower capacity bins can be directly predictive of feed flowability in higher capacity bins.

Two experiments were conducted. In each experiment, two lots (15.4 metric tonnes each) of a typical commercial swine finisher diet used in the United States were purchased from a commercial feed mill located within 8 km of the research site (two lots per experiment, four lots total). Diet composition was 55% corn, 3% soybean meal, 40% maize DDGS, and 2% minerals and vitamins. Corn was ground through a double pair roller mill (RMS 12-30 roller mill, Harrisburg, S.D. or Roskamp Champion 12-24 roller mill, Waterloo, Iowa) so that the target mean particle size of the final diet was 600 microns. Diet formulation and processing characteristics were designed to mimic poor flowability from commercial feed storage bins.

MEASUREMENTS AND CALCULATIONS IN EXPERIMENT 1

Experiment 1 was designed to evaluate flowability of feed from each of the three bin designs chosen. The experiment was conducted twice with one lot of feed (15.4 metric tonnes) delivered during summer and a second lot delivered in fall when ambient temperatures were cooler and humidity was expected to be lower. Feed was divided among the six bins and was not disturbed for three days. On the third day, a grain auger was placed under the bin and the boot slide was fully opened to allow feed to flow freely. Time was recorded from the moment the slide was opened until all feed flowed out of the bin. Discharged feed was augered into a bulk feed wagon such that feed flow was not limited by the auger. The previously-tared feed wagon and tractor were weighed on a truck scale to determine the quantity of feed that flowed out of the bin. Feed flow was calculated as the weight of feed delivered per minute. If upon opening the boot outlet bridging occurred and feed did not flow immediately, a rubber mallet was used to tap on the bin cone to initiate feed flow. Taps were applied to an area that encompassed the bottom 45 cm of the hopper cone and approximately 25% of the cone circumference. The number of taps required to establish feed flow was recorded. In addition, a subjective flowability score (1 = free flowing, 10 = completely bridged) was assigned to the feed flow as described by Johnston et al. (2009). Tapping and subjective flowability scores were performed by the same individual throughout the trial. Once the bin was emptied, the feed was augered back into the bin and this procedure was repeated 7 and 21 days after initial delivery.

At delivery, a sample of the feed was collected, sealed in a plastic bag, and frozen for subsequent analysis. Laboratory (University of Missouri, Columbia, Mo.) analyses according to AOAC (2006) procedures included: geometric particle size (mean and standard deviation) (*ASABE Standards*, 2009), moisture content (Method 934.01), and proximate analysis crude protein (Method 990.03), crude fat (Method 920.39), ash (Method 942.05), crude fiber (Method 978.10). In addition, each sample was subjected to several bench-top tests to estimate flowability of the feed samples, which included the following Carr Indices (Carr, 1965): angle of repose, loose bulk density, packed bulk density, compressibility, and Hausner ratio. These Carr Indices were selected based on prior work by Ganesan et al. (2007) and Bhadra et al. (2009) which identified these measurements as key flowability indicators.

Angle of repose is defined as the angle which forms between a horizontal plane and the slope of a pile (at rest) formed by flow of the bulk material from some elevation. Bulk solids with an angle of repose between approximately 25° and 35° are generally considered free flowing (Ganesan et al., 2008b). Higher values indicate poor flowability. Cohesion of particles, moisture content, particle size, and angularity of particles all influence Angle of Repose and thus flowability. Although not an actual indicator of flowability, bulk density is used to determine effective capacities for storage bins and containers. This measure is defined as the mass of a granular material that will occupy a specific volume. Bulk density not only includes particle mass, but it also represents the air entrapped in the void spaces between the particles. Two unique types of bulk density important to feed flowability are loose bulk density (BD_L) and packed bulk density (BD_P). Loose bulk density is the most common measure of density of a bulk material because it is the easiest to measure and is determined by pouring a quantity of granular material into a container of known volume. Briefly, loose bulk density was measured using a common bushel tester (Seedburo Equipment Co., Chicago, Ill.), which consisted of a brass hopper mounted on a tripod and a ½-L steel measuring cup; after the cup was filled via the hopper, excess material was leveled off with gentle zigzag strokes using the standard Seedburo striking stick, and the mass contained within the cup volume was measured. This measure is representative of a bulk solid which has not been subjected to compression or packing. Packed bulk density is the density of the material after it has been compressed, and thus, some of the entrapped air between particles has been removed. Packed bulk density was determined by tapping the filled cup from a standardized height onto the laboratory benchtop 50 times; after tapping, the volume reduction due to packing was measured, and the packed bulk density was calculated. This is representative of the material's actual bulk density during storage and transport, and is a more realistic measure to use for quantifying feed flowability. Both loose bulk density and packed bulk density were determined according to standard Carr Index procedures, as discussed in Ganesan et al. (2008a) and Bhadra et al. (2009). Some granular materials have a propensity to become tightly packed while others do not. After determining loose and packed bulk densities, the compressibility of a material can be calculated as:

$$C = \left(\frac{BD_P - BD_L}{BD_P} \right) \times 100 \qquad (1)$$

where C is compressibility (%). This parameter provides an indication of particle size, shape, uniformity, and cohesion, and thus, the overall flowability of the material. Bulk solids with a compressibility value less than about 18% are generally considered free flowing while materials with greater than 18% may be problematic (Ganesan et al., 2008b). Hausner ratio (HR) is related to compressibility, and is defined as:

$$HR = \frac{BD_P}{BD_L} \qquad (2)$$

Non-compressible materials have an HR defined as 1.0. The greater the HR for a feed sample, the poorer the flowability (Ganesan et al., 2008b).

Feed samples were also collected on days 3, 7, and 21. These samples were used to determine moisture content of the feed and a field test of the poured and drained angles of repose using a modified Hele-Shaw cell as described by McGlinchey (2005) and Johnston et al. (2009; fig. 2). Daily high and low temperature and humidity were recorded using data loggers (Hobo Pro Series Model H08-032-08 or Hobo Pro V II). Outside readings were recorded via data loggers placed on the underside of two randomly selected
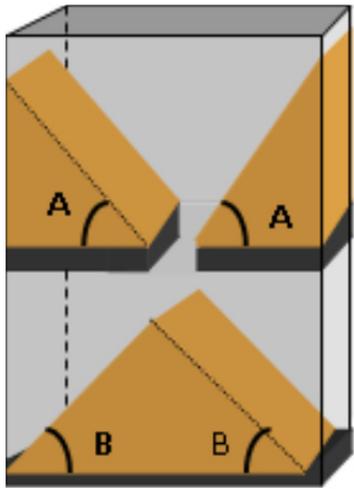
Figure 2. Modified Hele-Shaw cell used to measure drained angle of repose (indicated by angle labeled "A") and poured angle of repose (indicated by angle labeled "B"; Johnston et al., 2009).

bins. Internal bin readings were determined via data loggers mounted in the headspace of each bin just above the feed. Daily high and low readings for temperature and humidity represent the average of the highest and lowest reading from each data logger for each day of the trial.

STATISTICAL ANALYSIS FOR EXPERIMENT 1

The primary response criterion was the amount of feed delivered from each bin per unit time. These data were analyzed statistically using the Mixed Procedure of SAS (SAS version 9.3, Cary, N.C.) with repeated measures in time. The statistical model included the fixed effects of bin type (Steel60, Poly60 and Steel67), cumulative days since feed delivery, and their interaction. Replicate (summer or fall) was included as a random effect. Previous research reported from our laboratory indicated that flowability of feed was reduced substantially once moisture content exceeded 10% (Johnston et al., 2009) and feed is

Figure 3. Passive feed flow agitator used in Experiment 2 (Sure Flo Agitator, Farmer Boy Ag Supply, Myerstown, Penn.).

hygroscopic and can absorb water from the surrounding environment. Thus, moisture content of the feed corresponding with the day of feed flow determinations was used as a covariate in all statistical analyses. Significant effects of treatments were set at P < 0.05 with P < 0.10 indicating a trend.

MEASUREMENTS AND CALCULATIONS IN EXPERIMENT 2

In Experiment 2, use of a passive feed agitator (Sure Flo Agitator, Farmer Boy Ag Supply, Myerstown, Pa.; fig. 3) for improving feed flowability from the storage bins described in Experiment 1 was evaluated. The agitator was a free-spinning, polyethylene cone mounted on a steel bracket secured to the bin collar just above the boot. The agitators are promoted to be a low-cost method of reducing build-up, coning, bridging, and "rat-holing" of feed in bins. The concept is that, as the feed begins to flow out and past the agitator, the fins on the agitator are deflected which moves the entire cone. The moving cone disturbs feed in contact with the cone on all sides which encourages feed flow. The effectiveness of these passive agitators has not been evaluated objectively. Procedures and data collected for this experiment were identical to Experiment 1 with two exceptions. First, one randomly selected bin of each design was fitted with an agitator; and second, because effects of bin type and agitator would be confounded in this experiment, we added additional data collection days and conducted the feed flow evaluations on days 2, 3, 6, 7, 20, and 21. This approach provided replication in time for each bin/agitator combination.

STATISTICAL ANALYSIS FOR EXPERIMENT 2

Statistical analysis of data was similar to that described for Experiment 1 using the Mixed Procedure of SAS. The statistical model included fixed effects of bin design, agitator, cumulative days since feed delivery, and all two- and three-way interactions among these effects. Moisture content of feed on the day of feed flow evaluations was used as a covariate in all analyses and replicate (summer or fall) was included in the statistical model as a random effect. Significant effects of treatments were set at P < 0.05 with P < 0.10 indicating a trend.

Characteristics of feed (e.g. particle size (geometric mean and standard deviation), bulk density, moisture content, water activity, nutrient content, angle of repose, Hausner ratio, and compressibility) were used to predict flowability from the bin using classification and regression tree (CART) analysis as described by Johnston et al. (2009). This analysis used 24 feed samples collected throughout Experiments 1 and 2. A Least Squares fitting method was used with a minimum split index value of 0.05 and a minimum improvement in proportional error reduction of 0.05. Minimum count at each node was set at 5. The objective of this analysis was to identify traits of the feed used in both experiments that were predictive of feed flowability.

RESULTS

OUTDOOR TEMPERATURE AND RELATIVE HUMIDITY

Each experiment was replicated twice to encompass seasonal differences. Beginning and ending dates along with environmental conditions for each replicate are presented in table 1. As expected, temperatures during the summer replicates were warmer than those experienced during the fall replicates. We expected lower humidity readings during fall replicates compared to summer replicates, which occurred for Experiment 1 but not for Experiment 2.

FEED CHARACTERISTICS

Chemical and physical characteristics of the feed for each trial are shown in table 2. These characteristics were evaluated on samples collected the day each feed allotment was delivered to the research site. The DDGS used in the feed was sourced from two different ethanol plants, but it was not possible to accurately identify the specific DDGS source for each lot of feed. In general, geometric mean particle size of the diet (ranged from 736 to 1015 microns) was somewhat greater than our targeted particle size of 600 microns, likely due to the presence of syrup balls contributed by the DDGS.

Angle of Repose. In this study, angle of repose values ranged from 49° to 70° (table 3), indicating that each lot of feed received could potentially have poor flowability.

Loose Bulk Density. BD_L of the feeds ranged from 516 to 550 kg/m³. Anecdotally, a bulk density of approximately 481 kg/m³ is common for maize DDGS. The higher bulk density observed in these feed samples was likely due to the other feed constituents in the mixture. Feed ingredients can exhibit large variability, due to a variety of reasons, including differences in manufacturing operations, process settings, and raw materials used. For example, Schofield (2005) has shown that the loose bulk density of ground corn can range from 545 to more than 577 kg/m³, while that of corn meal can range from approximately 600 to 640 kg/m³. Soybean meal can vary from 545 to more than 673 kg/m³, while vitamin and mineral mixes can range from 300 to more than 1,400 kg/m³. Bulk density is a function of particle size (geometric mean and standard deviation) and shape, the mass of each individual particle, and how the particles are placed into the storage vessel.

Packed Bulk Density. BD_P ranged from 678 to 707 kg/m³, which was considerably higher than the loose bulk densities of the feeds and suggests potential for poor flowability.

Compressibility. C values ranged from 20.9% to 24.4%. Because the value was fairly high (>18%), we anticipated that these feeds would probably have flow problems from the bins during the bin flow experiments.

Table 2. Characteristics of feed used in each trial (as-fed basis).[a]

Season	Moisture (%)	Crude Protein (g/kg)	Crude Fat (g/kg)	Crude Fiber (g/kg)	Geometric Particle Size (microns) Mean	Std. Dev.
Experiment 1						
Summer	12.8	152	58	32	1,015	1,857
Fall	11.8	170	53	34	736	2,210
Experiment 2						
Summer	12.0	177	46	35	860	2,069
Fall	14.4	165	48	33	863	1,885

[a] Analysis of samples collected upon feed arrival.

Hausner Ratio. In this study, HR ranged from 1.27 to 1.32, which indicates a 27% to 32% reduction in flowability relative to ideal granular material which is free-flowing. This parameter is related to C, and thus both predict potential problematic flow.

Overall, the laboratory-scale flowability assessments indicated that all feed samples would likely exhibit poor flowability from the bins. So, the feed used for the bin flow experiments were expected to create flowability challenges and thus feed bin design could be evaluated properly.

RESULTS OF EXPERIMENT 1

This experiment was designed to evaluate the effects of bin design on flowability of feed after 3, 7, or 21 days of storage. There were no interactions between bin design and day of storage for any parameter measured in this experiment. Therefore, only the main effects of bin design will be discussed subsequently. As expected, bin design did not affect the average temperature or relative humidity in the headspace of the bin (table 4) and should not have contributed to differences in feed flowability. Furthermore, we observed no caking or crusting of feed at any time during the experiment. Temperature and humidity readings were averaged over both replicates from readings recorded every 30 min throughout the experiment. Relative humidity was consistent from day 3 (56.2%) to day 7 (55.6%) but declined (P < 0.05) by day 21 (52.2%).

Neither drained nor poured angles of repose were influenced by feed bin design. This observation is not surprising because the angle of repose is a property of the feed and is highly influenced by the size and shape of feed particles, as well as the interactions among feed particles. It is unlikely that the bin design would influence these properties of the feed, and consequently affect angle of repose.

Feed flow out of the bins was influenced (P < 0.05) by design of the bin and day of storage. Feed flowed faster (P < 0.05) from Poly60 bins compared to Steel60 bins, with feed flow from Steel67 bins being intermediate. Since the size of the opening in the boot was the same for all bins, and the slope of the bin cones was the same for Poly60 and

Table 1. Average outdoor temperature (°C) and relative humidity (%) conditions for each experiment.

Season	Start Date	End Date	Daily High Temperature	Daily Low Temperature	Daily High Humidity	Daily Low Humidity
Experiment 1						
Summer	6/12/12	7/3/12	29.8	16.6	94.3	39.4
Fall	9/10/12	10/1/12	23.7	7.3	74.7	23.3
Experiment 2						
Summer	7/17/12	8/7/12	30.9	18.9	100.0	50.0
Fall	10/9/12	10/30/12	11.9	2.9	92.7	57.7

Table 3. Flowability characteristics of feed used in each trial (lab analysis).

Season	Angle of Repose (°)	Loose Bulk Density (kg/m³)	Packed Bulk Density (kg/m³)	Compressibility (%)	Hausner Ratio
			Experiment 1		
Summer	49	539.1	686.8	21.5	1.27
	(3.0)[a]	(3.10)	(0.92)	(0.01)	(0.01)
Fall	63	516.5	678.1	23.8	1.31
	(5.7)	(2.27)	(3.92)	(0.63)	(0.01)
			Experiment 2		
Summer	71	535.1	707.4	24.4	1.32
	(4.9)	(1.30)	(3.13)	(0.21)	(0.01)
Fall	63	550.2	696.0	21.0	1.27
	(5.2)	(2.60)	(8.38)	(0.84)	(0.01)

[a] Indicates standard deviation

Table 4. Effect of bin design on headspace conditions in bins and flowability of feed (Exp. 1).[a]

Trait	Steel60[b]	Poly60	Steel67	SE	P value
Avg. temperature (°C)	23.6	22.9	22.6	2.93	NS[c]
Avg. relative humidity (%)	55.3	54.7	53.9	5.30	Day 0.01
Drained angle of repose[d] (°)	54	54	53	2.3	NS
Poured angle of repose (°)	28	29	30	0.6	NS
Feed flow (kg/min)	602.9a	736.8b	663.3ab	141.1	Bin 0.05, Day 0.05
Taps required[e]	3.8a	7.5b	6.0b	2.23	Bin 0.01
Flowability score[f]	3.7a	4.9b	4.2ab	1.32	Bin 0.01

(Bin Design column header spans Steel60, Poly60, Steel67)

[a] Values followed by different letters within each row are statistically different at a 95% confidence level.
[b] Steel60 = steel bin with 60° angled cone, Poly60 = polyethylene bin with 60° angled cone, Steel67 = steel bin with 67° angled cone.
[c] Non-significant.
[d] Drained and poured angle of repose measured in the field.
[e] Number of taps on bin required.
[f] Subjective score assigned to flowability (1 = free flowing; 10 = completely bridged).

on this bin. Interestingly, the bin with the slowest flow rate (Steel60) required the fewest (P < 0.05) number of taps to establish feed flow. Feed flow was greater (P < 0.05) on day 3 (762 kg/min) compared to day 7 (635 kg/min) and day 21 (606 kg/min). An explanation for this difference is not readily apparent.

RESULTS OF EXPERIMENT 2

Unlike Experiment 1, average temperature in the bin headspace tended to be slightly higher (P < 0.06) for Steel60 compared to Steel67 bins (table 5). This may be due to the relative location of these bins. The Steel60 bins were located randomly on the south end of the research site while the Steel67 bins were located on the north end of the research site. All of the bins were arranged in a row that was oriented in a north-south direction. The second trial of this experiment was conducted during the coolest temperature period of the study. It is possible that the Steel60 bins received more sun exposure and were warmer because of their location compared to the Steel67 bins. Similar to Experiment 1, drained and poured angles of repose were not affected by bin design or the presence of agitators in the bins. These results were expected.

Steel60, it is reasonable to expect that the polyethylene material used to manufacture the Poly60 bins contributed to the improved feed flow. Materials used in the Steel67 bin were very similar to those used in the Steel60 bin, which suggests that improved feed flow from the Steel67 bin may be attributable to the steeper slope of the sides of the cone

Table 5. Effect of bin design and passive flow assist agitators on headspace conditions in bins and flowability of feed (Exp. 2).[a]

Trait	Steel60[b] No Agitator	Steel60 Agitator	Poly60 No Agitator	Poly60 Agitator	Steel67 No Agitator	Steel67 Agitator	SE	P value
Avg. temperature (°C)	20.1	20.4	19.6	19.5	19.0	18.8	10.9	Bin 0.10 Day 0.05
Avg. relative humidity (%)	58.3	65.0	65.0	61.3	61.1	63.8	1.62	Day 0.01 Bin × Agit. 0.10
Drained angle of repose[c] (°)	54	54	54	54	54	54	1.4	NS[d]
Poured angle of repose (°)	27	26	27	27	27	28	1.8	Day 0.05
Feed flow (kg/min)	826.7a	826.8a	831.4a	970.0b	807.4a	880.2a	184.0	Bin 0.01 Agit. 0.01 Bin × Agit. 0.01
Taps required[e]	2.1	2.0	5.2	2.5	3.2	2.0	3.1	NS
Flowability score[f]	2.3	2.6	4.2	2.9	3.7	2.3	3.0	NS

[a] Values followed by a different letter within each row are statistically different at a 95% confidence level.
[b] Steel60 = steel bin with 60° angled cone, Poly60 = polyethylene bin with 60° angled cone, Steel67 = steel bin with 67° angled cone.
[c] Drained and poured angle of repose measured in the field.
[d] Non-significant.
[e] Number of taps on bin required to establish feed flow.
[f] Subjective score assigned to flowability (1 = free flowing; 10 = completely bridged).

We observed an interactive effect (P < 0.01) of bin design and presence of agitators on flow rate of feed out of the bins. Presence of an agitator increased feed flow in the Poly60 bin compared to the Poly60 bin without an agitator. In the steel bins, the presence of the agitator did not affect feed flow. Among all bin designs, the presence of an agitator improved (P < 0.01) feed flow (892 vs. 822 kg/min). However, the magnitude of this improvement was not equal across all bin designs, as evidenced by the interaction. Poly60 bins provided greater (P < 0.01) feed flow than Steel60 or Steel67 bins (901 vs. 826 or 844 kg/min, respectively). Unlike Experiment 1, there was no significant difference in the number of taps required to establish feed flow among the 6 bin/agitator combinations.

CART analysis. The CART procedure considers all characteristics of the feed simultaneously and selects the one characteristic that has the most influence on feed flow rate. Feed flow rate was most influenced by bulk density of the feed in this study. When bulk density of the diet was greater than 689 kg/m^3, flow rate was 989 kg/min, but flow rate decreased to 694 kg/min when bulk density was less than 689 kg/m^3. Bulk density of the feed accounted for about 63% of the variation in flow rate observed in this experiment. In this analysis, no other variables were identified that explained a meaningful portion of the variation in flow rate. These results should be viewed with caution though, because in both experiments, there were only four lots of feed used, with six observations of flow rate for each lot of feed.

The main objective of these experiments was to examine the effects of bin design on flow rate. Therefore, it was important that the feed be as uniform as possible from one replicate to the next. Uniformity of feed was important to minimize the effects of feed characteristics on flow rate so that effects of bin design could be detected. Thus, the uniformity in the formulation consistency and manufacturing reduced the usefulness of the CART analysis, which is most robust when there are a large number of samples spanning a wide range of feed characteristics. In previous CART analysis of feed ingredient flow (Johnston et al., 2009), moisture content of feed was identified as the most useful characteristic to predict feed flow when moisture content ranged from 7.6% to 12.2%. In that study, feed flow increased when moisture content was less than 10%. In the current study, moisture content of feed ranged from 11.8% to 14.4%. This moisture range was smaller and overall moisture was generally higher than our previous study. No feed samples in the current study contained less than 10% moisture.

DISCUSSION

In Experiment 1, feed flow from the Poly60 bins was significantly greater than that from the Steel60 bins. In Experiment 2, feed flow did not differ across the treatments when no passive agitator was used. With the use of the agitator, flow from the Poly60 bins was significantly greater than flow from either steel bin. Our results seem to indicate a marginal advantage for bins constructed of polyethylene

material to improve flowability of feed containing a high concentration of DDGS, at least after flow is initiated (as evidenced by the number of taps required). In that regard, the Steel60 bin had the advantage in requiring fewer taps to establish feed flow than either the Poly60 or Steel67 bins. In a commercial setting, this may be more desirable than a faster flowing bin in that less time and fewer trips are required outside of the barn reducing overall exposure to possible biosecurity risks. Material used for bin construction seemed to have a larger effect on feed flowability than slope of the bin's discharge cone. There was no advantage for the 67° slope over the 60° slope in galvanized steel bins. Presence of a passive agitator in the bin cone was most beneficial in the polyethylene bin compared to bins constructed of steel. However, there was weak evidence (P < 0.07) that the agitator provided some benefit in the steel bin with a steeper slope of the discharge cone.

CONCLUSIONS

Results of these experiments indicate that feed bin design can influence flowability of feed containing high concentrations of DDGS. Of the bins tested, the Poly60 bin produced the highest flow rate once feed flow was established. Passive agitators installed in feed bins appear to increase the speed of feed flow in some but not all bins. The combination of a passive agitator in the Poly60 bin produced the fastest feed flow.

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