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Agents to Improve Flowability of DDGS in Commercial Systems

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Introduction

Large quantities of dried distillers grains with solubles (DDGS) are available for feeding livestock domestically and internationally. DDGS has many positive attributes for the feeding of livestock (University of Minnesota, 2006). Unfortunately, DDGS can have some undesirable handling characteristics related to poor flowability under certain conditions (AURI and MN Corn Growers Assoc., 2005). Reduced flowability, or the potential for reduced flowability of DDGS prevents the routine use of railcars for transport. Some rail freight companies do not permit the use of their railcars for transport of DDGS (NCERC, 2005). This prohibition negatively influences commerce related to DDGS. Reduced flowability and bridging of DDGS in bulk storage containers and transport vehicles limits the use of DDGS for feeding livestock and poultry. Livestock producers and feed mills do not want to deal with the inconvenience and expense of handling a feedstuff that does not flow through their feeding and milling systems. Consequently, some pork producers have used DDGS in the past but have discontinued their use of DDGS due to poor flowability (J. Goihl, Agri-Nutrition Services, personal communication).

Very few attempts to characterize factors affecting flowability of DDGS have been reported in controlled studies. The AURI and MN Corn Growers Assoc. (2005) studied a limited number of DDGS samples under laboratory conditions. They reported that relative humidity greater than 60% seemed to reduce flowability of DDGS which was likely due to the product's ability to adsorb moisture. While moisture in the environment and moisture content of DDGS likely influence flowability, many other factors have been suggested as possible controllers of flowability such as particle size, content of solubles, dryer temperature, moisture content at dryer exit, and others.

Most interventions to improve flowability of DDGS have been limited to trial and error approaches within ethanol plants. These interventions relate to the completeness of fermentation, adjusting moisture content, and changing particle size, but have not been reported in the public domain. ILC Resources (2003) investigated the utility of including 2% calcium carbonate in DDGS as a flowability agent. They reported a 6 to 12% reduction in the angle of repose determined in a laboratory setting when calcium carbonate was added to DDGS after drying. Determination of flowability under practical industry conditions was not attempted in their study. Similarly, Ganesan et al. (2006) evaluated the addition of calcium carbonate to DDGS that contained varying concentrations of solubles and moisture in a laboratory setting. They reported reduced flowability of DDGS as concentration of solubles and moisture increased. Addition of calcium carbonate had no significant effect on flowability of DDGS. Because moisture and relative humidity seem to play an important role in flowability of DDGS, some have suggested use of zeolites and/or grain conditioners as a way of controlling moisture migration through DDGS. However, no controlled studies to evaluate this concept have been reported.

Realizing the importance of handling challenges presented by DDGS and the lack of controlled studies under commercial conditions that evaluate solutions to these handling problems, we designed a study to determine if the addition of selected flowability agents is effective in improving flowability of DDGS under practical commercial conditions. Our secondary objective was to identify physical and/or chemical characteristics of DDGS that might be responsible for poor flowability.

Materials and Methods

This experiment was conducted at a dry-grind ethanol plant (BushMills Ethanol Inc., Atwater, MN) constructed in 2005. Experimental treatments were replicated on four separate days beginning on September 1, 2006 and ending on October 27, 2006.

Treatments were imposed in a 2 x 4 factorial arrangement (eight total treatments). The main treatment effects were moisture content of DDGS (9% vs. 12%) and type of flowability agent (FA). The moisture treatments were selected to represent DDGS that is expected to flow readily (9%) and DDGS that is expected to present poor flowability (12%). The FA treatments were: 1. Control, 2. a grain conditioner purported to control moisture migration (5 lb/ton, DMX-7, Delst, Inc.), 3. calcium carbonate (2% Unical-P, ILC Resources, Inc.) and 4. a clinoptilolite zeolite (1.25% St. Cloud Zeolite, St. Cloud Mining Co.). The control was standard DDGS produced in the plant on a selected day with no FA added. The FA's were incorporated at the desired level to DDGS containing 9 or 12% moisture from the plant's stockpile.

During the night shift prior to our arrival at 9:00 am, the ethanol plant produced DDGS containing 9% or 12% moisture and placed it in two separate stockpiles. Stockpiles were housed in the plant's warehouse and all experimental work was completed in the warehouse. At about 10:00 am, we began applying FA treatments to the DDGS. About 5,000 lbs of DDGS was augered into a New Holland portable on-farm grinder mixer (Model 358) by-passing the grinding hammers and the appropriate FA was added. This mixer was equipped with a single vertical screw in the mixing hopper and an electronic scale. Solid FA agents (calcium carbonate, zeolite) were added to DDGS through the hand-add hopper and the hopper was flushed with DDGS. The liquid FA (DMX-7) was sprayed on DDGS with a garden hand sprayer as it exited the top of the vertical mixing screw. The DDGS and FA were allowed to mix for 3 minutes after all the DDGS was added. Treated lots of DDGS were loaded into one of eight individual compartments in an auger-equipped feed truck. Weight of each lot at loading was recorded. Flowability agents were applied to one moisture level of DDGS before switching to the other moisture level. Order of selecting moisture level and application of FA's was random. Environmental temperature and relative humidity outside the warehouse was recorded every 10 minutes during the period that the truck was being loaded (about 4 to 6 hours). Temperature of each lot of DDGS was recorded immediately after being placed in the truck.

Once the truck was loaded on Friday afternoon, it traveled 150 miles and sat idle for about 60 hours over the weekend. On Monday morning, the truck traveled 150 miles back to the ethanol plant where it was unloaded back into the warehouse. Speed of the unload augers was held constant for each compartment and across unloading days. Time required to unload each compartment was recorded and flow rate (pounds/minute) for DDGS in each compartment was calculated. The operator assigned a subjective flowability score (scale: 1 = free flowing; 10 = completely bridged) to each compartment based on the number of interventions (pokes, prods, blows to side of compartment) required to unload the compartment. The same truck and operator were used on four different days (4 loads total) which provided 32 truck compartments (4 loads x 8 compartments/load). Before the start of the experiment, each of the eight truck compartments used for the experiment were loaded with 5,000 lbs of DDGS containing the same moisture content and no FA's. The truck was immediately moved from the load-out area to the warehouse and unloaded as described above. This provided a baseline unload rate of DDGS from each compartment under ideal conditions. This baseline rate was used to correct flow rate of experimental DDGS from each compartment to adjust for inherent differences in the truck which were unrelated to treatments.

At the time of loading, a sample of DDGS was collected. Each sample was analyzed for moisture, nutrient content (protein, calcium, phosphorus, crude fiber, crude fat, ash), particle size, bulk density, residual sugars, color, and angle of repose. Drained angle of repose (McGlinchey, 2005) was measured on DDGS samples at the time of loading and after storage of DDGS samples for a minimum of 4 weeks. Angle of repose is a laboratory estimate of flowability of materials. These characteristics of each DDGS sample were related to the measure of flowability recorded at truck unloading.

The PROC GLM procedure of SAS (SAS Institute Inc., 2002) was used to conduct least squares analysis of variance to determine the effects of replicate day, and the effects of moisture level and FA's on flowability. The statistical model to determine the effects of replicate day included: day, moisture level, FA, day by moisture level, and day by FA. Physical constraints of the truck prevented replication of all 8 treatments on one day. Consequently, day and treatments were confounded. The statistical model to determine the effects of treatments included: moisture level, FA, and the moisture level by FA interaction. Where necessary, treatment means were separated by the PDIFF option of SAS.

Our secondary objective was to identify physical and/or chemical characteristics of DDGS that might predict flowability. For this analysis, we conducted two separate analyses (stepwise linear regression and Classification and Regression Trees, CART) to identify which characteristics of the DDGS samples collected in this experiment are most predictive of DDGS flowability. The characteristics considered in both of these analyses included: temperature and moisture content of DDGS at loading and unloading; particle size; acid detergent fiber concentration; neutral detergent fiber concentration; ash content; bulk density; Hunter L*, a*, and b* color scores; ambient temperature and humidity; flowability agent; and concentration of residual sugars.

Results and Discussion

As described above, this experiment was conducted on four separate days beginning September 1, 2006. The same truck was used on each day to control variation in unloading rate that would likely occur among different trucks. The necessity to standardize the truck used, limited our ability to replicate treatments within each experimental day since the feed truck contained only eight compartments. Consequently, experimental treatments and day are confounded which limits our ability to determine any interactive effects of ambient environmental conditions and flowability treatments.

Environmental conditions and DDGS production conditions for each replicate day are presented in Table 1. Logistical considerations with Double B Trucking and the ethanol plant dictated that replicate days be spaced at least 14 days apart. Obviously, there were differences in environmental temperature and humidity recorded just outside the warehouse where the experiment was conducted. However, addition rate of syrup to the DDG before drying and dryer temperatures were relatively consistent.

Table 1. Production conditions on replicate days of the experiment

	Day			
Item	9/1/06	9/15/06	9/29/06	10/27/06
Outdoor temperature (°F)	74.9	80.2	67.8	55.2
Outdoor humidity (%)	67.1	34.2	42.1	42.5
Syrup addition to DDG (gal/min)	50	46	51	51
Dryer temperature ranges (°F):				
Entry	800 – 852	788 – 865	849 – 861	601 – 867
Drop box	201 – 207	200 – 206	213 – 220	218 - 224

The differences in environmental temperature apparently influenced temperature of the DDGS at loading (Table 2). It is interesting to note that the coolest DDGS at loading occurred on the day with the coolest environmental temperature. Moisture content of the DDGS varied slightly across replicate days at both loading and unloading. There was no significant drying of the DDGS while it sat in the feed truck because the moisture content at loading and unloading was very similar. Flow rate of DDGS did vary across replicate days. The lowest flow rate occurred on Sept. 29, and the fastest flow rates occurred on Sept. 15 and Oct. 27. Subjective flowability score seemed to have limited ability to accurately reflect flow rate across days. The high flowability score for the Sept. 15 trial may have resulted from inexperience of the scorer with the scoring system. However, familiarity with the scoring system improved by the last two trials and the scoring system became more accurate.

Table 2. Characteristics and flow rate of DDGS used on replicate days of the experiment

	Day				
Item	9/1/06	9/15/06	9/29/06	10/27/06	PSE[1]
No. of samples	8	8	8	8	--
DDGS temperature (°F) at:					
Loading	90.5^{a}	89.6^{b}	81.3^{b}	74.7^{c}	0.66
Unloading	75.0^{b}	79.5^{c}	75.8^{b}	64.6^{a}	0.78
DDGS moisture (%) at:					
Loading	10.4^{a}	9.8^{c}	10.8^{b}	10.4^{a}	0.09
Unloading	10.4^{a}	9.6^{c}	10.8^{b}	10.4^{a}	0.07
Particle size (microns)	632^{b}	584^{c}	636^{ab}	668^{a}	10.8
Flow rate (lb/min[2])	1061^{a}	1271^{b}	890^{c}	1231^{b}	42.5
Flowability score[3]	--	6.25^{a}	6.50^{a}	3.75^{b}	0.29

[1] Pooled standard error.

[2] Rate of DDGS unloading from transport truck.

[3] Subjective score assigned by truck operator. Scale: 1 = Free flowing, 10 = Badly bridged.

[abc] Means with different superscripts differ ($P < 0.05$).

We observed no significant interactions between moisture level of the DDGS and flowability agents for any of the response criteria measured in this experiment. This suggests that the response to flowability agents was similar regardless of the moisture content of the DDGS. Consequently, we will present only main effect means and no interaction means. Temperature of DDGS at loading or unloading was not influenced by moisture content of the DDGS (Table 3). As designed, the 9% DDGS contained significantly less moisture than the 12% DDGS. The production staff at the ethanol plant effectively controlled the moisture content of the DDGS and provided product that allowed true evaluation of the treatments imposed in this study. Particle size of DDGS was smaller ($P < 0.05$) for the 12% DDGS compared with the 9% DDGS. An explanation for this difference is not readily apparent. Particle size did not seem to influence flow rate of DDGS. In a preliminary analysis of data, particle size did not explain a meaningful proportion of the variation in flow rate when it was used as a covariate in the statistical analysis. Flow rate and flowability score were clearly poorer ($P < 0.05$) for 12% DDGS compared with 9% DDGS. Reduced flowability of 12% DDGS was confirmed by a significantly higher drained angle of repose measured on the day of loading and after storage of DDGS samples in a freezer at -20 C for a minimum of one month. Similarly, the Carr poured angle of repose determined after storage of DDGS samples was greater for 12% DDGS compared with 9% DDGS. Interestingly, the magnitude of difference in angle of repose measurements determined after storage was much less than the difference recorded on the day of loading. Angle of repose measured after storage requires the caked sample to be broken apart before conducting the test. Breaking the caked sample improves flowability, particularly of a poorly flowing sample, and masked differences between samples.

Table 3. Effect of moisture level on flowability of DDGS

	Targeted moisture level		
Item	9 %	12 %	PSE[1]
No. of samples	16	16	--
DDGS temperature (^{o}F) at:			
Loading	85.2	82.8	2.01
Unloading	74.1	73.4	1.68
DDGS moisture (%) at:			
Loading	9.0^{a}	11.6^{b}	0.14
Unloading	9.0^{a}	11.6^{b}	0.18
Particle size (microns)	677^{a}	583^{b}	11.2
Flow rate (lb/min[2])	1368^{a}	859^{b}	58.7
Flowability score[3]	3.7^{a}	7.3^{b}	0.5
Drained angle of repose (degrees):			
Day of loading	57.7^{a}	65.7^{b}	0.80
After storage	64.6^{a}	67.6^{b}	0.98
Poured angle of repose after storage (degrees):			
Carr method	40.9^{a}	42.0^{b}	0.25
Modified Hele-Shaw	38.2	37.7	0.27

[1] Pooled standard error.

[2] Rate of DDGS unloading from transport truck.

[3] Subjective score assigned by truck operator. Scale: 1 = Free flowing, 10 = Badly bridged. n = 12.

[ab] Means with different superscripts differ ($P < 0.05$).

Flowability agents had no effect on temperature or moisture content of DDGS at loading or unloading (Table 4). Similarly, particle size of DDGS was not different among the FA treatments tested in this experiment. None of the flowability agents significantly altered the flow rate of DDGS compared to the control treatment which used no flowability agents. The flow rate of DDGS treated with DMX-7 was significantly lower than that of Zeolite-treated DDGS but neither of these was different than using no additive (Control). The drained angle of repose determined on the day of loading was significantly higher (worse) for DMX-7-treated DDGS compared with all other treatments. However, there were no differences among treatments in any of the angle of repose measurements recorded after storage. Angle of repose measurements recorded after storage were of limited value in assessing flowability of DDGS under commercial conditions.

Table 4. Effect of selected additives on flowability of DDGS

Item	Additives				PSE[1]
	Control	DMX-7	Calcium carbonate	Zeolite	
No. of samples	8	8	8	8	--
DDGS temperature (°F) at:					
Loading	83.3	84.2	84.2	84.4	2.85
Unloading	72.2	75.2	73.1	74.4	2.37
DDGS moisture (%) at:					
Loading	10.3	10.6	10.2	10.3	0.20
Unloading	10.3	10.6	10.0	10.4	0.25
Particle size (microns)	636	640	621	623	15.9
Flow rate (lb/min[2])	1123^{ab}	973^{a}	1129^{ab}	1229^{b}	83.0
Flowability score[3]	6.0^{ab}	6.5^{a}	5.5^{ab}	4.0^{b}	0.71
Drained angle of repose (degrees):					
Day of loading	61.0^{a}	65.1^{b}	60.4^{a}	60.3^{a}	1.13
After storage	66.7	67.2	64.4	66.1	1.38
Poured angle of repose after storage (degrees):					
Carr method	41.0	41.7	41.8	41.4	0.36
Modified Hele-Shaw	37.7	38.1	37.6	38.3	0.38

[1] Pooled standard error.

[2] Rate of DDGS unloading from transport truck.

[3] Subjective score assigned by truck operator to 6 samples per treatment.
Scale: 1 = Free flowing, 10 = Badly bridged.

[ab] Means with different superscripts differ ($P < 0.05$).

We used stepwise linear regression to identify the characteristics of DDGS that were most predictive of flowability as measured by truck unloading rate. In this statistical procedure, we used the observed truck unloading rate (flow rate) of each

DDGS sample and the other measured characteristics of each respective sample (Table 5) in the regression analysis. The stepwise procedure selects the measured characteristic that is the most effective predictor of the observed flow rate. The procedure then selects the next best predictor of flow rate and so on until all the measured characteristics have been evaluated. The measured characteristics that are effective predictors of flow rate are retained in the prediction equation and the others are removed. In this experiment, moisture content at loading ($P < 0.01$) and Hunter b* score ($P < 0.05$) were the two characteristics that predicted flow rate of DDGS. Moisture content at loading was the most effective predictor of flow rate as it explained about 70% of the variation in truck unloading rate. For every increase in DDGS moisture at loading of 1%, unloading rate decreased by 222 lb/minute. Anecdotal observations from truckers, feedmill managers, and pork producers suggest that flowability of DDGS declines with increased moisture content. Ganesan et al. (2006) reported a general trend for declining flowability of DDGS with increasing moisture content. However, these investigators studied moisture levels ranging from 10 to 30%, which is far in excess of moisture levels typically found in commercial situations. Rosentrater (2006) found a significant negative correlation between moisture content of DDGS and angle of repose (a laboratory measure of flowability). But, moisture content only explained about 11% of the variation in angle of repose measurements in Rosentrater's experiment.

Table 5. Characteristics of DDGS samples subjected to stepwise regression and CART analysis

Trait	Average[1]	Minimum	Maximum
DDGS temperature (°F):			
At loading	84.0	72.0	96.7
At unloading	73.8	60.2	82.8
DDGS moisture (%):			
At loading	10.35	7.93	12.16
At unloading	10.31	7.64	12.16
Particle size (microns)	630	522	772
Bulk density (g/cm^3)	68.4	65.3	70.7
Crude fiber (%)	5.9	4.5	7.1
NDF (%)	28.0	24.8	31.4
ADF (%)	11.1	9.1	13.2
Ash (%)	5.5	4.2	7.1
Residual sugars (%)[2]	0.76	0.30	1.30
Hunter L	57.8	55.0	60.5
Hunter a	12.4	11.2	14.0
Hunter b	43.4	40.8	47.4
Ambient conditions at loading:			
Temperature (°F)	69.5	55.2	80.2
Humidity (%)	46.5	34.2	67.1

[1] Average represents 32 observations.

[2] Sum of fructose, glucose, maltose, and sucrose.

Hunter b* score was positively related to flow rate; however, it only accounted for about 4% of the variation in flow rate. As Hunter b* score increased, flow rate also increased. A positive Hunter b* score indicates the sample has a yellow color while a negative score suggests a blue color. The Hunter b* scores of samples in this experiment were all positive indicating that all samples were yellow in color. While our regression analysis suggests that increasing yellowness elicits significant improvements in flow rate, the magnitude of those improvements are of little practical significance. None of the other measured characteristics of the DDGS samples collected in this experiment explained a meaningful proportion of the variation in flow rate.

The objectives of CART analysis are similar to stepwise linear regression in that the goal is to identify which characteristics of DDGS have the most impact on flow rate. However, the approach in this analysis is to consider all of the characteristics simultaneously and select the one characteristic that has the most influence on flow rate. Once this characteristic is selected, the analysis splits the data into two sub-groups in order to minimize the variation in the observed flow rate within each sub-group. Then these two sub-groups are evaluated, and the next most important characteristic with regard to flow rate is selected, and the sub-groups are again further divided. The tree is "grown" until the variation in flow rate cannot be reduced any further. In this analysis, moisture content at unloading was the characteristic determined to have the most influence on flow rate. If moisture content was less than 10.06%, flow rate averaged 1,449 lb/minute, but flow rates of DDGS with greater than 10.06% moisture were only 884 lb/minute. After moisture content, Hunter b* score was the next characteristic selected. Similar to the regression analysis, a higher Hunter b* score was indicative of greater flow rate. However, the influence of Hunter b* score on flow rate was far less than that of moisture content. The CART analysis identified no other measured characteristics that had a meaningful influence on flow rate of DDGS in this study.

Considering the stepwise regression and CART analyses together, it appears that moisture content of DDGS has an overpowering influence on flowability of DDGS under the commercial conditions of this study.

Conclusions

The flow agents and concentrations selected for this experiment provided little evidence for improved flowability of DDGS. Clearly, increasing moisture content of

DDGS from 9 to over 11.5% significantly decreased flowability of DDGS. There appears to be a linear decrease in flowability as moisture content of DDGS increases. In this study, DDGS with moisture content below 10% displayed the best flowability. More extensive sampling of DDGS with a greater range in moisture concentrations will be necessary to identify the ideal moisture concentration for optimal flowability.

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