Ethanol industry coproducts in swine liquid feeding: Aspects on nutritional value, welfare and carcass characteristics of wean-to-finish pigs

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TABLE OF CONTENTS

INTRODUCTION 2

OBJECTIVES 4

PROCEDURES 4

RESULTS 10

DISSEMINATION OF PROJECT RESULTS 19

LITERATURE CITED 20

II. Introduction:

A reduction in growth rate of piglets following weaning, known as ‘post-weaning growth check’ (Pajor *et al*., 1991), is commonly observed in wean-finish systems. This inhibition of piglet growth rate is associated with reduced feed intake (Bark *et al*., 1986; McCracken *et al*., 1995). Poor growth performance immediately after weaning also leads to subsequent problems in the growing and finishing phases such as an increase in days to market and variation in performance. The form of feeding is very important factor immediately after weaning as piglets are abruptly moved away from the sows and a predominantly liquid (sow’s milk) form of diet. It has been suggested that liquid feeding after weaning stimulates average daily feed intake (ADFI) and increases growth rate (Brooks *et al*., 1996; Jensen and Mikkelsen, 1998). Similarly, another trial (MLC, 2004) involving 1024 pigs, showed that *ad libitum* liquid feeding improved average daily gain (ADG) and feed conversion ratio (FCR) by 5.6 and 10.3% respectively, with no adverse effect on carcass fatness. Based on extensive sensory analysis for tenderness, juiciness, flavor, abnormal flavor and odor, Thompson (2004) reported no difference in the fresh and sensory meat quality of liquid and dry fed pigs. Simpson (2002) also reported a lack of difference in carcass characteristics of pigs fed with dry or liquid feed.

An increase in ADFI is also associated with an increase in average daily gain. For instance, Jensen and Mikkelsen (1998), based on a review of several studies concluded that liquid feeding of newly weaned pigs resulted in 12% increase in ADG in comparison to dry feeding. Improving feed intake during the post-weaning period is very important for encouraging development of the small intestine and subsequent growth performance. An increase in ADFI after weaning associated with liquid feeding has also been suggested to be helpful in the development of the small intestine (Simpson, 2002) and in maintaining gut integrity and villous height (Deprez *et al*., 1987; Pluske *et al*., 1997), thereby preventing the “growth lag” associated with weaning. Studies have also confirmed the protective effects of liquid feeding on intestinal integrity and absorptive capacity in terms of villi height and surface area (Deprez *et al*., 1987; Hurst *et al*., 2001). Several studies have reported food safety benefits as well in terms of a lower Salmonella seroprevalence in bloods samples of finisher pigs fed on liquid feed compared to pigs fed on dry feed (Dahl, 1997; van der Woolf *et al*., 2001; MLC, 2004; Farzan *et al*., 2006).

Studies have also indicated other health benefits of liquid feeding. A study by Scott *et al*., (2007) reported that in grow-finish pigs, liquid feeding lowered the scores of gastric ulcer scores at slaughter compared to dry pellet feeding. Other studies (Hillman *et al*., 2004; MLC 2004) reported that ileal, cecal and colon digesta samples from liquid fed pigs had lower coliform ratios suggestive of improved gut health. Liquid feeding is also suggested to be more welfare-friendly compared to dry feeding. For instance, a higher level of resting behavior and lower oral activity directed at the pig and pen parts in grow-finish pigs fed liquid feed have been reported by Scott *et al.*, (2007). The authors attributed this to increased gut fill and improved sense of satiety from intake of large volumes of liquid feed. Thompson (2004) also indicated that liquid fed pigs were less active (59% vs. 52% of time spent ‘sleeping’) and spent less time performing investigatory behaviors, particularly towards other pigs (7.5% v 9.4%) and pen parts (6.3% v 9.1%). However, Rasmussen *et al*., (2006) observed that satiation from liquid feeding lasts for a shorter time and feed must be provided several times during the day. Further, with the high water content in the feed, the pigs may take longer time to consume the same amount of digestible energy in the form of liquid feed compared to dry feed.

Liquid feed may offer environmental benefits as well. It enables the recycling of high moisture, industry byproducts. For instance, the byproducts such as distillers grains and solubles from the ethanol industry are accepted by grow-finish pigs. Liquid feeding reduces N excretion by 0.5-0.6kg/pig compared to dry feeding. This represents a total reduction of about 4 ton /year in N emissions from a grow-finish unit with 2000 pigs (Gill, 2007). Although the effluent volume is increased when pigs are fed on liquid feed in comparison to dry pellets, the increased biological efficiency of the pig is suggested to lower the amount of N and minerals voided per kilogram of growth (Russell *et al.*, 1996). The other advantages of liquid feeding compared to dry feeding are a reduction in dust load (fewer cases of respiratory diseases for both the pigs and the workers) and the use of self-produced feed components. Thompson (2004) reported that significantly more pigs were removed from the dry fed groups for respiratory conditions compared those fed on liquid feed.

Traditionally dry feed is mixed with water to prepare liquid feeds. A major ingredient in pig's feed is corn. The use of corn in ethanol production also results in the generation of byproducts that have the potential to be used for feeding pigs. One bi-product of dry ethanol production is wet corn solubles. In most of the ethanol plants in Minnesota this bi-product is sprayed on distiller grains to produce distiller grains and solubles (DGS). DGS is then dried to produce Distillers Dried Grains and Solubles (DDGS) to avoid deterioration in quality and to increase keeping quality. However, the drying process is very energy consuming. Wet corn solubles have a high nutrient profile consisting of 18% protein, 15% fat, 1.25% phosphorus and essential amino acids. Feed rations for growing and finishing swine require all of these ingredients in their rations and in their dry forms are relatively expensive. Further, it has been suggested that liquid feeding has the potential to improve pig health and performance, reduce nutrient excretion, and enhance the safety and quality of the pork and pork products (Gill, 2007). As a category, newly-weaned piglets may be benefited the most from liquid feeding. This is because the delivery of nutrients and water together eliminates the need to establish separate drinking and feeding behaviors, and reduces the risk of food and water deprivation. This will help to minimize growth check and loss of enteric function and intestinal integrity after weaning (Kelly *et al*., 1991; Pluske *et al*., 1996).

Despite the beneficial effects of liquid feeding, it is not widely used in commercial wean-finish systems in the US. In Ontario about 20% of growing-finishing pigs are currently raised on liquid feeding systems (SLFA, 2006). Similarly, despite the nutritional advantages of the byproducts of the ethanol industry, their inclusion in swine feed remains to be challenging owing to logistical and practical limitations of the existing mechanical swine feeding systems. A study conducted at the University of Minnesota (Johnston *et al*., 2007) indicated the practical problems such as reduced flowability of using the byproducts (DDGS) from the ethanol industry. It is also important to evaluate the performance and welfare of pigs fed with these byproducts in the liquid form before recommendations can be made for field use. Fresh Corn Distillers Solubles **(**CDS) contain 30% dry matter and, on a dry matter basis, 22% protein, 19% fat, 8.4% ash (1.4% phosphorus), 10% starch, and about 6% soluble sugars and the feeding value of CDS may be captured more fully and drying costs reduced when condensed CDS is fed in a liquid form to pigs (de Lange, *et al*., 2007).

Specialized liquid feeding equipment and ingredient storage capacity are required to utilize liquid feed ingredients. A key feature of modern computerized liquid feeding system is the control and monitoring of feed intake and feeding programs. Practices such as split-sex feeding, phase or blend feeding, introduction of new (liquid) feed ingredients, or modest feed intake restriction prior to slaughter, are easily implemented when using modern liquid feeding systems. Moreover, sudden changes in feed intake that may indicate a sudden onset of disease may be identified quickly. Installation of a liquid feed generation system suitable for these byproducts would solve these limitations and would enable the industry to make economic advantage by reducing the feed cost. It would also help the ethanol industry to minimize the energy requirement for drying.

There are two major types of liquid feeding systems. One type delivers the meal in discrete amounts in long troughs. Feeding will be completed in 20-30 min. Feed residues are flushed out of the pipelines between meals. The second type of liquid feeding system involves a sensor and feed troughs (e.g. Big Dutchman liquid feeding system). In this system feed is continuously charged into the feed delivery lines. There are liquid sensors in the trough that determine feed deliveries. The system also permits to override the sensors if needed to clean the pipelines. In both types, feed is prepared centrally and delivered through a chain of pipes and valves. A Big Dutchman liquid feeding system installed in the research trial. The Big Dutchman liquid feeding system prepares new batch of liquid feed for each feeding and for individual troughs. It also uses high-pressure air to move liquid feed to the feeders unlike the conventional liquid feeding system which uses water or feed. The conventional liquid feeding system also prepares batches of feed for several troughs at one time. The Big Dutchman liquid feeding system can be remotely controlled and ensures better accuracy of rationing through computer controls.

III. Objectives:

To determine the effects of liquid feeding using byproducts from ethanol industry (Dried Distillers Grains and Solubles, Wet Distillers Grains and solubles, Wet Solubles, Spray-Dried Solubles) on the performance and welfare of wean-finish pigs in comparison to feeding conventional dry corn soybean meal.

Specific objectives:

1. To determine the performance in terms of average daily gain, average daily feed intake and carcass characteristics of wean-finish pigs when fed liquid feed using byproducts from ethanol industry (Dried Distillers Grains and Solubles, Wet Distillers Grains and solubles) and conventional dry corn soybean meal.

2. To determine the welfare in terms of behavior, stress physiology, intestinal health, injury levels and longevity of wean-finish pigs when fed with liquid feed using byproducts from ethanol industry (Dried Distillers Grains and Solubles, Wet Distillers Grains and solubles) and conventional dry corn soybean meal.

IV. Procedures:

Animal Management and Production Data Collection

The experimental protocols used in this study were approved by the University of Minnesota Institutional Animal Care and Use Committee. The experiment was conducted at the University of Minnesota, Southern Research and Outreach Center, Swine Research Center, Waseca, Minn. The study involved 480 wean-finish pigs and was conducted at the University of Minnesota-Southern Research and Outreach Center wean-to finish facility at Waseca. The dietary treatments were as follows:

Treatment 1:	Control-Conventional corn/soybean (CSB)
Treatment 2:	30% Dried Distillers Grains and Solubles (DDGS)
Treatment 3;	30% Spray-dried thin solubles (DS, Phase 1 / DDGS (Phase 2 -6)
Treatment 4	30% Wet Solubles (thin stillage)(WS).
Treatment 5:	30% Wet Distillers Grains (WDG)
Treatment 6:	30% Wet Distillers Grains with solubles (WDGS) (25.5% WDG + 4.5% WS)

The Big Dutchman liquid feeding system installed at the wean to finish facility at the University of Minnesota-Swine Research Unit at Waseca, Minn., was used for the study. The system was capable of preparing feed for individual troughs and delivering liquid feed to individual troughs using high-pressure air. Eight pens were allocated to each of the six dietary treatments. Pigs were housed in groups of 10 per pen. Pigs of either sex will be randomly allocated to the study at weaning and will be maintained up to market weight. All pigs will be weighed individually at weaning and at different phases during the wean-finish period. Twenty-eight days after weaning, two pigs per pen were sacrificed for intestinal health evaluation. The remaining pigs (8 pigs per pen) maintained maintained up to market weight. Data on production parameters (ADG, ADFI, G:F ratio) and water consumption were recorded. Carcass characteristics (carcass weight, carcass yield, fat depth, loin depth, percentage of lean, grade index, and carcass values) of pigs were recorded. The welfare of pigs in different feeding treatments was assessed in terms of intestinal health and behavior, injury levels, stress hormone levels, morbidity and mortality.

Dietary Treatments

The ethanol coproducts (DDGS, WDG, CDS) used in this study was Guardian Energy, Janesville, Minn. The composition of the ethanol coproducts is presented in Table 1. The diet composition and analyses are presented in Table 1 to 7. All dietary treatments were formulated on true ileal digestible lysine and iso-nitrogenous basis and formulated to meet or exceed NRC (1998) nutrient requirements for wean to finish pigs (7 kg to 120 kg live BW). Same sources of corn, soybean meal, and DDGS, WDG and CDS were used during the duration of the study.

Table 1: Nutrient Composition of Ethanol Co-products				
	DDS[1]	WDG[2]	DDGS[3]	CDS[4]
DM, %	92.8	36.9	90.0	37
GE, kcal/kg	4015	1823	4406	807
CP, %	18.6	10.8	24.7	7.1
Lysine, %	0.84	0.41	0.91	0.36
Threonine, %	0.74	0.44	0.98	0.28
Cysteine, %	0.35	0.24	0.46	0.14
Valine, %	0.92	0.63	1.24	0.39
Methionine, %	0.28	0.25	0.48	0.13
Isoleucine, %	0.61	0.49	0.95	0.28
Leucine, %	1.33	1.54	2.89	0.63
Tyrosine, %	0.57	0.47	0.97	0.23
Phenylalanine	0.58	0.61	1.11	0.26
Histidine	0.51	0.31	0.66	0.24
Tryptophan	0.17	0.10	0.20	0.08

[1] DDS = Spray-Dried Corn Distillers Solubles

[2] WDG = Wet Distillers Grain

[3] DDGS = Distillers Grain with Solubles

[4] CDS = Corn Distillers Solubles

Statistical Analysis:

Data were analyzed in completely randomized design by using the analytical software Statistix® 8 (Analytical Software, Tallahassee, FL). The model was $Y_{ij} = \mu + a_i + g_j + e_{ij}$; where Y_{ij} is the dependent variable, μ is the overall mean; a_i is the effect of the diet,

i=1,2,3,4,5,6; g_j is the effect of the block, j=1, 2…..8; e_{ij} represents random error. The multiple comparisons were used for the effects of dietary treatments by Tukey-Kramer adjustment when there was a significant difference ($P < 0.05$) in the model. A time lapse video recording system (Nuvico AI1600) was used to record the behavior of the pigs over a 24 hour period. Before recording, the focal pigs were marked with paint to distinguish them from the other pigs in the pens. The recordings were analyzed to determine the frequency of active and postural behaviors performed by the focal pigs as shown in the ethogram below. The behaviors were recorded by hand and data entered into an excel spreadsheet for analysis.

BEHAVIOR:

This study involved 23 randomly selected wean-finish pigs (five groups of 4, and one group of 3) housed in groups of 10 pigs per pen. Six dietary treatments were in place and were as follows:

The Big Dutchman liquid feeding system was used for the behavior study. Ten pigs were allocated to each of the dietary treatments for a total of 10 pigs per pen. Four pigs from each dietary treatment were randomly selected as focal pigs for behavioral observation (except for Treatment 5 where only 3 pigs were observed).

For 4 - 6, the pigs were fed equal meals using the liquid feeding system eight times daily. For the conventional dry feeding system (treatments 1 -3), pigs were fed ad libitum from single space feeders. Water was available for all pigs ad libitum from nipple drinkers.

Table 2: Behavioral ethogram

Postural behaviors	
Lying laterally	Recumbent on one side with all four legs straight, not supported by legs
Lying sternally	Lying on sternum with at least one leg tucked under the body
Total lying	Both lateral and sternal lying behaviors combined
Standing	Pig upright on all four feet
Sitting	Rear on the ground and body supported by one or two front legs
Kneeling	Standing on two hind legs, with one or two front legs tucked under the body
Rearing	Pig upright on all four feet, with the two front feet propped against the pen.

Table 3: Active behaviors

Feeding	Head within feeder
Drinking	Head within water bowl
Walking	Moving from one area to another at a moderate pace
Running	Moving from one area to another at a swift pace
Idle	Still, no behaviors performed
Rooting/nosing other pig	Nosing, sniffing, rooting, or any nose-to-body contact of any part of the body of another pig
Rooting/nosing pen	Nosing, sniffing or rooting any inanimate object in the pen (except when feeding or drinking)
Head butt	Rapid upward or sideways thrust of the head or snout against the neck, head or ears of another pig
Mount	Pig upright on all four feet, with the two front feet propped upon another pig
Queuing	Standing near and facing a feeder that is being used, sometimes involves pushing near the feeder
Other act	Any act not defined above

V. Results :

PERFORMANCE:

Body weight: Type of feed, liquid or dry, did not influence (P=0.55) the final body weight of the pigs (Table 4)

Average Daily Gain: Type of feed, liquid or dry did not influence (P=0.62) the average daily gain of the pigs (Table 4).

Average Daily Feed Intake: Pigs fed DDGS tended to consume more feed than pigs fed the dry corn (CORN) and spray-dried corn distillers solubles (DDS) (P=0.06). There were no effects of the other dietary treatments on feed intake (Table 4).

Gain to Feed Ratio: From DO to D14 of the study, pigs fed wet distillers grain with solubles (WDGS) were more efficient (P<0.01) than pigs fed CORN, DDGS and CDS. Gain to feed was not influenced by dietary treatment during the final stages (d 98 – D112) of the study.(Table 5).

Average Dry Matter Intake: Dry matter intake was higher (P<0.01) for pigs fed the dry feed than pigs fed the liquid feed throughout the study. (Table 5).

Gain to Dry Matter Intake: Pigs on liquid feed were more efficient (P=0.04) than pigs on dry feed from the D0 to D 98. However, the overall efficiency was not influenced (P<0.07) by dietary treatment. (Table 5) .

Water Intake: Average daily water intake was higher (P<0.01) for the liquid fed pigs throughout the study (Table 6).

Table 4. Body weight, average daily gain and feed intake of pigs fed dry and liquid diets based on distillers co-products from wean to finish

* Due to feed outages, the liquid fed pens in reps 3 to 8 were held 2wk longer (D126) so as to allow for final comparisons based on slaughter weight.

	CDS		WDG		WDGS		Corn		DDGS		DDS		*P* - values	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Diet	Rep
Body weight, kg														
D0	12.7^{BC}	0.2	12.0^{C}	0.2	12.3^{C}	0.2	14.0^{A}	0.2	14.2^{A}	0.2	13.3^{AB}	0.2	<.0001	<.0001
D14	21.9^{BCD}	0.4	21.2^{D}	0.3	21.6^{CD}	0.3	23.2^{AB}	0.3	23.6^{A}	0.3	22.8^{ABC}	0.3	<.0001	<.0001
D42	41.1^{C}	0.7	41.7^{BC}	0.7	41.4^{C}	0.7	44.4^{AB}	0.7	44.8^{A}	0.7	43.1^{ABC}	0.7	0.0011	<.0001
D70	64.2^{C}	1.3	64.3^{C}	1.2	66.9^{BC}	1.2	71.8^{A}	1.2	71.7^{AB}	1.2	69.5^{AB}	1.2	<.0001	0.0004
D98	93.8^{BC}	1.8	92.4^{C}	1.8	93.8^{BC}	1.8	101.5^{A}	1.5	100.5^{AB}	1.5	97.2^{ABC}	1.5	0.0014	<.0001
D112	112.0^{AB}	2.3	108.6^{B}	2.3	114.7^{AB}	2.3	116.9^{AB}	1.9	117.9^{A}	1.9	115.4^{AB}	1.9	0.0589	<.0001
Final*	120.1	2.8	115.0	2.8	120.8	2.8	116.9	2.3	117.9	2.3	115.4	2.3	0.5517	0.0271
Average daily gain, kg/d														
D0-14	0.664	0.017	0.655	0.015	0.666	0.015	0.662	0.015	0.674	0.015	0.679	0.015	0.8952	0.0002
D14-42	0.683	0.019	0.732	0.017	0.708	0.017	0.758	0.017	0.759	0.017	0.724	0.017	0.0427	0.0813
D42-70	0.825^{BC}	0.029	0.809^{C}	0.027	0.909^{ABC}	0.027	0.978^{A}	0.027	0.962^{A}	0.027	0.944^{AB}	0.027	0.0002	0.2077
D70-98	1.029	0.033	0.987	0.033	0.938	0.033	1.061	0.028	1.027	0.028	0.989	0.028	0.1184	0.0002
D98-112	1.299	0.141	1.156	0.141	1.494	0.141	1.098	0.117	1.240	0.117	1.297	0.117	0.375	0.2054
D98-Final*	1.168	0.132	1.037	0.132	1.257	0.132	1.098	0.110	1.240	0.110	1.297	0.110	0.6214	0.0626
Average daily feed intake, kg/d (as fed)														
D0-14	0.953^{AB}	0.026	0.923^{B}	0.024	0.928^{B}	0.024	1.037^{A}	0.024	1.056^{A}	0.024	1.055^{A}	0.024	0.0001	0.0001
D14-42	1.402^{B}	0.041	1.579^{A}	0.038	1.543^{AB}	0.038	1.576^{A}	0.038	1.677^{A}	0.038	1.582^{A}	0.038	0.0013	0.0199
D42-70	2.030^{B}	0.087	2.229^{AB}	0.080	2.283^{AB}	0.080	2.417^{A}	0.080	2.478^{A}	0.080	2.358^{AB}	0.080	0.0102	0.0079
D70-98	2.725^{B}	0.076	2.789^{B}	0.076	2.783^{B}	0.076	2.992^{AB}	0.063	3.171^{A}	0.063	2.943^{AB}	0.063	0.001	0.0006
D98-112	3.181^{AB}	0.083	3.079^{AB}	0.083	3.258^{AB}	0.091	3.067^{B}	0.069	3.380^{A}	0.069	3.093^{AB}	0.069	0.0266	0.0032
D98-Final*	3.206^{AB}	0.073	3.214^{AB}	0.073	3.294^{AB}	0.081	3.067^{B}	0.061	3.380^{A}	0.061	3.093^{B}	0.061	0.0124	0.0044

Table 5. Feed efficiency and average daily DM intake of pigs fed dry and liquid diets based on distillers co-products from wean to finish

	CDS		WDG		WDGS		Corn		DDGS		DDS		*P* - values	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Diet	Rep
Gain to feed ratio (as fed)														
D0-14	0.6984^{ABC}	0.0183	0.7132^{AB}	0.0169	0.7204^{A}	0.0169	0.6399^{C}	0.0169	0.6378^{C}	0.0169	0.6449^{BC}	0.0169	0.0011	0.6926
D14-42	0.4869	0.0091	0.4650	0.0084	0.4607	0.0084	0.4814	0.0084	0.4532	0.0084	0.4577	0.0084	0.0529	0.1215
D42-70	0.4095	0.0105	0.3682	0.0097	0.3999	0.0097	0.4056	0.0097	0.3881	0.0097	0.4007	0.0097	0.0588	0.0832
D70-98	0.3795^{A}	0.0114	0.3523^{AB}	0.0114	0.3368^{AB}	0.0114	0.3549^{AB}	0.0095	0.3244^{B}	0.0095	0.3361^{AB}	0.0095	0.0149	0.5571
D98-112	0.4083	0.0706	0.3742	0.0706	0.5769	0.0706	0.3589	0.0588	0.3618	0.0588	0.4213	0.0588	0.2177	0.5466
D98-Final*	0.3642	0.0720	0.3182	0.0720	0.4949	0.0720	0.3589	0.0599	0.3618	0.0599	0.4213	0.0599	0.5272	0.4021
Average daily dry matter intake, kg/d														
D0-14	0.765^{B}	0.021	0.693^{B}	0.020	0.697^{B}	0.020	0.937^{A}	0.020	0.957^{A}	0.020	0.965^{A}	0.020	<.0001	0.0001
D14-42	1.116^{B}	0.033	1.167^{B}	0.030	1.142^{B}	0.030	1.413^{A}	0.030	1.506^{A}	0.030	1.439^{A}	0.030	<.0001	0.0147
D42-70	1.614^{B}	0.069	1.643^{B}	0.064	1.685^{B}	0.064	2.164^{A}	0.064	2.221^{A}	0.064	2.139^{A}	0.064	<.0001	0.0086
D70-98	2.168^{B}	0.064	2.063^{B}	0.064	2.061^{B}	0.064	2.677^{A}	0.054	2.840^{A}	0.054	2.668^{A}	0.054	<.0001	0.0005
D98-112	2.530^{BC}	0.114	2.276^{C}	0.114	2.180^{C}	0.114	2.744^{AB}	0.095	3.027^{A}	0.095	2.804^{AB}	0.095	<.0001	0.3751
D98-Final*	2.550^{BC}	0.112	2.376^{BC}	0.112	2.206^{C}	0.112	2.744^{AB}	0.093	3.027^{A}	0.093	2.804^{AB}	0.093	<.0001	0.484
Gain to dry matter intake ratio														
D0-14	0.8702^{A}	0.0221	0.9499^{A}	0.0205	0.9595^{A}	0.0205	0.7076^{B}	0.0205	0.7043^{B}	0.0205	0.7046^{B}	0.0205	<.0001	0.5867
D14-42	0.6117^{A}	0.0115	0.6292^{A}	0.0106	0.6226^{A}	0.0106	0.5365^{B}	0.0106	0.5046^{B}	0.0106	0.5034^{B}	0.0106	<.0001	0.1403
D42-70	0.5160^{A}	0.0135	0.4996^{AB}	0.0125	0.5418^{A}	0.0125	0.4530^{BC}	0.0125	0.4330^{C}	0.0125	0.4417^{C}	0.0125	<.0001	0.0612
D70-98	0.4785^{A}	0.0140	0.4787^{A}	0.0140	0.4571^{A}	0.0140	0.3968^{B}	0.0116	0.3621^{B}	0.0116	0.3707^{B}	0.0116	<.0001	0.4493
D98-112	0.5138^{AB}	0.0914	0.5067^{AB}	0.0914	0.7809^{A}	0.0914	0.4012^{B}	0.0760	0.4040^{B}	0.0760	0.4647^{AB}	0.0760	0.0477	0.5694
D98-Final*	0.4581	0.0935	0.4307	0.0935	0.6697	0.0935	0.4012	0.0778	0.4040	0.0778	0.4647	0.0778	0.3004	0.4171

* Due to feed outages, the liquid fed pens in reps 3 to 8 were held 2wk longer (D126) so as to allow for final comparisons based on slaughter weight.

Table 6. Average daily water intake of pigs fed dry and liquid diets based on distillers co-products from wean to finish

	CDS		WDG		WDGS		Corn		DDGS		DDS		*P* - values	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Diet	Rep
Average daily water intake, L/d														
D0-14	3.254[A]	0.311	3.324[A]	0.287	3.129[A]	0.287	2.827[A]	0.287	2.534[A]	0.287	2.921[A]	0.287	0.4091	0.1541
D14-42	5.160[A]	0.474	5.518[A]	0.438	5.001[A]	0.438	4.803[A]	0.438	4.836[A]	0.438	4.711[A]	0.438	0.8038	0.6809
D42-70	7.034[A]	0.408	7.124[A]	0.377	6.963[A]	0.377	4.774[B]	0.377	4.882[B]	0.377	4.239[B]	0.377	<.0001	0.5115
D70-98	7.969[A]	0.359	7.926[A]	0.359	7.981[A]	0.359	3.922[B]	0.299	4.279[B]	0.299	3.771[B]	0.299	<.0001	0.4085
D98-112	8.881[A]	0.457	8.381[A]	0.457	7.943[A]	0.457	3.835[B]	0.380	4.274[B]	0.380	4.061[B]	0.380	<.0001	0.5419
D98-Final*	8.843[A]	0.437	8.742[A]	0.437	7.990[A]	0.437	3.835[B]	0.363	4.274[B]	0.363	4.061[B]	0.363	<.0001	0.422

* Due to feed outages, the liquid fed pens in reps 3 through 8 were held for an extra 2 weeks (D126) so as to allow for final comparisons based on slaughter weight.

BEHAVIOR:

There was no difference in the postural behaviors of the pigs receiving dry feed or liquid feed. However there was a slight trend for those receiving liquid feed to kneel slightly more than those receiving dry feed. This tended to occur around the feeder between feeding bouts. In terms of the active behaviors, those pigs that were liquid fed walked significantly more than the dry fed pigs. In addition, the liquid fed pigs rooted/nosed around the pen significantly more than the dry fed pigs. It was noted that more rooting behavior occurred around the liquid feeder between feeding bouts when no feed was present in the feeder. There was also a trend (though not significant) showing that the dry fed pigs spent more time feeding than those pigs that were liquid fed (Tables 7, 8 and 9).

Table 7: Proportion of time spent performing postural behaviors across feeding groups.

Feed Type	**Liquid**	**Dry**		
	Mean	**Mean**	**SEM**	***P*-value**
Lying laterally	49.28	53.59	2.01	0.15
Lying sternally	32.38	27.34	2.37	0.16
Total lying behavior	81.66	80.93	2.53	0.84
Standing	21.38	15.99	3.23	0.28
Sitting	0.75	1.14	0.17	0.15
Kneeling	0.43	0.09	0.11	0.08
Rearing	0.05	0.15	0.04	0.12

Table 8: Proportion of time performing active behaviors across feeding groups.

Feed Type	**Liquid**	**Dry**		
	Mean	**Mean**	**SEM**	***P*-value**
Feeding	3.28	6.15	1.01	0.06
Drinking	0.60	0.95	0.21	0.29
Walking	1.79	1.09	0.20	<0.05
Running	0.10	0.11	0.04	0.93
Idle	77.43	80.06	2.43	0.46
Rooting/nosing other pig	6.95	4.71	1.62	0.35
Rooting/nosing pen	7.43	4.48	0.90	<0.05
Head butt	0.22	0.14	0.03	0.10
Mount	0.01	0.01	0.00	0.45
Queuing	0.18	0.47	0.12	0.20
Other act	0.25	0.24	0.06	0.90

There was no difference in the postural behaviors of the pigs across the six feeding treatments. In addition, there were no differences in the active behaviors of the pigs across the six feeding treatments.

Table 9: Proportion of time spent performing postural behaviors across feeding treatments.

	Corn	DDGS	DDS	WS	WDG	WDGS	SEM	$P_{(value)}$
Lying laterally	55.69	55.44	52.65	48.41	52.74	47.54	3.43	0.64
Lying sternally	26.14	27.41	28.47	31.25	31.32	34.30	8.06	0.81
Total lying behavior	81.83	79.85	81.12	79.66	84.06	81.84	8.73	0.99
Standing	14.47	16.71	16.79	17.35	13.90	31.02	11.67	0.34
Sitting	1026	1.42	0.73	0.80	0.69	0.74	0.36	0.47
Kneeling	0.16	0.03	0.07	0.57	0.57	0.18	0.06	0.43
Rearing	0.09	0.14	0.23	0.11	0.00	0.03	0.02	0.46

Table 10: Proportion of time performing active behaviors across feeding treatments.

	Corn	DDGS	DDS	WS	WDG	WDGS	SEM	$P_{(value)}$
Feeding	4.94	6.63	6.88	3.10	2.73	3.88	2.80	0.54
Drinking	0.53	1.41	0.91	0.86	0.41	0.50	0.14	0.51
Walking	1.07	1.18	1.00	1.92	1.36	1.99	0.59	0.25
Running	0.11	0.15	0.07	0.18	0.03	0.08	0.05	0.78
Idle	83.26	79.27	80.63	76.47	81.01	75.69	3.88	0.78
Rooting/nosing other pig	4.31	3.18	6.65	6.61	10.81	4.39	1.24	0.60
Rooting/nosing pen	3.84	4.95	4.67	6.92	5.74	9.22	1.50	0.31
Head butt	0.18	0.12	0.12	0.19	0.29	0.20	0.02	0.46
Mount	0.02	0.00	0.02	0.01	0.00	0.00	0.00	0.61
Queuing	0.03	0.96	0.42	0.21	0.10	0.22	0.08	0.12
Other act	0.23	0.20	0.28	0.18	0.23	0.33	0.12	0.92

The six dietary treatments did not affect wean-to-finish pigs' postural or active behaviors. There was also relatively little difference in the behaviors shown across the liquid and dry fed groups. However liquid fed pigs did exhibit more walking and rooting/nosing behavior (particularly near the feeder). These results are likely to be a result of the liquid feed only being available at certain periods throughout the day, whereas dry feed was available ad libitum. It was seen that the pigs were more likely to kneel and root around the empty feeder and clean up any food that may have spilled. These findings show that pigs fed liquid diets produce comparable behavior to that of pigs that were dry fed.

INTESTINAL MORPHOLOGY:

Spray-dried corn distillers soluble (DDS) and wet distillers grain (WDG) improved ($P<0.01$) intestinal villi heights compared to pigs fed distillers dried grains with solubles. Pigs fed the control diet (Corn), wet distillers grain with solubles (WDGS) and corn distillers solubles (CDS) had no effect on villi heights. Crypt depth was not influenced by dietary treatments (Table 11).

Table 11: Impact of feeding ethanol co-products on morphological characteristics of the gastro-intestinal tract of growing pigs

Criteria	Corn	DDGS	DDS	CDS	WDG	WDGS	SEM	$P_{(value)}$
Villi heights (µm)								
25[1]	533ab	480.5b	629a	617ab	633a	590ab	44	0.01
50[2]	507	418	542	553	525	579	42	0.18
75[3]	459	493	465	528	508	519	35	0.79
Crypt depth (µm)								
25[1]	224	239	212	228	230	229	11	0.96
50[2]	204	221	216	236	243	228	11	0.21
75[3]	202	214	202	214	215	221	12	0.81

[1] 25 cm from the duodenum-jejunal junction

[2] 50 cm from the duodenum-jejunal junction

[3] 75 cm from the duodenum-jejunal junction

Dissemination of Project Results:

1. Presented at the January 2013 Minnesota Ag EXPO.

2. Presented at the February 2013 Ontario Liquid Feeding Symposium.

3. Preparation of a manuscript and abstracts in progress for submission to American Journal of Animal Science.

4. Preparation of an article for the *National Hog Farmer*.

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APPENDIX 1.

Phase: 1	Pre-Trial Diet
Ingredients, %	
Corn, %	44.04
SDPP	5.00
Whey Powder	15.00
SBM, 47.5 %	24.00
Oil	2.00
FISH Meal	6.00
Limestone	1.00
DCP	1.20
Lysine HCL	0.27
DL-Met	0.16
L-Threonine	0.18
L-Tryptophan	0.00
Salt	0.40
Vit-mix	0.50
Zinc Oxide	0.25
Mecadox	0.25
Total	100.00

APPENDIX 2: Proximate Analysis: Phase 1

ME	3433
ADF	2.43
NDF	6.12
Ca, %	1.20
P, %	0.88
dP, %	0.59
CP	24.54
lys, %	1.82
met, %	0.56
SAA	1.00
Thr, %	1.19
Trp, %	0.38
dLys	1.65
dMet	0.53
dSAA	0.91
dPhe	1.05
dThr	1.12
dTrp	0.24

APPENDIX 3: Phase 2 Diet:	Corn	DDGS	DDS	CDS	WDG	WDGS
Ingredients, %						
Corn	59.40	39.71	32.44	27.39	12.33	13.34
cDDGS	0	30	0	0	0	0
Spray-dried CDS	0	0	30	0	0	0
Liquid CDS	0	0	0	20	0	4.5
Wet Distillers Grains	0	0	0	0	30	25.5
SDPP	1.5	1.5	1.5	1.5	1.5	1.5
Whey Powder	8	8	8	8	8	8
SBM, (47.5% CP)	22.8	13.5	20	26	31	30
Soybean Oil	2	1	2	11	11	11
Fishmeal	3	3	3	3	3	3
Limestone	0.66	1.04	1.01	0.82	0.55	0.63
Dicalcium phosphate	0.6	0.06	0	0.3	0.73	0.6
Lysine HCL	**0.34**	**0.5**	**0.31**	**0.26**	**0.18**	**0.2**
DL-Methionine	**0.15**	**0.11**	**0.18**	**0.18**	**0.19**	**0.2**
L-Threonine	**0.14**	**0.14**	**0.15**	**0.15**	**0.12**	**0.13**
L-Tryptophan	**0.01**	**0.04**	**0.01**	**0**	**0**	**0**
Salt	0.4	0.4	0.4	0.4	0.4	0.4
Nursery Vit-TM mix	0.5	0.5	0.5	0.5	0.5	0.5
Zinc Oxide	0.25	0.25	0.25	0.25	0.25	0.25
Mecadox	0.25	0.25	0.25	0.25	0.25	0.25
Total	**100**	**100**	**100**	**100**	**100**	**100**

Proximate Analysis : Phase 2	Corn	DDGS	DDS	CDS	WDG	WDGS
DM	90.46	90.56	91.55	81.07	75.89	75.89
DE	1629	1640	1623	1590	1582	1564
ME	1552	1572	1549	1508	1496	1479
NE	1130	777	780	1082	945	949
CP	19.61	21.12	21.58	19.83	22.68	22.16
ADF	2.89	1.83	1.98	2.16	2.01	1.99
NDF	7.71	4.99	4.87	4.92	3.92	3.93
C Fiber	2.17	1.40	1.45	1.54	1.36	1.35
C Fat	5.32	3.27	4.18	13.17	12.73	12.74
Total Amino Acids						
Lys	1.37	1.44	1.45	1.39	1.49	1.48
Thr	0.89	0.96	1.00	0.93	1.02	1.01
Met	0.47	0.48	0.52	0.49	0.56	0.56
Cys	0.34	0.37	0.37	0.33	0.38	0.37
Trp	0.24	0.25	0.25	0.24	0.28	0.27
SID Amino Acids						
SID Lys	1.25	1.25	1.26	1.26	1.25	1.25
SID Thr	0.79	0.78	0.79	0.80	0.79	0.79
SID Met	0.44	0.43	0.45	0.45	0.46	0.47
SID Cys	0.29	0.30	0.29	0.28	0.27	0.27
SID Trp	0.21	0.22	0.21	0.21	0.23	0.22
Macro Minerals						
Ca	0.70	0.70	0.70	0.70	0.70	0.70
tP	0.60	0.61	0.82	0.59	0.61	0.60
dP	0.32	0.32	0.58	0.36	0.32	0.32