NUTRITIONAL AND VALUE ADDED BENEFITS OF FEEDING MAIZE DDGS AND OTHER DRY- MILL CO- PRODUCTS TO SWINE

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ABSTRACT

A significant amount of research has been conducted during the past 6 years demonstrating that maize (corn) DDGS, originating from new dry-mill fuel ethanol plants in the U.S., is a high quality source of energy, digestible amino acids, and available phosphorus when added to practical swine diets. Corn DDGS appears to have 110% the energy value of wheat DDGS due to the higher fat content (11.46 vs. 3.75%) and lower ash content (7.78 vs. 9.11%), when expressed on a dry matter basis. Furthermore, corn DDGS is higher in lysine content (0.94% vs. 0.69%), but lower in tryptophan (0.26% vs. 0.43%) and phosphorus content (0.77% vs. 1.15%) compared to wheat DDGS on a dry matter basis. Although corn DDGS is routinely added at a rate of 10% to commercial swine diets in the U.S., research studies have demonstrated that higher dietary inclusion rates can provide satisfactory performance when diets are formulated on a digestible amino acid basis. In addition to the nutrients provided by corn DDGS, it also appears to have unique, value-added properties. Results from recent studies have demonstrated that corn DDGS is effective in reducing the prevalence, severity, and length of lesions caused by a moderate *Lawsonia intracellularis* (ileitis) disease challenge. However, it is unclear whether corn DDGS is effective in reducing fecal shedding of *Salmonella* in market swine, due to the low level of infection that occurred in a recent disease challenge experiment. In sows, feeding diets containing high levels of corn DDGS during gestation and/or lactation increased litter size weaned during the subsequent reproductive cycle, of a two reproductive cycle study, compared to sows fed corn-soybean meal based diets. The high available phosphorus content of corn DDGS is a valuable addition, along with phytase, to practical swine diets. Adding these ingredients will reduce the amount of supplemental inorganic phosphorus in the diet and reduce manure phosphorus content. New corn distiller's solubles co-products have been developed, that when added (7.5 to 15%) to diets for weaned pigs, appear to support growth performance equal to, or superior to, diets containing growth promoting levels of carbadox. The diet containing 15% spray dried distiller's residual fraction increased villi height and villi height:crypt depth ratio in the upper 25% of the small intestine compared to these intestinal characteristics when a growth promoting level of carbadox was added to the diet. This suggests improved digestive and/or absorptive capacity of the small intestine compared to carbadox, when included in the diet as a growth promotant.

Introduction

Maize (corn) distiller's dried grains with solubles (DDGS) is a by-product of the dry-milling process used in ethanol production. Each bushel of corn (25.4 kg) fermented in a dry-mill ethanol plant will produce approximately 9.1 liters of ethanol, 8.2 kg of carbon dioxide, and 8.2 kg of DDGS. Yellow dent corn is most commonly used to produce ethanol and DDGS because it is an excellent source of readily fermentable starch. Corn contains approximately 62% starch, 3.8% corn oil, 8.0% protein, 11.2% fiber, and 15% moisture. Because most of the starch is converted to ethanol during fermentation, the resulting nutrient fractions (protein, oil, fiber) are 2 to 3 times more concentrated in DDGS compared to corn. A few ethanol plants use sorghum, barley, and wheat to make ethanol, and as a result, the nutritional composition of the DDGS produced from these grain sources is different compared to corn DDGS.

It is very important to understand the differences in corn by-products produced by the ethanol industry. Currently, approximately 40% of U.S. fuel ethanol is produced in dry-mills, whereas the other 60% of ethanol production is from wet-mills. Because the ethanol production processes are different between dry-mills and wet-mills, the resulting corn co-products are also nutritionally different. Dry-mills produce DDGS, but wet-mills produce corn gluten feed, corn gluten meal, and corn germ meal. According to Long (1985), wet milling of yellow dent corn involves its separation into the four major products (on a dry matter basis): corn starch (67.2 %), corn gluten feed (19.6 %), corn gluten meal (60% protein, 5.7 %), and corn germ (50% corn oil, 7.5 %). Corn gluten feed and corn gluten meal have different feeding value for swine compared to DDGS.

The beverage alcohol industry also produces DDGS (< 1 % of total U.S. DDGS production). However, DDGS from these plants is not well suited for swine feeds because it tends to be more variable in nutrient content (due to the type and source of grain used) and usually has lower levels of digestible nutrients compared to DDGS produced by "new generation" fuel ethanol plants. Furthermore, DDGS should not be confused with brewer's dried grain which is a by-product of the beer manufacturing industry, and consists of the dried residue of barley malt and other grains that have been used to provide maltose and dextrins for fermentation. Use of brewer's dried grains in monogastric diets is limited due to the relatively high fiber level (18 to 19%). A comparison of the nutrient composition of these grain co-products is shown in Table 1. The distinguishing features of corn DDGS from other grain by-products derived from various types of ethanol production processes is the relatively high fat and available phosphorus levels.

Table 1. Nutrient composition comparison (as fed basis) between "new generation" DDGS, corn gluten feed, corn gluten meal, and brewer's dried grains (NRC, 1998).

Nutrient	New Generation DDGS	Corn Gluten Feed	Corn Gluten Meal	Brewer's Dried Grains
Dry matter, %	89.0	90.0	90.0	92.0
Crude protein, %	27.2	21.5	60.2	26.5
Crude fat, %	9.5	3.0	2.9	7.3
ADF, %	14.0	10.7	4.6	21.9
NDF, %	38.8	33.3	8.7	48.7
DE, kcal/kg	3529	2990	4225	2100
ME, kcal/kg	3197	2605	3830	1960
Lysine, %	0.74	0.63	1.02	1.08
Methionine, %	0.49	0.35	1.43	0.45
Cystine, %	0.52	0.46	1.09	0.49
Threonine, %	1.01	0.74	2.08	0.95
Tryptophan, %	0.21	0.07	0.31	0.26
Calcium, %	0.05	0.22	0.05	0.32
Phosphorus, %	0.79	0.83	0.44	0.56
Available phosphorus, %	0.71	0.49	0.07	0.19

The U.S. ethanol industry is growing at a very rapid rate. Because of the lower capital investment needed, most of the growth is a result of construction of dry-mill ethanol plants in the upper Midwestern U.S. By the year 2005, industry experts have projected that 7 million metric tonnes of DDGS will be produced and available for livestock and poultry feeds, which is double the amount produced in the year 2000. In 2002, the U.S. exported approximately 30,000 metric tonnes of DDGS to Canada. Due to their relatively close proximity to Canada, two ethanol plants in North Dakota (Walhalla and Grafton) market a substantial amount of DDGS in the Western provinces of Canada. As more “new generation” DDGS is being produced in the U.S., more will be available for livestock and poultry feeds in Canada.

Compared the the U.S. ethanol industry, which produces 7 billion liters of ethanol per year, the Canadian ethanol industry is relatively small (200 million liters of ethanol per year), but is also expected to grow substantially during the next few years. It is uncertain if wheat or corn will be the primary grain used to produce ethanol in the new plants that will be constructed in Canada. Therefore, it is important to understand the nutritional differences between wheat and corn DDGS in swine diets.

Comparison of the Nutrient Content of U.S. Corn DDGS to Canadian DDGS Sources

Currently, there are four ethanol plants in Canada. The Gimli, MB plant produces whiskey and DDGS from corn and the Chatham, ON plant produces ethanol and corn DDGS. In contrast, the Minnedosa, MB plant produces a wheat DDGS and the Lanigan, SK plant produces a wet wheat distiller’s grains that is fed exclusively to cattle. Due to their relatively close proximity to Canada, two ethanol plants in North Dakota (Walhalla and Grafton) market a substantial amount of DDGS in the Western provinces of Canada. In 2002, the U.S. exported approximately 30,000 metric tonnes of DDGS to Canada. Table 2 shows a comparison of several nutrients in DDGS samples collected in 2003 from “new generation” corn ethanol plants in Minnesota, Iowa, and South Dakota to nutrient profiles from the Gimli, Minnedosa, and Chatham ethanol plants.

Note that the nutrient profiles are almost identical when comparing the average of 9 “new generation” corn DDGS sources produced in the U.S. with corn DDGS produced by the Chatham, ON ethanol plant. However, when comparing the corn DDGS from the “new generation” U.S. plants and the Chatham, Ontario plant to the wheat DDGS produced by the Minnedosa, MB plant, the corn DDGS is substantially higher in crude fat and lower in ash content resulting in substantially higher calculated DE, ME, and NE values (Table 2). Corn DDGS is also higher in lysine, but lower in tryptophan and phosphorus than wheat DDGS. The digestibility of amino acids and the available phosphorus content has not been determined in wheat DDGS. Because of the differences between wheat and corn DDGS in concentrations of these important nutrients, feeding a blend of these two DDGS sources may be complimentary in swine diets. Note that “new generation” U.S. corn DDGS is lighter in color (Figure 1) compared to wheat DDGS (Figure 2)

Corn DDGS produced by the Gimli, MB plant was highest in crude protein, lysine, methionine, crude fat, and lowest in ash content, resulting in the highest calculated energy values among all DDGS sources in this comparison. However, due to the darker color of the corn DDGS from the Gimli and Chatham plants (Figure 3 and 4) compared to the golden colored “new generation” U.S. DDGS (Figure 1), it would be expected that amino acid digestibility, particularly lysine, may be significantly lower than the U.S. “new generation” corn DDGS sources.

Unpublished results from Noll and Parsons (2003) involved determining true amino acid digestibility values for poultry from several “new generation” corn DDGS sources and conducting a regression analysis to determined the relationship between lysine, cystine, and threonine digestibility and DDGS Minolta color scores (Figures 5, 6, and 7, respectively). True lysine digestibility for poultry was highly related to L* scores (lightness score; 0 = black, 100 = white) and b* (measure of yellowness; + 60 yellow, - 60 blue), with R^2 values of 0.71 and 0.74, respectively (Figure 5). This means that lighter colored DDGS is higher in lysine digestibility than darker colored samples. Knowing that lysine is highly subjected to the Maillard reaction, which occurs when protein sources are overheated during drying, this relationship should be expected. Digestibility of cystine is also reasonably related to lightness and yellowness of the DDGS source with R^2 values of 0.66 and 0.67, respectively (Figure 6). However, threonine digestibility is not well related to lightness or yellowness of DDGS, with R^2 values of 037 and 0.40, respectively (Figure 7). However, no studies have been conducted to determine the relationship between color of wheat DDGS with amino acid digestibility.

Table 2. Nutrient composition comparison (dry matter basis) between the average of 9 "new generation" DDGS sources in the U.S. and corn and wheat DDGS produced by Canadian ethanol plants.

Nutrient	New Generation Corn DDGS	Gimli, MB Beverage Corn DDGS	Minnedosa, MB Wheat DDGS	Chatham, ON Corn DDGS
Dry matter, %	89.2	80.7	93.0	90.2
Crude protein, %	31.61	35.39	30.54	32.99
Crude fat, %	11.46	13.02	3.75	11.95
Crude fiber, %	6.15	7.78	4.38	5.31
ADF, %	11.15	12.02	11.08	13.05
Ash, %	7.78	6.63	9.11	8.63
DE, kcal/kg[1]	3970	4147	3604	3971
ME, kcal/kg[1]	3719	3851	3384	3708
NE, kcal/kg[2]	2104	2175	1886	2028
Lysine, %	0.94	0.99	0.69	0.91
Methionine, %	0.63	0.74	0.67	0.67
Cystine, %	0.69	0.68	0.91	0.71
Threonine, %	1.19	1.21	1.25	1.24
Tryptophan, %	0.26	0.22	0.43	0.25
Calcium, %	0.07	0.15	0.20	0.08
Phosphorus, %	0.77	0.99	1.15	0.84

[1] DE = 4151 – (122 x % Ash) + (23 x % CP) + (38 x % Fat) – (64 x % Crude Fiber) Noblet and Perez (1993)
ME = DE x [1.003 – (0.0021 x % CP)] Noblet and Perez (1993)
[2] NE = 328 + (0.599 x ME) – (15 x % Ash) – (30 x % ADF) Ewan (1989)

Figure 1. U.S. "New Generation" Corn DDGS

Figure 2. Wheat DDGS from Minnedosa, MB

Figure 3. Corn DDGS from Gimli, MB

Figure 4. Corn DDGS from Chatham, ON

Figure 5. Regression of true digestible lysine (%) and color (L*, b*)

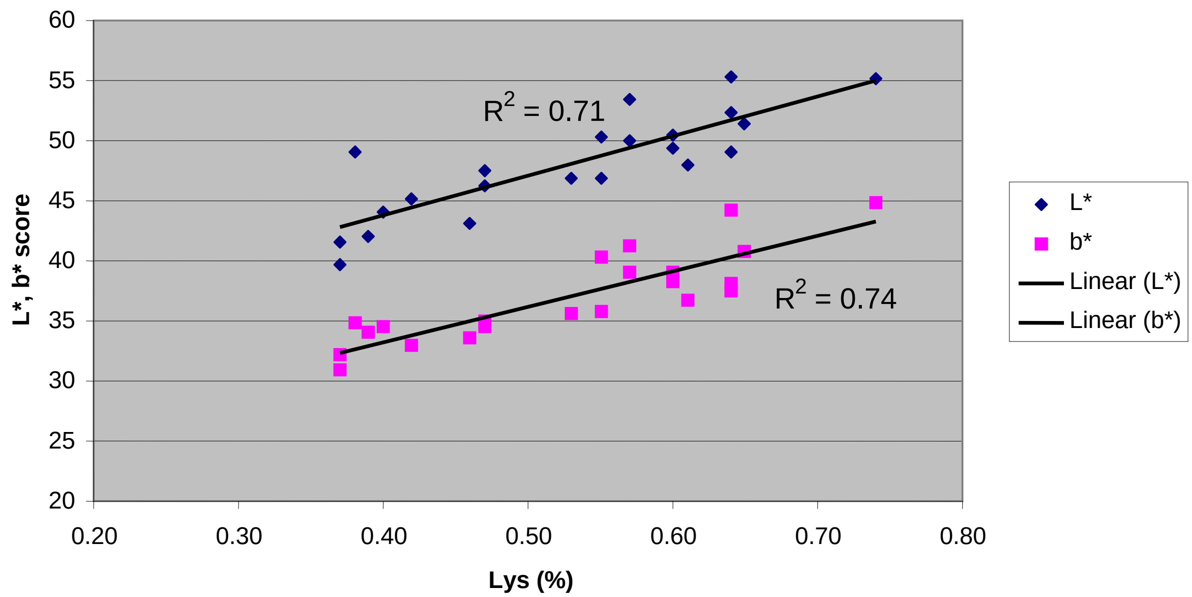


Figure 6. Regression of true digestible cystine (%) and color (L*, b*)

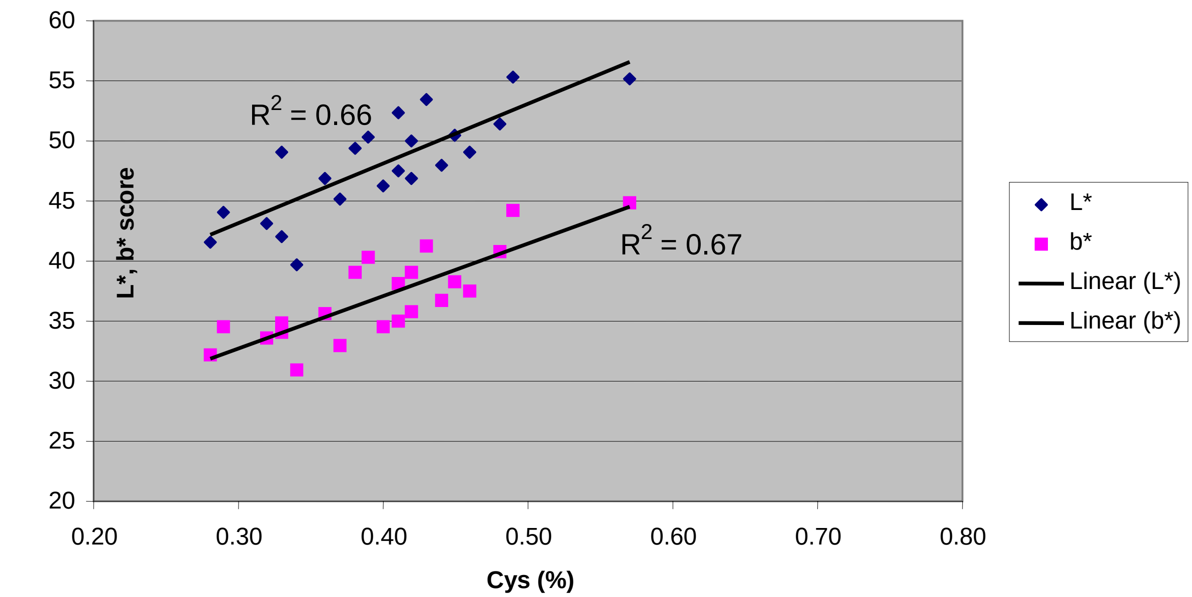
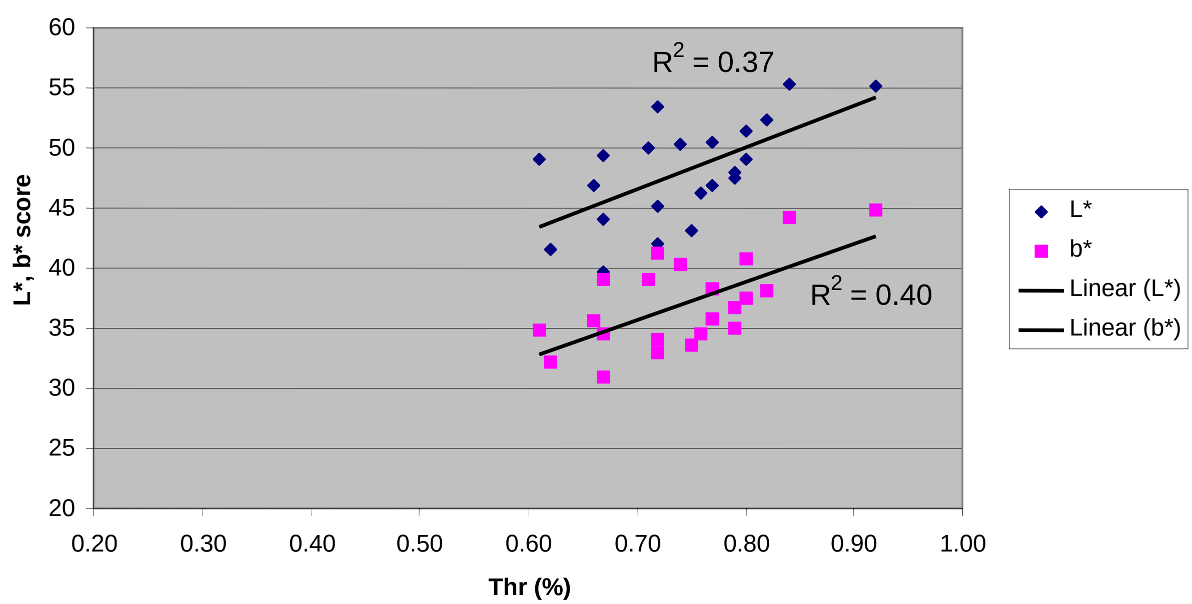


Figure 7. Regression of true digestible threonine (%) and color (L*, b*)



Comparison of the Economic Value of "New Generation" Corn DDGS to Wheat DDGS

It is probable that the amino acid digestibility of wheat DDGS from the Minnedosa, MB plant is lower than in the "new generation" U.S. corn DDGS sources. However, if we assume that wheat DDGS has the same amino acid digestibility coefficients as the values for corn DDGS (determined at the University of Minnesota), corn DDGS from the U.S sources would be worth $5.10 (US dollars) more per tonne than wheat DDGS in a growing pig diet when providing the same level of essential nutrients (Table 3).

Table 3. Breakeven cost of wheat vs "new generation" corn DDGS in growing pig diets.

Ingredient	New Generation Corn DDGS, kg/tonne	Ingredient Cost, $US/kg	Minnedosa, MB Wheat DDGS	Ingredient Cost, $US/kg
Corn	638.59	0.1103	658.28	0.1103
Soybean meal, 47%	204.56	0.3308	181.71	0.3308
Corn DDGS	**100.00**	**0.1506**	**0.00**	**---**
Wheat DDGS	**0.00**	**---**	**100.00**	**0.1455**
Animal fat	29.92	0.3749	32.76	0.3749
Dicalcium phosphate	9.19	0.2646	7.60	0.2646
Limestone	9.06	0.0441	9.72	0.0441
L-lysine HCl	3.07	4.410	4.05	4.410
Salt	3.00	0.1323	3.00	0.1323
VTM premix	2.00	2.5799	2.00	2.5799
L-threonine	0.39	3.3957	0.62	3.3957
DL-methionine	0.22	2.8224	0.28	2.8224
Total	1000.00	---	1000.00	---
Cost/tonne, US$		188.25		188.25

Calculated nutrient levels: 3457 kcal ME/kg, 0.92% app. dig. lys, 0.52% app. dig. met+cys, 0.53% app. dig. thr, 0.15% app. dig. trp, 0.53 % total P, and 0.29% avail. P

Quality of Corn DDGS is Important

Historically, distiller's dried grains with solubles (DDGS) have not been used extensively in swine diets. The primary reasons for its limited use have been variability in quality and nutrient content, poor amino acid balance and digestibility from some sources, availability of supply, and concern about its energy value. However, our research at the University of Minnesota has clearly shown that "new generation" DDGS produced by small, and relatively new, ethanol plants in the upper Midwestern U.S., is very high quality and is an excellent partial substitute for corn, soybean meal, and dicalcium phosphate in swine feeding programs. As shown in Table 4, DDGS from "new generation" ethanol plants is higher in digestible and metabolizable energy, higher in total and digestible amino acids, and higher in available phosphorus compared to other DDGS sources and the values listed in NRC (1998). Use of low quality, dark colored DDGS has reduced feeding value and pig performance may be reduced if the lower levels of digestible nutrients are not considered in diet formulation.

Table 4. Nutrient composition comparison (dry matter basis) between "new generation" DDGS, "old generation" DDGS, and values published in NRC (1998) from Spiehs et al., (2002).

Nutrient	New Generation Corn DDGS	Old Generation Corn DDGS	DDGS NRC (1998)
Dry matter, %	88.9 (1.7)	88.3 (0.9)	93.0
Crude protein, %	30.2 (6.4)	28.1 (2.4)	29.8
Crude fat, %	10.9 (7.8)	8.2 (12.6)	9.0
Crude fiber, %	8.8 (8.7)	7.1 (4.2)	4.8
NDF, %	16.2 (28.4)	16.7	17.5
ADF, %	42.1 (14.3)	35.4	37.2
Ash, %	5.8 (14.7)	6.3 (17.5)	-
DE, kcal/kg[1]	3965	3874	3449
ME, kcal/kg[1]	3828	3521	3038
Arginine, %	1.20 (9.1)	0.92 (18.7)	1.22
Histidine, %	0.76 (7.8)	0.61 (15.2)	0.74
Isoleucine, %	1.12 (8.7)	1.00 (9.1)	1.11
Leucine, %	3.55 (6.4)	2.97 (12.4)	2.76
Lysine, %	0.85 (17.3)	0.53 (26.5)	0.67
Methionine, %	0.55 (13.6)	0.50 (4.5)	0.54
Phenylalanine, %	1.47 (6.6)	1.27 (8.1)	1.44
Threonine, %	1.13 (6.4)	0.98 (7.3)	1.01
Tryptophan, %	0.25 (6.7)	0.19 (19.8)	0.27
Valine, %	1.50 (7.2)	1.39 (2.3)	1.40
App. dig. arg, %	0.90	0.60	0.88
App. dig. his, %	0.51	0.30	0.45
App. dig. ile, %	0.72	0.42	0.73
App. dig. leu, %	2.57	1.84	2.10
App. dig. lys, %	0.44	0.00	0.31
App. dig. met, %	0.32	0.24	0.39
App. dig. phe, %	0.89	0.68	1.09
App. dig. thr, %	0.62	0.36	0.56
App. dig. trp, %	0.15	0.15	0.14
App. dig. val, %	0.92	0.51	0.88
Calcium, %	0.06 (57.2)	0.44 (34.7)	0.22
Phosphorus, %	0.89 (11.7)	0.90 (7.5)	0.83
Avail. Phosphorus, %	0.80	--	0.64

Values in parentheses are coefficients of variation among ethanol plants.

[1] DE = 4151 – (122 x % Ash) + (23 x % CP) + (38 x % Fat) – (64 x % Crude Fiber) Noblet and Perez (1993)

ME = DE x [1.003 – (0.0021 x % CP)] Noblet and Perez (1993)

Maximum Recommended Inclusion Rates of DDGS in Swine Diets

Based upon research studies we have conducted at the University of Minnesota, our current recommendations for maximum usage rate of DDGS in swine diets are as follows:

Production Phase	**Maximum % of Diet**
Nursery pigs (> 7 kg)	25
Grow-finish pigs	20
Developing gilts	20
Gestating sows	50
Lactating sows	20
Boars	50

These recommendations assume that high quality DDGS is free of mycotoxins. Nursery diets containing up to 25% DDGS will support growth performance equivalent to feeding pigs fed diets with no DDGS if they are formulated on a digestible amino acid and available phosphorus basis and fed to pigs weighing more than 7 kg in body weight (Whitney and Shurson, 2004). Similarly, grow-finish and gilt development diets containing levels up to 30% DDGS should provide equivalent growth performance compared to pigs fed corn-soybean meal diets if they are formulated on a digestible amino acid and available phosphorus basis (Whitney et al., 2001). However, due to concerns of reduced belly firmness and soft pork fat at high levels of DDGS inclusion, we recommend no more than 20% DDGS be added to grow-finish and developing gilt diets.

One study has been conducted at the University of Minnesota (Wilson et al., 2003) to evaluate previously recommended maximum inclusion rates of DDGS in gestation (50%) and lactation (20%) diets for sows through two reproductive cycles. Sows fed the DDGS diets weaned more pigs per litter during the second reproductive cycle compared to sows fed the control corn-soybean meal diets. This improvement in litter size weaned is similar to the litter size response observed in other studies where sows were fed high fiber diets. It is unknown if this response can be obtained when feeding gestation and lactation diets containing lower levels of DDGS. Based upon the results of this experiment, up to 50% DDGS can be effectively used in gestation diets and up to 20% DDGS can be used in lactation diets when diets are formulated on a digestible amino acid basis. However, when sows are abruptly switched from a corn-soybean meal diet to diets containing high levels of DDGS in gestation or lactation, feed consumption may be reduced for approximately 5 to 7 days until sows adjust to diets containing high amounts of DDGS. This is a significant issue during lactation when our goal is to maximize feed (energy) intake. No reductions in feed consumption occur when 10% DDGS is added to lactation and gestation diets. If high amounts of are to be fed during gestation, formulate diets to contain 10% DDGS and then increase DDGS inclusion level when each new batch of feed is made to allow the sows to adapt to the DDGS diet and avoid any reduction in feed intake. If high amounts are to be fed during lactation (> 10%) feed gestation diets containing at least 20% DDGS at least one week prior to farrowing or increase the DDGS level in lactation diets after the first week of lactation. If there is concern that the DDGS source being used may contain mycotoxins, it may be best not to include DDGS in sow diets, or limit its use to 10% of the diet or less. Although no studies have been conducted to evaluate feeding diets containing DDGS to boars, it is assumed that if a diet containing 50% DDGS results in satisfactory performance of gestating sows, it should also provided adequate performance for boars.

Formulation of DDGS Diets

Only golden colored, "new generation" DDGS should be used to formulate swine diets to ensure good performance. The apparent digestible amino acid and available phosphorus values shown in Table 4 should be used to formulate practical diets for all phases of swine production to ensure that optimal performance is obtained, particularly when adding more than 10% DDGS to any swine diet. Formulating diets using total amino acid and phosphorus values may provide acceptable performance at low inclusion rates (< 10%) of DDGS in swine diets.

Like most by-products, nutrient content and digestibility of DDGS is variable among sources. However, DDGS quality and nutrient variability is relatively consistent within plants. We recommend selecting one or two "new generation" ethanol plants to add to a "preferred suppliers" list to minimize the risk of variable nutrient composition and quality. The "Nutrient Profiles" section of our DDGS web site (www.ddgs.umn.edu) provides nutrient composition and photos of a variety of "new generation" DDGS sources and direct marketers of "new generation" DDGS. Typical corn DDGS trading specifications and physical specifications are:

Moisture – maximum 12%
Crude protein – minimum 27%
Crude fat – minimum 10%
Crude fiber – maximum 7.5%

Bulk density – 35.7± 2.79 lbs/cubic ft. (range 30.8 to 39.3 lbs/cubic ft)
Particle size - 1282± 305 microns (range 612 to 2125 microns)
Smell – fresh, fermented
Color – goldenrod

Special Considerations When Formulating and Feeding DDGS Diets to Swine

Pork Fat Quality

Our studies have shown that when feeding DDGS to grow-finish pigs (50-250 lbs), the oil present in DDGS will make pork carcass fat softer and more oily with increasing levels of DDGS in the diet. Similar effects have been shown when adding any high oil grain or grain co-product to swine grow-finish diets. Although softer fat and reduced belly firmness are a concern for packers and meat processors, there generally are no price penalties for pork producers for marketing pigs with reduced pork fat quality. Results from our studies show that feeding up to 20% DDGS in grow-finish diets will result in acceptable belly thickness, belly firmness score, and iodine value compared to carcasses from grow-finish pigs fed conventional corn-soybean meal diets.

Mycotoxins

The incidence of documented cases of mycotoxicosis from feeding DDGS to swine is extremely low. However, corn is susceptible to molds that can produce mycotoxins prior to harvest, as well as during storage. The primary mycotoxins of concern to swine are zearalenone, vomitoxin (deoxynivalenol), T-2 toxin, fumonisin, and aflatoxins. In the Midwestern U.S., zearalenone and vomitoxin are the greatest risks.

If corn containing mycotoxins is delivered to an ethanol plant for ethanol production, these mycotoxins are not destroyed or inactivated during the fermentation process and will be present in DDGS produced from this corn source. In fact, the concentration of mycotoxins in DDGS will be 2 to 3 times higher than the initial concentration in the grain because the removal of starch during the fermentation process concentrates all of the unfermentable residual portions of the grain that remain after fermentation.

Many “new generation” ethanol plants monitor incoming corn for mycotoxins and reject loads that are contaminated to prevent mycotoxins in DDGS. There is an incentive to only use high quality, mycotoxin free corn in ethanol production because poor quality corn results in poor ethanol yields. Furthermore, most of the corn supplied to “new generation” ethanol plants is produced locally and corn produced in the upper Midwest has a low risk for mycotoxins. Buyers of DDGS are encouraged to work with their suppliers to establish a quality control protocol for the production of DDGS that should include screening tests and procedures for mycotoxins.

If DDGS is suspected to contain mycotoxins, laboratories that use either thin layer chromatography (TLC) or HPLC should be used for testing mycotoxins in DDGS. Use of ELISA and other analytical methods can result in false positive readings.

Manure Management

Feeding corn DDGS diets to swine will increase fecal output. In a recent study, Fu et al. (2004) showed that fecal volume increased 5.7% and 13.2% when diets contained 10% and 20% corn DDGS, respectively.

Due to the high nitrogen (crude protein) content of DDGS relative to lysine, and the fact that swine diets are formulated to meet the lysine needs of pigs, feeding DDGS diets will increase nitrogen levels in swine

manure. However, use of synthetic amino acids and formulating diets on a digestible amino acid basis will help minimize excess nitrogen excretion.
One of the advantages of feeding corn DDGS to swine is its relatively high available phosphorus content. Adding 20% corn DDGS to swine diets and formulating diets on an available phosphorus basis can reduce phosphorus excretion in manure by approximately 12%. Therefore, DDGS can help minimize the accumulation of P in high phosphorus soils and the need for acquiring more cropland for proper manure application if manure phosphorus guidelines must be met.

Spiehs et al. (2000) conducted a study to evaluate odor characteristics of swine manure and nutrient balance of grow-finish pigs fed diets with and without distiller's dried grains with solubles. Feeding a 20% DDGS diet had no effect on ammonia and hydrogen sulfide emissions, and odor detection threshold compared to feeding corn-soybean meal diets.

DDGS and Swine Health

Lawsonia intracellularis

Many pork producers have observed improvements in gut health in grow-finish pigs, particularly in herds with recurring problems with ileitis (porcine proliferative enteropathy), when DDGS diets were fed. Ileitis is caused by *Lawsonia intracellularis,* a microaerophil bacteria that infects immature cells located in the crypts of the small intestine. This organism inhibits intestinal cell maturation, which causes cells to multiply without being sloughed off. As a result, the intestinal wall thickens and hemorrhages.

Three disease challenge studies have been conducted at the University of Minnesota to study the effects of various dietary treatments, including adding 10 or 20% DDGS to the diet in pigs that were infected with *Lawsonia intracellularis*, on the incidence and severity of intestinal lesions. Conducting disease challenge studies to measure dietary effects on gastrointestinal health is difficult due to the challenge of administering an inoculation dose comparable to field conditions.

In the first experiment, the inoculation dose of *L. Intracellularis* was much higher than desired and no benefit of feeding diets containing 10 or 20% DDGS on reducing the incidence or severity of intestinal lesions caused by ileitis was observed (Whitney et al., 2003). In the second experiment, pigs were infected with an inoculation dose close to the goal of 1×10^8 organisms and the majority of the pigs became infected. In this study, adding 10% DDGS reduced the overall prevalence and severity of gastrointestinal tract lesions similar to the response observed from adding a recommended BMD™ and chlortetracycline therapeutic regimen. However, there were no additive effects when both antimicrobials and DDGS were combined in the diet (Whitney et al., 2003). In the third experiment, the same source of pigs and the same infection dose were used as for the second experiment (a dose considered by most veterinarians to be much higher than the infection dosage found in commercial swine operations). However, the incidence and severity of lesions caused by the infection were much more severe than in the second experiment. Feeding a diet containing 20% DDGS tended to provide some benefit toward reducing the incidence and severity of intestinal lesions, but adding 5% soy hulls to the diet tended to be as effective if not more effective than DDGS. Therefore, it appears that there may be some benefit from adding DDGS to grow-finish diets to improve gut health of pigs when confronted with a *Lawsonia* infection, but our results have been inconsistent, and appear to be related to the severity of the disease challenge. The beneficial effect of DDGS in reducing the incidence and severity of intestinal lesions caused by ileitis may be due to its high insoluble fiber content (42%) and/or the presence of compounds with nutraceutical properties.

Salmonella Typhimurium

In recent years, food safety issues have received considerable attention from consumers, industry groups, and governmental agencies both in the United States and around the world. *Salmonella* is the leading cause of food borne illness in the United States (White et al., 2001). The Center for Disease

Control and Prevention (2001) estimates approximately 40,000 cases of Salmonellosis each year and approximately 1,000 fatalities due to this food borne pathogen, with *Salmonella* from pork being recognized as the second most significant source of human Salmonellosis (Blaha, 1998). Clearly, there is a need to reduce on-farm *Salmonella* contamination of the pork supply. By implementing production procedures related to reducing or eliminating food borne pathogens at the farm level, potential for contamination in the slaughter facilities and further down the food chain can be dramatically reduced. One component of the pre-harvest pork production system that has some potential to reduce on-farm contamination of the pork supply is nutrition. However, there is very little known about the interactions of food borne pathogens and nutrition in the scientific literature.

Previous studies have suggested that high fiber diets increase gastrointestinal tract hypertrophy (Bohman et al., 1955; Kass et al., 1980; and Pekas et al., 1983) and decrease some pathogenic bacteria populations (Lee and Close, 1987 and Anugwa et al., 1989), perhaps by influencing the secretory or absorptive function of the epithelium of the large intestine, which influences bacterial adhesion. Additionally, high fiber diets have been shown to increase total organic acids in the colon of pig (Kass et al., 1980), which decreases intestinal pH, thereby potentially reducing pathogenic bacteria population, such as *Salmonella* in the gut of the pig. Distiller's dried grains with solubles contains approximately 6 to 8% crude fiber, and is high in insoluble fiber (42.2%) and low in soluble fiber (0.7%) (Shurson et al., 2000). Furthermore, previous research has demonstrated that the soluble portion of DDGS (distiller's dried solubles; DDS) may contain unidentified growth factors (Catron et al., 1954; Beeson et al., 1959; Conrad, 1961; Wallace and Combs, 1964). These unidentified growth factors may have "antibacterial-like" properties, or provide other immunological benefits due to the presence of several beneficial immunological compounds such as glutamine, biologically active peptides and proteins, nucleic acids, mannanoligosaccharides, chitin, and beta-glucans from the residual yeast used in ethanol fermentation. These compounds may enhance the immune system of the pigs by working like direct fed microbials or prebiotics in the gut of the pig.

We recently completed a *Salmonella* Typhimurium disease challenge study to determine the effect of feeding a corn-soybean meal diet containing 50% DDGS, and a diet containing a polyclonal antibody specific for *Salmonella* Typhimurium on growth performance, fecal shedding, and clinical signs of *Salmonella* infection. Pigs near market weight were orally inoculated with 10^9 CFU of 5 strains of *S.* Typhimurium one week after arrival to the disease isolation facilities on the University of Minnesota St. Paul campus, but fecal shedding of *Salmonella* was low. Pigs were re-infected one week after the initial inoculation, but fecal shedding was again determined to be low. Pigs were infected intranasally in a third and final attempt, using an inoculation dose of 10^9 CFU of the same 5 strain mixture of *S.* Typhimurium, 3 weeks after the second inoculation. Pigs were euthanized and necropsied one week after the final inoculation, and tissue samples were collected and analyzed for the presence of *S.* Typhimurium.

Due to the low level of fecal shedding in this experiment, we were not able to quantitatively determine the level of fecal shedding between pigs fed the corn-soybean meal control, DDGS, and polyclonal antibody diets. The tonsil is considered to be the most likely tissue to detect the presence of *Salmonella*, and in this study, 66% of all tonsil samples tested positive for *Salmonella* (Figure 8). As for the fecal samples, there was a low overall level of *Salmonella* in tissue samples, and there were no differences between dietary treatments in the tonsil, mandibular lymph nodes and cecum. However, there was a trend ($P < .08$) for pigs fed the 50% DDGS diet to have fewer ileal-cecal lymph nodes test positive for *Salmonella* compared to pigs fed the polyclonal antibody (Figure 9). There was also a trend ($P < .08$) for pigs fed the polyclonal antibody diet to have fewer infected ileum samples than pigs fed the 50% DDGS diet. However, due to the lack of our ability to induce a clinical infection in this study, it is unclear whether DDGS is effective in reducing fecal shedding and clinical signs of Salmonellosis.

Figure 8. Average incidence of Salmonella in tissues of pigs infected with S. Tyhpimurium

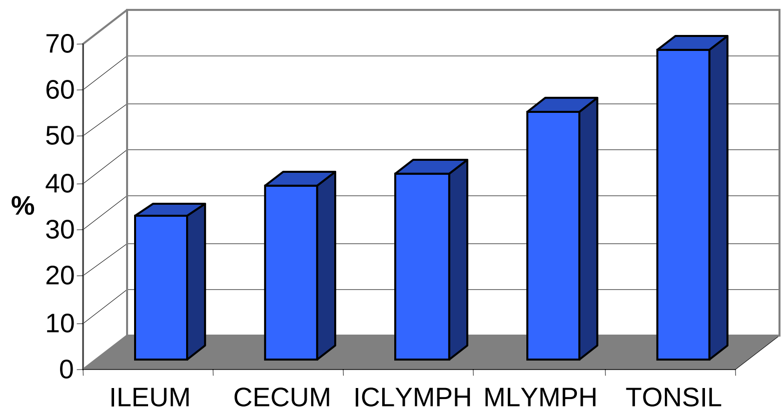
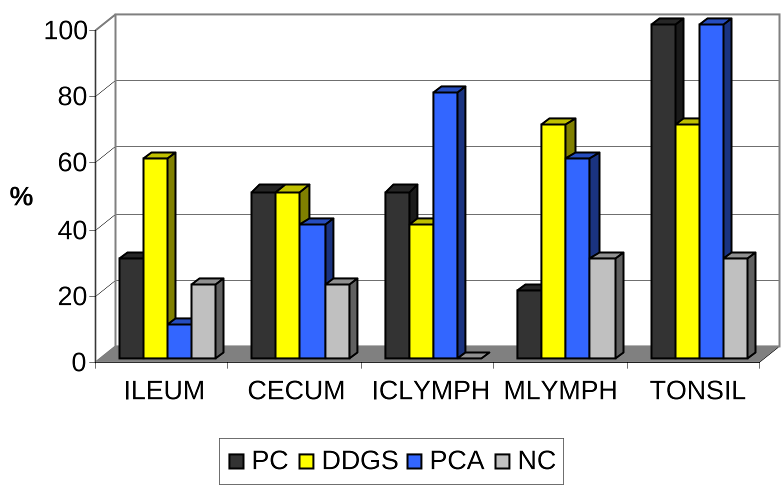


Figure 9. Incidence of S. Typhimurium in tissues of pigs



Spray Dried Distiller's Solubles Co-Products

We have developed a process to manufacture spray dried corn distiller's solubles, and two fractions derived from it – spray dried yeast cream and spray dried residual solubles (Figure 10).

Figure 10. Appearance of spray dried distiller's solubles, spray dried yeast cream, and spray dried residual solubles.

These high energy ingredients were evaluated in diets for early weaned pigs. In this experiment, 560 pigs weaned at 18 days of age were used to provide 10 pigs per pen and 8 replications/treatment with 7 dietary treatments. One pig from each pen (total of 56 pigs) was slaughtered at day 10 to determine effects of diet on intestinal morphology. The 7 dietary treatments fed from day 0 to day 10 post-weaning and included:

NC = negative control
DS = spray dried distiller's solubles added at 15% of the diet
YC = spray dried yeast cream added at 7.5% of the diet to replace animal fat
RS = spray dried residual solubles added at 15% of the diet
AB = carbadox added to provide 50 g/ton
PP = spray dried porcine plasma added at 6% of the diet
PC = spray dried porcine plasma + carbadox added to provide 6% PP + 50 g/ton AB

All experimental diets contained corn (13 to 36%), soybean meal 46% (7.5% in PP and PC diets, 22.5% in all other diets), lactose (20%), oat groats (12.5%), fish meal (11%), and minerals and vitamins to meet or exceed requirements. All experimental diets contained 3440 Kcal ME/kg, 6.2 to 7.5% crude fat, 1.6% lysine, 0.91% methionine + cystine, 1.03% threonine, 0.29% tryptophan, 0.87% calcium, and 0.80% phosphorus. Common phase 2 (days 10 to 21) and phase 3 (days 21 to 42) diets were fed for the remainder of the 6 week-trial.

As shown in Figure 11, there were no differences in ADG among the NC, DS, YC, RS, AB, and PP dietary treatments during phase 1, but pigs fed the PC diet grew faster than all other treatments (P < .05). These results suggest that pigs fed the diets containing the 3 distiller's solubles fractions performed comparable to pigs fed the carbadox and spray dried porcine plasma diets but grew slower than pigs fed the diet containing both carbadox and spray dried porcine plasma. No differences in ADG were observed during phase 2, phase 3, and overall. There were no among dietary treatments for average daily feed intake (P > .05) in phase 1, phase 2, phase 3, and overall, indicating that the diets containing the distiller's solubles fractions were highly palatable (Figure 12).

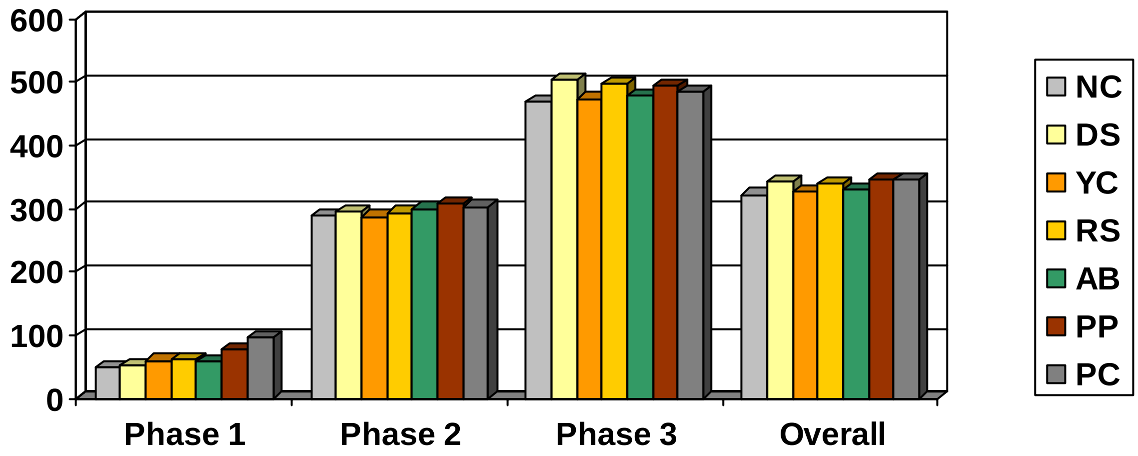


Figure 11. Average daily gain of pigs fed diets containing spray dried corn distiller's solubles fractions compared to pigs fed diets containing carbadox, spray dried porcine plasma, and the combination of carbadox and spray dried porcine plasma.

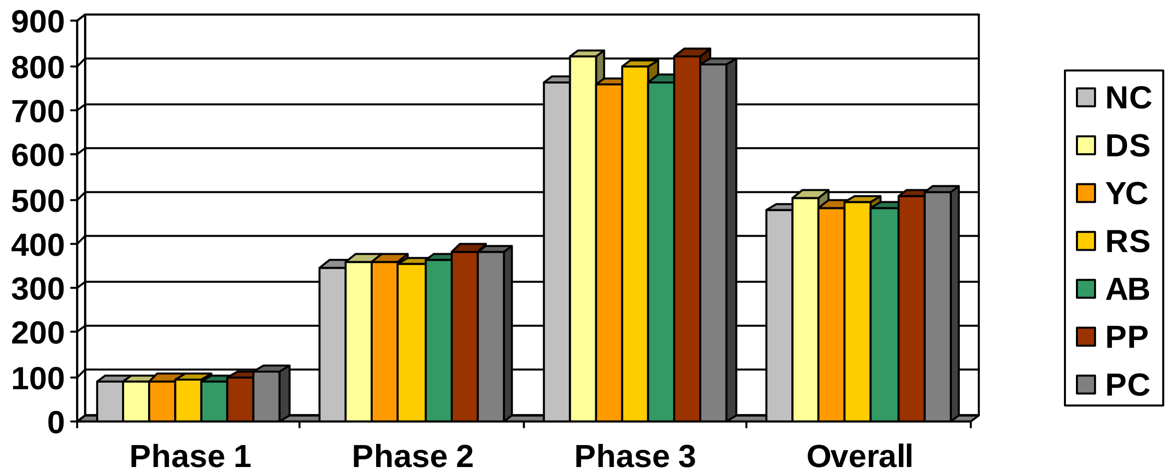


Figure 12. Average daily feed intake of pigs fed diets containing spray dried corn distiller's solubles fractions compared to pigs fed diets containing carbadox, spray dried porcine plasma, and the combination of carbadox and spray dried porcine plasma.

Furthermore, there were no differences in gain/feed among dietary treatments in each phase and overall (P > .05), although pigs fed the PP and PC diets had numerically higher gain/feed than all other treatments, and the diets containing the distiller's solubles fraction numerically had equal to superior gain/feed compared to pigs fed the carbadox diet during phase 1 (Figure 13).

It is interesting that when villi height was measured in the upper 25% of the small intestine, pigs fed the residual solubles diet and the PC diet had significantly longer villi ($P < .05$) compared to pigs fed the NC, DS, YC, and AB diets (Figure 14). This suggests that there are compounds present in the residual solubles that appear to promote intestinal health or protect mucosal integrity. There were no differences among dietary treatments in crypt depth in the upper 25% of the small intestine.

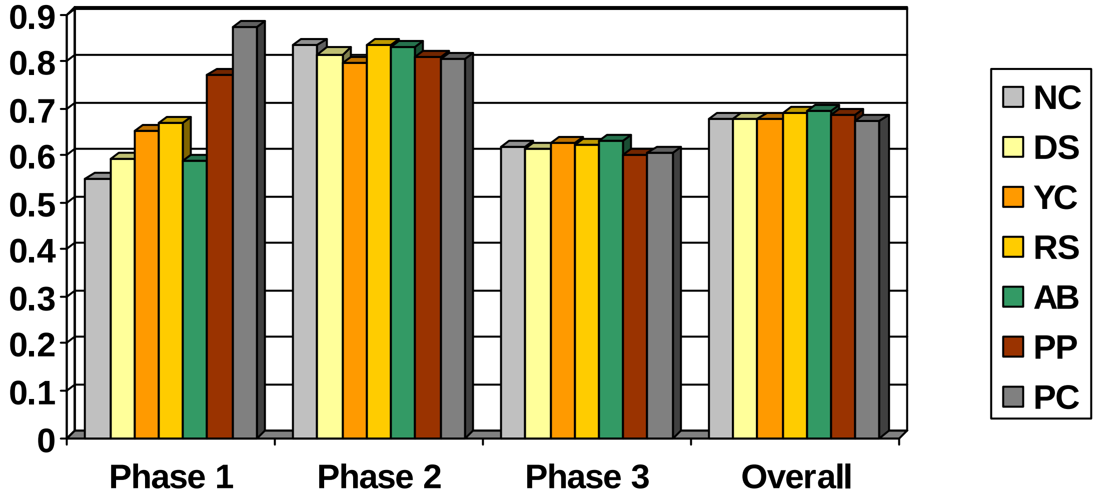


Figure 13. Gain/feed of pigs fed diets containing spray dried corn distiller's solubles fractions compared to pigs fed diets containing carbadox, spray dried porcine plasma, and the combination of carbadox and spray dried porcine plasma.

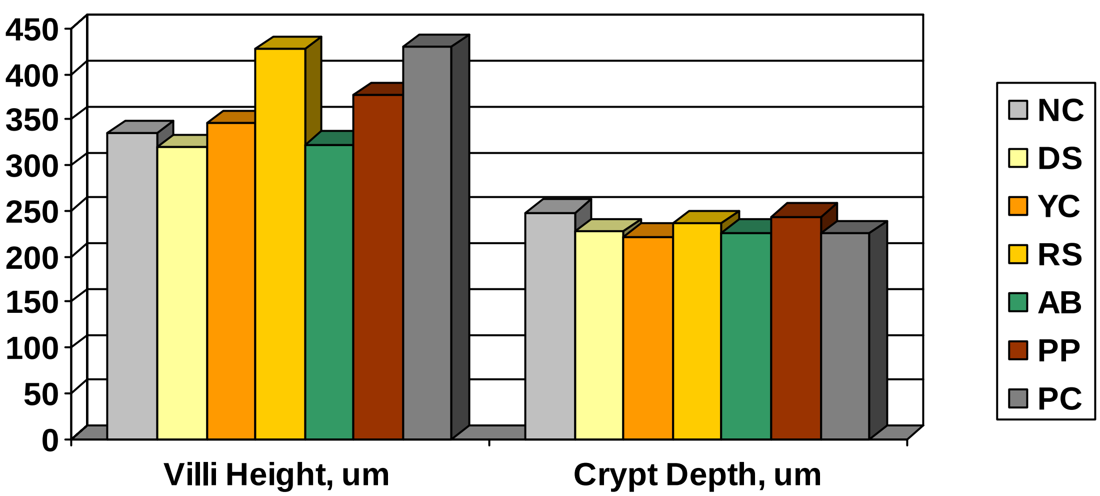


Figure 14. Villi height and crypt depth in the upper 25% of the small intesting of pigs fed diets containing spray dried corn distiller's solubles fractions compared to pigs fed diets containing carbadox, spray dried porcine plasma, and the combination of carbadox and spray dried porcine plasma.

Villi height to crypt depth ratio is generally considered to be a measure of absorptive capacity of the small intestine. Figure 15 shows that pigs fed the residual solubles diet had similar absorptive capacity in the upper small intestine to pigs fed the PC diet and superior (P < .05) to pigs fed the NC, DS, and AB diets. This suggests that components in the residual solubles diet will promote greater absorptive capacity of the upper small intestine than when carbadox is fed. When viewing the actual villi from pigs fed the RS and AB diets, there are distinct differences in villi length and shape (Figure 16 and 17).

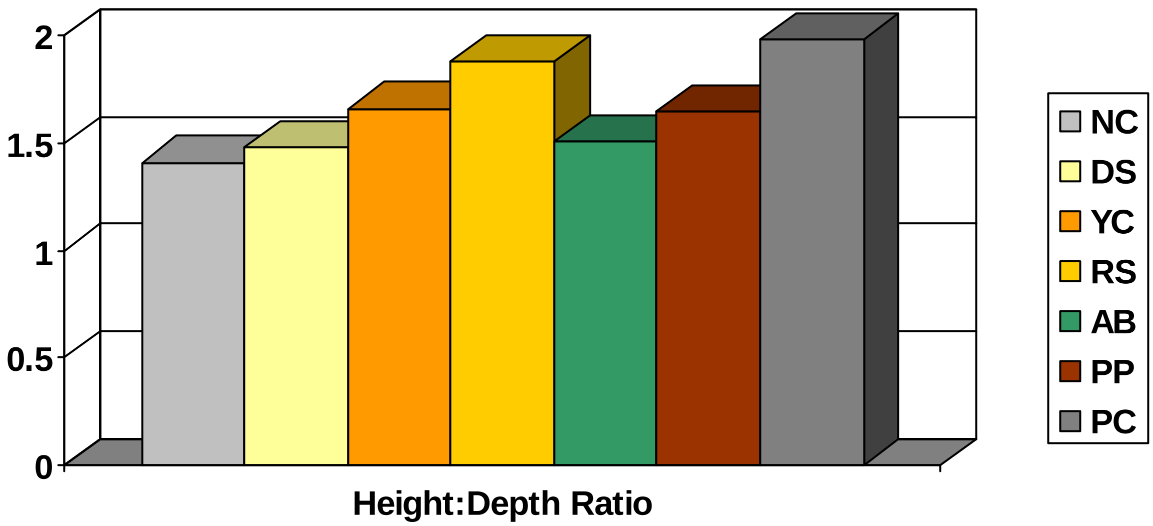


Figure 15. Villi height:crypt depth ratio in the upper 25% of the small intesting of pigs fed diets containing spray dried corn distiller's solubles fractions compared to pigs fed diets containing carbadox, spray dried porcine plasma, and the combination of carbadox and spray dried porcine plasma.

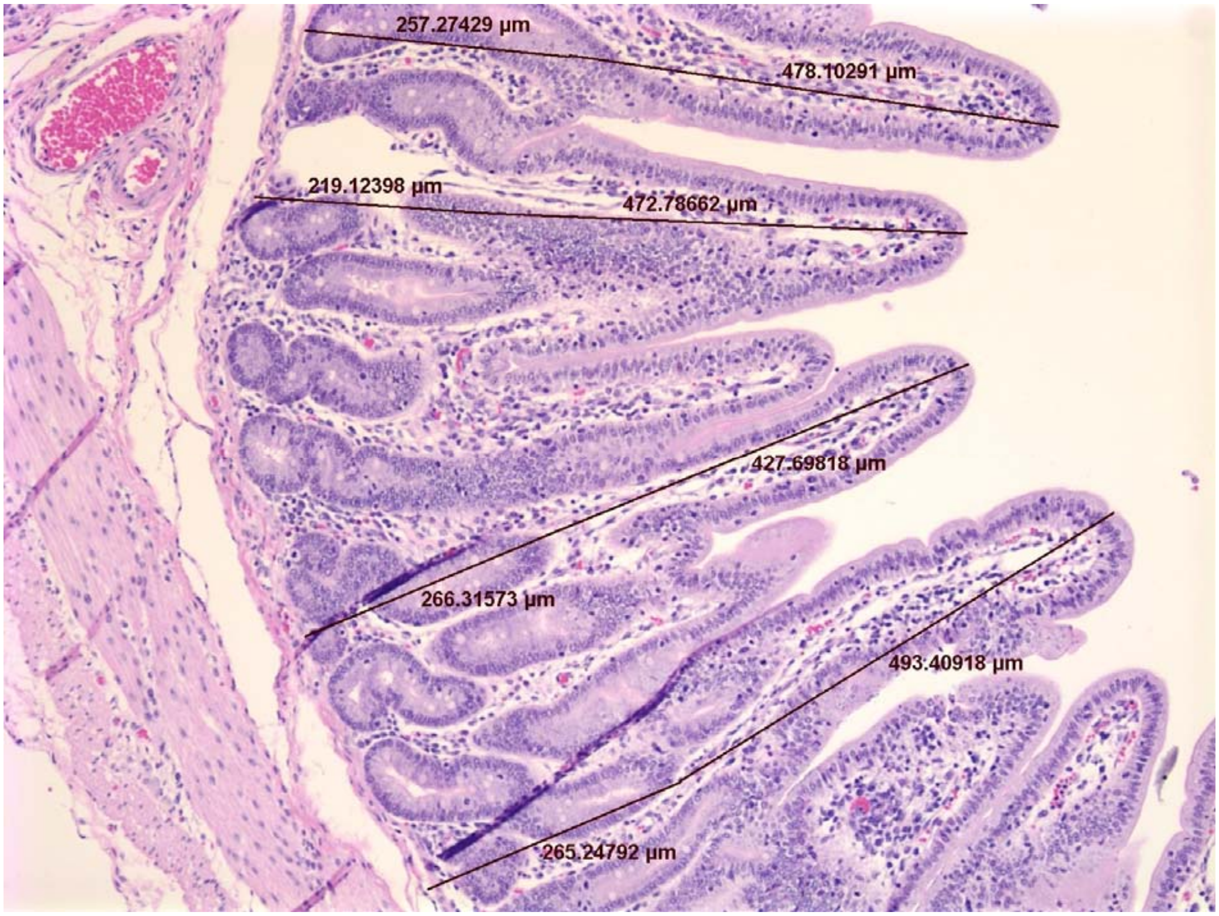


Figure 16. Villi measurements from the upper 25% of the small intestine from a pig fed the residual solubles diet (10X).

Figure 17. Villi measurements from the upper 25% of the small intestine from a pig fed the carbadox diet (10X).

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