FEED VALUE BENEFITS OF SORGHUM FOR SWINE

SORGHUM THE SMART CHOICE

INTRODUCTION

Grain sorghum is a feedstuff with an excellent nutritional value for swine and can be used as the primary grain source in all swine diets. Numerous feeding trials in the last 20 years with nursery and finishing pigs and gestating and lactating sows have demonstrated the value of feeding sorghum relative to corn and other grains. When processed correctly and balanced for digestible amino acid and digestible phosphorus concentrations, sorghum can be an economical replacement for corn, wheat or barley in swine diets. In the past, research demonstrated sorghum grain contained 96 percent the energy content of corn (Cromwell et al., 1985).

However, new reference values indicate today's sorghum varieties will contain approximately 98-99 percent the energy content of corn (INRA, 2014). The increased energy values correspond with more recent studies that have observed 98-103 percent the feeding value of corn. In addition, its greater digestible phosphorus content also requires less supplemental inorganic phosphorus sources (monocalcium- or dicalcium-phosphate) than corn-based diets and reduces phosphorus excretion in swine waste, a benefit for the environment. Grain sorghum contains slightly less oil than corn. However, sorghum has more saturated fatty acids and less polyunsaturated fatty acids than corn. From a carcass fat quality prospective, this is positive as pigs fed sorghum will deposit a firmer carcass fat, providing an advantage relative to corn for bacon processors and in many fresh pork markets.

Only recently has research been conducted with sorghum dried distillers grains with solubles (DDGS). But like corn DDGS, the nutritional value of sorghum DDGS will depend on its oil concentration. As more and more ethanol plants are further extracting the oil in production of DDGS, comparisons among pigs fed sorghum vs. corn DDGS must be carefully made as the two sources might contain different oil concentrations. However, data indicates a similar growth rate can be achieved with diets containing low concentrations of sorghum DDGS as with diets containing corn DDGS. Similar to the comparison between their parent grains, sorghum DDGS may have a slightly lower oil content than corn DDGS, but again, may vary based on the oil extraction procedures at the ethanol plant.

Grain sorghum provides an excellent opportunity for swine producers or feed suppliers to lower feed costs. As our understanding of feed processing and the nutrient profile of grain sorghum increases, greater opportunities for expanded grain sorghum use exist to capitalize on its full potential in swine diets.

ENERGY VALUE

Grain sorghum can completely replace all the corn, wheat or barley in all swine diets as the primary energy source. In the past the energy content of grain sorghum was generally considered to be 96 percent relative to that of corn (Cromwell et al., 1995). In fact, the pre-1990 data supported this conclusion as pigs fed sorghum-based diets generally had 3-4 percent poorer feed efficiency than those fed corn. With new varieties of grain sorghum now available and better feed processing techniques, it appears from the literature that the energy content and feeding value of sorghum has increased. Recent reference values based on the chemical composition of sorghum suggest a net energy value of 99 percent that of corn (INRA, 2014; Table 1).

GRAIN SORGHUM FEEDING VALUE

TABLE 1. TYPICAL NUTRIENT COMPOSITION (AS-FED)[1]

	SORGHUM	CORN
DRY MATTER, %	89.4	88.3
NET ENERGY, KCAL/LB[2]	1,186	1,202
CRUDE PROTEIN, %	9.4	8.2
CALCIUM, %	0.02	0.02
PHOSPHOROUS, %	0.27	0.26
DIGESTIBLE PHOSPHOROUS, %	0.108	0.088
CRUDE FAT, %	3.4	3.5
CRUDE FIBER, %	2.1	2.0
NDF, %	10.6	9.11
ADF, %	4.9	2.9
LINOLEIC ACID, %[3]	47.3	55.8
SATURATED FATTY ACIDS, %[3]	19.1	17.9
MONOUNSATURATED FATTY ACIDS, %[3]	29.5	23.8
POLYUNSATURATED FATTY ACIDS, %[3]	50.2	57.5

[1]Values are derived from NRC. 2012. Nutrient Requirements of Swine. 11th rev. ed. Natl. Acad. Press, Washington, D.C., unless otherwise indicated.
[2]INRA. 2014. EvaPig. EvaPig® was created, designed and developed by Jean Noblet (INRA, UMR SENAH), Alain Valancogne (INRA, UMR SENAH), Gilles Tran (AFZ) and AJINOMOTO EUROLYSINE S.A.S.
[3]Derived from Sotak et al. 2015.

GRAIN SORGHUM FEEDING VALUE

AMINO ACID PROFILE

Sorghum contains more of the essential amino acids threonine, tryptophan and valine than corn on a standardized ileal digestible basis (Table 2). Thus, greater quantities of supplemental amino acids (lysine and methionine) can be used to replace soybean meal in the diet. This advantage allows for potentially less expensive formulation options with grain sorghum-based diets compared with corn. With the expanded use of crystalline amino acid-fortified diets in the swine industry, the economic advantage for grain sorghum in swine diets has increased compared to corn. This also can reduce the nitrogen concentration in swine waste and be better for the environment.

When substituting grain sorghum for corn in swine diets, slight adjustments in the amounts of soybean meal and crystalline amino acids should be made to take full advantage of grain sorghum's nutrient composition. Therefore, when using grain sorghum it is very important to use its standardized ileal digestible (SID) amino acid content values in diet formulations.

TABLE 2. TOTAL AND STANDARDIZED ILEAL DIGESTIBLE (SID) AMINO ACID PROFILES OF SORGHUM AND CORN[1]

	SORGHUM			CORN		
		SID			SID	
ITEM	TOTAL, %	COEFFICIENT, %	SID, %	TOTAL, %	COEFFICIENT, %	SID, %
ARG	0.36	80	0.29	0.37	87	0.32
HIS	0.21	74	0.16	0.24	83	0.20
ILE	0.36	78	0.28	0.28	82	0.23
LEU	1.21	83	1.00	0.96	87	0.84
LYS	0.20	74	0.15	0.25	74	0.19
MET	0.16	79	0.13	0.18	83	0.15
MET & CYS	0.34	73	0.25	0.37	82	0.30
PHE	0.48	83	0.40	0.39	85	0.33
THR	0.30	75	0.23	0.28	77	0.22
TRP	0.07	74	0.52	0.06	80	0.05
VAL	0.46	77	0.35	0.38	82	0.31

[1]Values are derived from NRC. 2012. Nutrient Requirements of Swine. 11th rev. ed. Natl. Acad. Press, Washington, D.C. Total represents the total amino acid content of the grain; SID coefficient refers to the standardized ileal digestibility coefficient; and SID refers to the standardized ileal digestible content (total x SID coefficient).

DIGESTIBLE PHOSPHORUS

An important characteristic from an economic and environmental standpoint is that grain sorghum contains greater digestible phosphorus than corn. Therefore, diets formulated with grain sorghum require less supplemental inorganic phosphorus (monocalcium- or dicalcium-phosphate). As a result, there is less phosphorus excreted in swine waste, a benefit to the environment. This also improves the economic advantage of sorghum grain compared to corn in swine diets.

FATTY ACID PROFILE

The fatty acid profile of the diet fed to pigs influences the carcass fat iodine value, a measure of carcass fat firmness. Fat quality is extremely important in today's pork processing industry. Pork products with soft fat (more unsaturated fatty acids) are discriminated against as they can become rancid faster and the bellies are more difficult to slice for bacon as the fat has a higher tendency to "smear" resulting in a less desirable product. The more favorable fatty acid profile (less

GRAIN SORGHUM FEEDING VALUE

unsaturated fat) provides sorghum with a distinct advantage over corn in improving pork fat quality. Research has shown that pigs fed sorghum-based diets had less linoleic acid and polyunstaturated fatty acids in back- and jowl-fat than pigs fed corn (Benz et al., 2011; Table 3). More recently, Jordan et al. (2015b) also observed firmer fat (decreased iodine value) of pigs fed sorghum- vs. corn-based diets. These studies confirm pigs fed sorghum-based diets will have firmer fat than those fed corn. Another advantage of the low iodine value of grain sorghum is that it allows more flexibility in diet formulation. Nutritionists can add co-product ingredients generally high in iodine value, such as added fat or dried distillers grains with solubles, and still maintain lower iodine values compared to corn-based diets containing the same amounts of these co-products (Sotak et al., 2015).

In summary, grain sorghum has many attributes that enhance its nutritional value for pigs. Grain sorghum has more favorable digestible amino acid and fatty acid profiles, as well as more digestible phosphorus, for pig diets. When processed correctly, the energy concentration (NE and ME) is approximately 98-99 percent that of corn.

GRAIN SORGHUM FEEDING VALUE

TABLE 3. EFFECTS IF GRAIN SOURCE ON PORK FAT QUALITY[1]

	GRAIN SOURCE			
ITEM	CORN	SORGHUM	SE	P-VALUE
BACKFAT QUALITY				
PALMITIC ACID (16:0), %	24.2	24.4	0.2	0.26
STEARIC ACID (18:0), %	12.5	12.5	0.2	0.97
OLEIC ACID (18:1C9), %	38.7	40.4	0.04	0.01
LINOLEIC ACID (18:2N6), %	14.3	12.2	0.3	0.01
PUFA:SFA RATIO	0.42	0.36	0.01	0.01
IODINE VALUE, G/100 G	65.8	63.9	0.5	0.01
JOWL FAT QUALITY				
PALMITIC ACID (16:0), %	22.8	23.1	0.2	0.16
STEARIC ACID (18:0), %	9.6	9.8	0.1	0.19
OLEIC ACID (18:1C9), %	41.2	42.6	0.2	0.01
LINOLEIC ACID (18:2N6), %	14.6	12.9	0.3	0.01
PUFA:SFA RATIO	0.49	0.43	0.01	0.01
IODINE VALUE, G/100 G	70.3	68.3	0.5	0.01

[1]Adapted from Benz et al. 2011.

SUMMARY OF FEEDING TRIALS WITH SORGHUM RELATIVE TO CORN

NURSERY PIGS

Starch provided from cereal grains is the major energy-yielding component of the diet of weanling pigs where it contributes more than double the digestible energy compared with that from dietary fat. Corn is a commonly used cereal in weanling pig diets because of its wide availability, low fiber and high energy content; however, numerous studies have demonstrated that sorghum can be used successfully to replace corn in nursery diets.

In a summary of 12 nursery studies comparing pigs fed sorghum to corn-based diets, the average relative value of sorghum was 99, 100 and 99 percent of the value of corn for average daily gain (ADG), average daily feed intake (ADFI), and feed per pound of gain (F/G), respectively (Table 4). The more recent studies, 2000 and later, observed better responses of pigs fed sorghum-based diets than studies conducted in the 1990s. This is likely a result of new varieties of sorghum, more precise diet formulation, and proper feed processing.

In early studies (pre-2000) there was greater variation in ADG and ADFI responses to feeding sorghum between studies. Researchers in one study observed lower ADFI and ADG in weanling pigs fed

TABLE 4. RELATIVE VALUE (%) OF SORGHUM VERSUS CORN IN NURSERY PIGS

STUDY	ADG	ADFI	F/G	REFERENCE
1	90	91	99	RICHERT ET AL. (1992) EXP. 1
2	113	112	101	RICHERT ET AL. (1992) EXP. 2
3	80	84	95	HEALY ET AL. (1994) HARD
4	84	88	95	HEALY ET AL. (1994) SOFT
5	111	104	108	HONGTRAKUL ET AL. (1998)
6	103	105	99	JONES ET AL. (2000) MILL-RUN
7	105	105	100	JONES ET AL. (2000) RED
8	103	101	102	JONES ET AL. (2000) WHITE
9	96	103	93	FIALHO ET AL. (2004)
10	101	99	102	SOTAK ET AL. (2011) EXP. 1
11	102	107	96	SOTAK ET AL. (2011) EXP. 2
12	100	100	99	JORDAN ET AL. (2014)
AVERAGE	99	100	99	

SUMMARY OF FEEDING TRIALS WITH SORGHUM RELATIVE TO CORN

sorghum in one experiment but improved ADFI and ADG in a subsequent experiment (Richert et al., 1992). Some of these differences might be explained by older sorghum varieties or formulation methods. Other researchers compared both hard and soft sorghum to corn in nursery diets with both sorghum varieties resulting in significantly lower ADFI and ADG compared to pigs fed corn-based diets (Healy, et al., 1994). However, in that study sorghum replaced corn on a weight for weight basis. Because the two sorghum varieties contained less lysine than the corn used in the study, it cannot be ruled out that the decreased growth performance of the sorghum diets was actually a response to decreased dietary lysine. More recent studies showed no differences in ADG, ADFI and F/G between nursery pigs fed sorghum- and corn-based diets (Fialho et al., 2004; Sotak et al., 2014; Jordan et al., 2015a). In conclusion, with formulation on a digestible amino acid basis and proper feed processing, it appears that feeding sorghum to weanling pigs has minimal effects on ADG and F/G compared with pigs fed corn-based diets (Table 4).

GROWING-FINISHING PIGS

In a 1985 summary involving 10 growing-finishing experiments, it was reported that pigs fed sorghum had 98 percent of the ADG and 97 percent of the F/G of pigs fed corn (Cromwell et al., 1985). However, more recent studies reveal greater feeding value for sorghum in finishing pigs than previously described (Table 5). On average, these studies show that sorghum-fed pigs had 102, 105 and 98 percent of the ADG, ADFI and F/G of finishing pigs fed corn, respectively (Table 5). The observed improvements in the relative feeding value of sorghum may be due mainly to the introduction and widespread use of improved cultivars of sorghum and a better knowledge of processing sorghum-based diets. Overall, grain sorghum can be used to replace all of corn without affecting growth performance of finishing pigs.

Generally, feeding sorghum to finishing pigs does not affect carcass characteristics (Shelton et al., 2004; Jordan et al., 2015b). However, because of its lower polyunsaturated fatty acid concentrations, studies observe that pigs fed sorghum-based diets have firmer fat (lower iodine values) than those fed corn diets.

SUMMARY OF FEEDING TRIALS WITH SORGHUM RELATIVE TO CORN

TABLE 5. RELATIVE VALUE (%) OF SORGHUM VERSUS CORN IN FINISHING PIGS

STUDY	ADG	ADFI	F/G	REFERENCE
1	104	109	96	BRAND ET AL. (1990) VARIETY 1
2	102	108	95	BRAND ET AL. (1990) VARIETY 2
3	98	104	95	HANCOCK ET AL. (1992)
4	100	100	100	CABRERA ET AL. (1993) SOFT SORGHUM
5	104	107	97	CABRERA ET AL. (1993) HARD SORGHUM
6	106	106	100	JOHNSTON ET AL. (1998)
7	104	109	95	SHELTON ET AL. (2004) WAXY SORGHUM
8	106	114	93	SHELTON ET AL. (2004) NON-WAXY SORGHUM
9	104	100	104	ISSA (2009)
10	99	100	100	SEABOARD FARMS (2010)
11	106	105	101	BENZ ET AL. (2011)
12	103	103	100	PAULK ET AL. (2015)
13	96	101	97	JORDAN ET AL. (2014)
AVERAGE	102	105	98	
CROMWELL (1985 REVIEW)	98	102	97	10 EXP SUMMARY

LACTACTING SOWS

Research assessing the value of feeding sorghum to sows is limited. Louis et al. (1991) fed gestating and lactating sows either corn- or sorghum-based diets that were formulated on a weight/weight substitution (Table 6). There were no differences in the number of pigs born or weaned, but pigs from sows fed the corn-based diet were 7 percent heavier and had 8 percent greater total litter weight gain than those fed sorghum. In a second study, Johnston et al. (1998) fed sorghum- or corn-based diets that were fed in meal or pelleted form to lactating sows and observed a 3 percent decrease in litter weaning weight among litters of sorghum fed sows in a meal form, but no difference when fed pelleted diets. Sotak-Peper et al. (2015) also fed sows corn- or sorghum-based diets during lactation and observed greater feed intake and less lactation weight loss in sorghum fed sows. However, pig and litter weight gains were decreased in sows fed sorghum. Additional research is needed to more appropriately determine the feeding value of sorghum in sow diets; however, feeding sorghum to sows can support a similar level of reproductive

SUMMARY OF FEEDING TRIALS WITH SORGHUM RELATIVE TO CORN

performance, but litter weaning weights appear to be slightly lower during lactation compared with sows fed corn-based diets.

TABLE 6. RELATIVE VALUE (%) OF SORGHUM VERSUS CORN IN LACTATING SOWS

	RELATIVE VALUE		
ITEM	LOUIS ET AL. (1991)	JOHNSTON ET AL. (1998)	SOTAK ET AL. (2015)
SOW PERFORMANCE			
LACTATION ADFI	90	102	104
LACTATION WEIGHT CHANGE	90	62	74
WEANING-TO-ESTRUS INTERVAL	94	111	---[1]
LITTER PERFORMANCE			
LITTER SIZE BORN ALIVE	108	---[2]	---[2]
LITTER SIZE AT WEANING	103	99	99
LITTER BW AT BIRTH	99	---[2]	---[2]
LITTER BW AT WEANING	93	98	98
LITTER BW GAIN	92	97	94

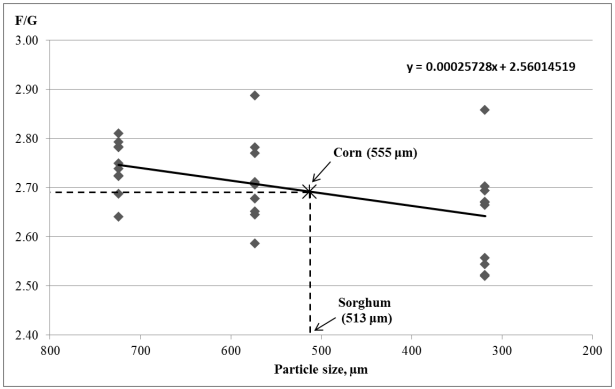
[1]Wean-to-estrus duration was not measured.
[2]In these two studies, sows were allotted to treatment on day 110 of gestation and litters size and weight were equalized across treatments.

One factor essential to maximize sorghum's energy content is proper feed processing. Grain sorghum has a small hard kernel relative to corn. Thus, proper processing by fine grinding is essential to obtain the optimum particle size. The swine industry's understanding of proper feed processing of sorghum over the last 15 years may be one of the reasons why its nutritional value has increased relative to corn in more recent experiments.

Research has evaluated growth performance of piglets weaned at 21 days of age and fed starter diets in which the grain (corn, and hard or soft endosperm sorghum) was ground to 900, 700, 500 or 300 microns (Healy et al., 1994). In this study, reducing particle size had very little impact on average daily gain, but as particle size was reduced a significant improvement was observed for feed efficiency. Pigs fed grain ground to 500 microns had a 6 percent improvement in feed efficiency compared with those pigs fed diets containing grain ground to 900 microns. The study also observed that fine grinding of grain sorghum can increase its digestible energy content by 3 percent compared with coarse grinding. Grinding grain sorghum from a particle size of 900 microns to 500 microns improves

SORGHUM PROCESSING

FIGURE 1.



The effects of decreasing particle size of grain sorghum and its effects on feed efficiency (Paulk et al., 2016). The solid line represents the improvement in feed efficiency (F/G) as sorghum particle size decreases. The dashed lines represent the actual target particle size (513 µ) needed to grind sorghum to have similar feed efficiency as pigs fed a corn-based diet ground to 555 µ.

feed efficiency by 6 percent. However, also important is the trend for decreased feed intake and poorer F/G of pigs fed the diets containing grain ground to 300 microns. Therefore, these and other data suggest a dietary particle size of approximately 500-600 microns, or grinding as finely as possible yet maintaining flowability of the diet through automatic feeding systems to optimize both pig performance and milling efficiency.

Feed processing research by Cabrera et al. (1994) and more recently by Paulk et al. (2016), demonstrate the importance of proper particle size to maximize sorghum's feeding value for finishing pigs. Cabrera et al. (1994) observed a linear improvement (7 percent) in F/G with decreasing particle size of sorghum-based diets. Paulk et al. (2016) also observed a similar linear improvement in F/G with decreasing particle size and determined if sorghum were ground approximately 50 microns finer than corn, there would be equal F/G (Figure 1).

In the past, a hammer mill or a roller mill has been considered to be sufficient for grinding sorghum. Each type of mill has its own advantages and disadvantages. With hammer mills, the small kernel size of grain sorghum will

SORGHUM PROCESSING

require a small screen (1/8 inch or 3 mm or less) in order to achieve the targeted particle size of 500-600 microns. A disadvantage of grinding sorghum with a hammer mill is that it will have a greater standard deviation of particles. (The distribution of particles will be wider than grain ground with a roller mill.) A roller mill will tend to slice the grain producing a more uniform shaped particle and one with less standard deviation or dustiness. It is recommended that the rolls on a roller mill have 14-16 corrugations per inch to aid in the slicing action. Because grain ground with a roller mill is more uniform in shape and distribution, research has shown it will have greater flowability than grain ground with a hammer mill. This is especially important as we process grains to finer particle sizes to maximize growth and feed efficiency. Freer flowing grain will also allow nutritionists the potential to add more co-products like added fat to the diet and still maintain diet flowability.

RECOMMENDATIONS FOR FEEDING GRAIN SORGHUM

Grain sorghum can replace all corn, wheat or barley in diets fed to all classes of swine. Because of its nutrient profile, including greater amounts of digestible threonine, tryptophan, valine and digestible phosphorus, it affords nutritionists different opportunities for diet formulation. Therefore, to take full advantage of sorghum's nutritional value, it is recommended to formulate sorghum-based diets on a standardized ileal digestible (SID) amino acid as well as digestible phosphorus basis (Table 7). This will take into account both the greater amino acid digestibility and digestible phosphorus content of grain sorghum relative to corn. Notice when compared to a nutritionally similar corn-based diet, sorghum diet option 1 (Table 7) contains greater amounts of crystalline amino acids and less soybean meal and monocalcium phosphate. It takes full advantage of grain sorghum's highly digestible threonine, tryptophan and valine concentrations and allows for greater use of crystalline amino acids. This reduces the amount of soybean meal in the diet and helps decrease nitrogen excretion in swine waste. Option 2 (Table 7) adds a small amount of fat to the diet to balance the energy content of the diet.

TABLE 7. EXAMPLE DIETS CONTAINING SORGHUM OR CORN FOR GROWING PIGS

		SORGHUM	
INGREDIENT, %	CORN	OPTION 1[1]	OPTION 2[2]
SORGHUM	- - -	79.35	78.20
CORN	77.27	---	---
SOYBEAN MEAL, (46.5% CP)	20.06	17.81	18.25
CHOICE WHITE GREASE	- - -	---	0.70
MONOCALCIUM P, 21% P	0.60	0.53	0.53
LIMESTONE, GROUND	1.03	1.08	1.08
SALT	0.35	0.35	0.35
L-LYSINE-HCl	0.290	0.385	0.385
DL-METHIONINE	0.030	0.090	0.095
L-THREONINE	0.060	0.085	0.085
L-TRYPTOPHAN	0.005	0.013	0.013
VITAMIN PREMIX	0.15	0.15	0.15
TRACE MINERAL PREMIX	0.15	0.15	0.15
TOTAL	100	100	100
STANDARDIZED ILEAL DIGESTIBLE AMINO ACIDS, %			
LYSINE	0.90	0.89	0.90
ISOLEUCINE:LYSINE	62	63	63
LEUCINE:LYSINCE	143	153	152
METHIONINE:LYSINE	29	32	32
MET & CYS:LYSINE	56	56	56
THREONINE:LYSINE	61	61	61
TRYPTOPHAN:LYSINE	18	18	18
VALINE:LYSINE	70	70	70
TOTAL LYSINE, %	1.02	0.99	1.00
NET ENERGY, KCAL/LB	1,132	1,119	1,132
CRUDE PROTEIN, %	16.3	16.4	16.5
CALCIUM, %	0.55	0.55	0.55
TOTAL P, %	0.47	0.45	0.45
DIGESTIBLE P, %	0.25	0.25	0.25

[1]Diet option 1 is an example formulating a sorghum-based diet without adjusting for the energy content differences between corn and sorghum.
[2]Diet option 2 takes into account the slight differences in energy content between sorghum and corn and equalizes the net energy among the two diets.

RECOMMENDATIONS FOR FEEDING GRAIN SORGHUM

In this option the corn and sorghum diets not only contain the same amino acid fortification, but also the identical net energy content. Therefore, nutritionists have numerous options to take advantage of sorghum's versatility in diet formulation.

In conclusion, recent research with nursery and growing-finishing pigs shows improved nutritional and feeding value of grain sorghum than studies conducted in the 1970s and 1980s. The higher feeding value is likely because of better sorghum varieties and improved understanding of the digestible amino acids and phosphorus contained in grain sorghum as well as improvements in feed processing. Where in the past grain sorghum was valued at 96 percent the value of corn, it now appears that sorghum has a greater feeding value than in the past. In addition, sorghum's flexibility in diet formulation offers nutritionists the ability to lower diet costs yet maintain similar growth performance of pigs.

SORGHUM DDGS FEEDING VALUE

The use of grain sorghum as a feedstock for ethanol production has been increasing in recent years and could make a large contribution to the nation's fuel ethanol requirements. The starch content and ethanol yield from grain sorghum is comparable to that of corn (Zhao, 2008). Currently, about 24 ethanol plants produce some portion of their ethanol production from grain sorghum. As a result, the annual percentage of sorghum production used for ethanol has steadily increased from 11 percent in 2004 to about 31 percent in 2013 (United Sorghum Checkoff Program, 2013). These trends indicate that the supply of co-products, such as sorghum dried distillers grains with solubles (DDGS), will increase with the growing demand for grain sorghum used for ethanol production.

Since 2014, many ethanol plants have implemented technology to extract approximately 30 percent of the oil from DDGS sources, regardless of the parent grain. This has a great impact on the nutritional value of all DDGS sources as the oil content has been shown to be directly related to the energy content of the DDGS. As a result, DDGS sources with 10 percent oil are going to be much more valuable and difficult to source than those with 7-8 percent oil (Graham et al., 2014). Therefore, when evaluating any DDGS source it is essential to know the oil content to

SORGHUM DDGS FEEDING VALUE

determine its economic value relative to cereal grains.

The available information on the nutrient composition of sorghum DDGS is highly variable and there are some limited or missing values, such as accurate energy estimates and digestibility of phosphorus that need to be explored. However, within the available literature and reference sources, sorghum DDGS will generally be higher in crude protein and contain more total phosphorus than corn DDGS (Table 8). Assuming a similar digestibility of phosphorus among the two DDGS sources, the use of sorghum DDGS will decrease the amount of supplemental inorganic phosphorus sources needed and, like its parent grain, will help reduce phosphorus excretion in swine waste and benefit the environment.

While research on the feeding value of sorghum DDGS in swine diets is limited, available data indicates that feeding 10-20 percent sorghum DDGS will have minimal effects on growth performance of nursey and finishing pigs. Furthermore, sorghum DDGS may offer some advantages compared with corn DDGS for pigs in carcass fat quality. Because oil from sorghum is less unsaturated than corn, this appears to result in firmer carcass fat in sorghum DDGS fed pigs compared with those fed similar amounts of corn DDGS.

SORGHUM DDGS COMPOSITION

ENERGY VALUE

There is limited published information on the energy content of sorghum DDGS. However, when evaluating any DDGS source it is essential to know the oil content to determine its economic value relative to other DDGS sources and cereal grains. The current estimated energy content in sorghum DDGS is based on it containing 9.8 percent oil (NRC, 2012; Table 8). These published energy values are slightly greater than both corn DDGS with 8.9 percent and 10.4 percent oil. One option for determining the energy value of sorghum DDGS with different oil concentrations would be to use equations that will predict energy content based on the ingredient's nutrient profile (INRA, 2014).

TABLE 8. TYPICAL NUTRIENT COMPOSITION OF SORGHUM AND CORN DRIED DISTILLERS GRAINS WITH SOLUBLES (AS-FED)[1]

	SORGHUM DDGS	CORN DDGS	
ITEM	9.8% OIL	>6% AND <10% OIL	>10% OIL
DRY MATTER, %	89.8	89.3	89.3
GROSS ENERGY, KCAL/KG	2,204	2,136	2,199
DIGESTIBLE ENERGY, KCAL/LB	1,758	1,624	1,642
METABOLIZABLE ENERGY, KCAL/LB	1,664	1,540	1,557
NET ENERGY, KCAL/LB	1,086	1,063	1,081
CRUDE PROTEIN, %	30.8	27.4	27.3
CALCIUM, %	0.12	0.08	0.12
PHOSPHORUS, %	0.76	0.60	0.73
DIGESTIBLE PHOSPHORUS, %	---[2]	0.39	0.47
CRUDE FAT, %	9.8	8.9	10.4
NDF, %	33.6	30.5	32.5
ADF, %	22.7	12.0	11.8

[1]Values are derived from NRC. 2012. Nutrient Requirements of Swine. 11th rev. ed. Natl. Acad. Press, Washington, D.C.
[2]Not available for sorghum DDGS.

AMINO ACID PROFILE

The differences in chemical composition between grain sorghum and corn are also reflected in the amino acid content of sorghum DDGS and corn DDGS. Currently, research to determine the SID amino acid content of sorghum DDGS is limited to one study (Urriola et al., 2009) on which the NRC (2012) estimates are based. Urriola et al. (2009) observed the SID coefficients of the major essential amino acids lysine, methionine, isoleucine, threonine, tryptophan and valine in sorghum DDGS and corn DDGS vary but when multiplied by the total amino acid concentration yield a very similar SID amino acid profile among the two sources (Table 9).

TABLE 9. AMINO ACID CONTENT OF SORGHUM DRIED DISTILLERS GRAINS WITH SOLUBLES (AS-FED)

	TOTAL AMINO ACIDS, %												
STUDY	ARG	HIS	ILE	LEU	LYS	MET	MET + CYS	PHE	PHE + TYR	THR	TRP	VAL	REFERENCE
1	1.11	0.71	1.46	4.27	0.76	---	0.96	---	2.92	1.14	0.23	1.75	SENNE ET AL. (1998) NORMAL ENDOSPERM
2	1.20	0.71	1.42	4.16	0.86	---	1.01	---	2.87	1.18	0.25	1.76	SENNE ET AL. (1998) HETEROWAXY ENDOSPERM
3	1.22	0.72	0.96	2.79	0.89	0.49	1.03	1.27	2.21	0.93	0.24	1.34	JENKINS (2003) SOURCE 1
4	1.23	0.79	1.25	4.03	0.89	0.56	1.18	1.64	2.86	1.08	0.21	1.60	JENKINS (2003) SOURCE 2
5	1.17	0.72	1.25	3.86	0.84	0.49	1.07	1.60	2.78	1.03	0.22	1.58	JENKINS (2003) SOURCE 3
6	1.29	0.77	1.25	3.93	0.95	0.58	1.16	1.46	2.59	1.09	0.20	1.67	JONES ET AL. (2009) SOURCE 1
7	1.15	0.70	1.25	3.92	0.84	0.50	1.02	1.42	2.50	1.03	0.19	1.62	JONES ET AL. (2009) SOURCE 2
8	1.10	0.71	1.36	4.17	0.68	0.53	1.02	1.68	---	1.07	0.35	1.65	URRIOLA ET AL. (2009)
9	1.17	0.67	1.37	3.84	0.88	0.55	---	1.48	---	1.04	0.26	1.67	SOTAK ET AL. (2014)
AVERAGE	1.18	0.72	1.29	3.89	0.84	0.53	1.06	1.51	2.68	1.07	0.24	1.63	AVERAGE OF 9 STUDIES
	79	72	74	77	64	77	--	77	--	70	72	74	SID COEFFICIENT, %[1]
	0.93	0.52	0.95	3.00	0.54	0.41	--	1.16	--	0.75	0.17	1.21	SID, %[2]
CORN DDGS	1.23	0.74	1.06	3.25	0.90	0.57	1.01	1.37	2.59	0.99	0.20	1.39	NRC, 2012
	81	78	76	84	61	82	--	81	--	71	71	75	SID COEFFICIENT, %[3]
	1.00	0.58	0.81	2.73	0.55	0.47	--	1.11	--	0.70	0.14	1.04	SID, %[2]

[1]Standardized ileal digestible (SID) coefficient refers to the amino acid digestibility coefficient (Urriola et al., 2014).
[2]Standardized ileal digestible (SID) concentration.
[3]Standardized ileal digestible (SID) coefficient refers to the amino acid digestibility coefficient (NRC, 2012).

DIGESTIBLE PHOSPHORUS

The concentration of phosphorus in sorghum DDGS is greater than that of corn DDGS (0.76 percent vs. 0.60 percent, respectively; NRC, 2012). In corn DDGS, the digestibility of total phosphorus is estimated to be 65 percent, but there are no referenced estimates of the standardized total tract digestibility values for sorghum DDGS. However, data on P bioavailability in sorghum DDGS is provided in one study. Jenkins (2003) evaluated P utilization in sorghum DDGS in growing pigs using both the slope ratio assay and digestibility study. Phosphorus bioavailability values from the slope ratio assay were 80 percent relative to monosodium phosphate for one source of sorghum DDGS and 60 percent for two other sources. Overall, sorghum DDGS had greater P bioavailability compared to grain sorghum. Though more research is needed, P digestibility in sorghum DDGS may be similar or greater than corn DDGS. Therefore, until further research is conducted, a conservative approach in diet formulation would be to use similar phosphorus digestibility coefficients for sorghum DDGS as corn DDGS. Using this approach in diet formulation, one of the advantages of using sorghum DDGS will still be a greater digestible P value compared with corn DDGS.

FATTY ACID PROFILE

Nearly 50 percent of the fatty acids in sorghum DDGS is linoleic acid (C18:2N6; Feoli et al., 2007a; Table 10). Other major fatty acids in sorghum DDGS are oleic acid (C18:1n6; 28 percent) and palmitic acid (C16:0; 17 percent). This is expected, as linoleic acid comprises 28-51 percent of the fatty acids in oil obtained from sorghum (Mehmood et al., 2008). However, linoleic acid content of corn oil ranges from 40-70 percent of the total fatty acids (White et al., 2007). Sotak et al. (2014) fed finishing pigs a sorghum-soybean meal diet, a sorghum-based diet with 30 percent sorghum DDGS, or a corn based diet with 30 percent corn DDGS. While adding 30 percent of either DDGS source to the diet increased unsaturated fatty acids and iodine value of backfat, pigs fed the sorghum-sorghum DDGS diet had significantly lower linoleic acid, polyunsaturated fatty acids, and thus a lower iodine value (firmer carcass fat) than those fed the corn-corn DDGS-based diet (Table 11). Therefore, when added to finishing diets, sorghum DDGS may be included at higher rates compared to corn DDGS with less affect on carcass fat quality. With proper diet formulation, sorghum DDGS can be used as effectively as corn DDGS in swine diets.

SORGHUM DDGS COMPOSITION

TABLE 10. FATTY ACID ANALYSIS OF SORGHUM, CORN AND THEIR RESPECTIVE DDGS (SOTAK ET AL., 2015)

ITEM	CORN	SORGHUM	CORN DDGS	SORGHUM DDGS
PALMITIC ACID (C16:0), %	16.30	14.35	15.02	16.82
STEARIC ACID (C18:0), %	1.71	2.25	2.13	1.84
OLEIC ACID (C18:1 *CIS*-9), %	26.36	22.42	26.25	27.57
LINOLEIC ACID (C18:2N-6), %	55.77	47.33	50.86	46.70
A-LINOLENIC ACID (C18:3N-3), %	2.55	1.52	1.91	2.41
TOTAL SFA[1], %	17.94	19.08	18.32	19.69
TOTAL MUFA[2], %	23.81	29.48	28.34	30.48
TOTAL PUFA[3], %	57.49	50.19	52.95	49.33
TOTAL *TRANS* FATTY ACIDS, %	1.52	2.55	1.98	2.53
IODINE VALUE, G/100G	121	114	118	114

[1]Total Saturated fatty acids
[2]Total Monounsaturated fatty acids
[3]Total Polyunsaturated fatty acids

In summary, the difference in the nutrient composition of sorghum and corn DDGS is similar to the differences between grain sorghum and corn. However, like corn DDGS, there is considerable variation in energy estimates in energy estimates in sorghum DDGS because of the difference in oil the extraction process used by ethanol plants. Sorghum DDGS appears to be higher in digestible phosphorus which will

decrease the amount of inorganic phosphorus needed in diet formulation and have a beneficial effect on the environment. Pigs fed sorghum DDGS will generally have firmer fat (a low iodine value) because it is lower in unsaturated fatty acids compared with corn DGS. These quality traits when feeding sorghum- or sorghum-DDGS=based diets may have an important role in pork export markets.

TABLE 11. EFFECT OF SORGHUM OR CORN DRIED DISTILLERS GRAINS WITH SOLUBLES (DDGS) ON BACKFAT FATTY ACID PROFILE[1]

ITEM	SORGHUM-SOYBEAN MEAL	SORGHUM DDGS, 30%	CORN DDGS, 30%	P-VALUE SORGHUM DDGS VS. CORN DDGS
PALMITIC ACID (C16:0), %	25.2	23.9	22.9	0.03
STEARIC ACID (C18:0), %	13.5	12.7	12.1	0.24
OLEIC ACID (C18:1 *CIS*-9), %	40.7	38.3	37.4	0.10
LINOLEIC ACID (C18:2N-6), %	9.4	14.2	17.2	0.01
TOTAL SFA[2], %	41.1	38.9	37.2	0.04
TOTAL MUFA[3], %	47.3	44.2	42.9	0.05
TOTAL PUFA[4], %	10.6	15.7	18.8	0.01
IODINE VALUE, G/100G	58.7	64.8	68.6	0.01
FAT COLOR				
L*	84.8	85.7	84.9	0.29
A*	3.3	3.0	2.7	0.34
B*	11.1	10.9	10.6	0.36

[1] Adapted from Sotak et al. 2015.
[2]Total Saturated fatty acids.
[3]Total Monounsaturated fatty acids.
[4]Total Polyunsaturated fatty acids.

NURSERY PIGS

A total of seven experiments have evaluated the effects of including sorghum DDGS in nursery diets (Table 12). Overall, sorghum DDGS included in up to 30 percent of the diet did not affect ADG, ADFI and F/G of weanling pigs compared with those fed diets without sorghum DDGS. One research study observed quadratic reductions in ADG and F/G of nursery pigs fed diets with 0, 15, 30, 45 and 60 percent sorghum DDGS (Senne et al., 1996). These changes in performance mainly resulted from a linear reduction in ADFI as inclusion of sorghum DDGS increased; however, most of the negative effects were observed at 45 and 60 percent inclusion of sorghum DDGS. Two studies compared the growth performance of nursery pigs fed diets with 30 percent corn or sorghum DDGS. The first study showed that pigs fed sorghum DDGS had similar ADG, but had higher ADFI and poorer F/G than pigs fed corn DDGS (Jones et al., 2010). The higher ADFI observed in this study may be a result of the lower energy content in sorghum DDGS relative to corn DDGS. In contrast, the second study showed

TABLE 12. GROWTH PERFORMANCE OF NURSERY PIGS FED SORGHUM DRIED DISTILLERS GRAINS WITH SOLUBLES

STUDY	BW (LB)	NO. OF PIGS	CRITERIA (LB)	SORGHUM-DDGS, % OF DIET							REFERENCE
				0	10	15	20	30	45	60	
1	15 TO 40	72	ADG	1.02	1.06	--	1.01	--	--	--	SENNE ET AL. (1995)
			ADFI	1.64	1.71	--	1.76	--	--	--	
			F/G	1.61	1.61	--	1.74	--	--	--	
2	13 TO 33	180	ADG	1.07	--	1.10	--	1.02	0.88	0.71	SENNE ET AL. (1996)
			ADFI	1.72	--	1.62	--	1.43	1.42	1.28	
			F/G	1.61	--	1.47	--	1.40	1.61	1.80	
3	17 TO 50	72	ADG	1.27	--	--	--	1.20	--	--	FEOLI ET AL. (2008A)
			ADFI	1.82	--	--	--	1.80	--	--	
			F/G	1.43	--	--	--	1.50	--	--	
4	24 TO 47	350	ADG	1.05	--	--	1.07	1.01	--	--	JONES ET AL. (2010) SOURCE 1
			ADFI	1.60	--	--	1.68	1.65	--	--	
			F/G	1.52	--	--	1.57	1.63	--	--	
5	24 TO 47	350	ADG	1.05	--	--	1.05	1.02	--	--	JONES ET AL. (20010) SOURCE 2
			ADFI	1.60	--	--	1.68	1.68	--	--	
			F/G	1.52	--	--	1.60	1.65	--	--	
6	15 TO 50	360	ADG	1.08	--	1.04	--	1.04	1.03	--	SOTAK ET AL (2014) EXP. 1
			ADFI	1.65	--	1.70		1.69	1.62	--	
			F/G	1.53	--	1.64	--	1.62	1.64	--	
7	24 TO 48	180	ADG	1.19	--	--	--	1.15	--	--	SOTAK ET AL. (2014) EXP. 2
			ADFI	1.90	--	--	--	1.85	--	--	
			F/G	1.60	--	--	--	1.61	--	--	

greater ADG and ADFI in pigs fed sorghum DDGS (Feoli et al., 2008a). As with corn DDGS, the differences in results may be attributed to the variability in oil content of different sorghum DDGS sources. In summary, sorghum DDGS can be used at 10-20 percent of the diet without affecting growth performance of nursery pigs.

GROWING-FINISHING PIGS

A number of studies evaluated the effects of including sorghum DDGS in growing-finishing diets (Table 13). In the first experiment, sorghum DDGS was added at 0, 10, 20 and 30 percent of the diet fed to growing-finishing pigs and showed no differences in growth performance (Senne et al., 1995). In another study, feeding sorghum DDGS from 0-60 percent of diets resulted in linear reductions in ADFI but did not affect ADG of finishing pigs (Senne et al., 1996). As a result, a linear improvement in F/G was observed with increasing sorghum DDGS. However, in more recent studies, feeding 40 percent sorghum DDGS to finishing pigs reduced ADG, ADFI and F/G compared to pigs fed a typical corn-soy diet (Senne et al., 1998; Feoli et al., 2007c; Feoli et

TABLE 13. GROWTH PERFORMANCE OF GROWING-FINISHING PIGS FED SORGHUM DRIED DISTILLERS GRAINS WITH SOLUBLES

STUDY	BW (LB)	NO. OF PIGS	CRITERIA (LB)	SORGHUM-DDGS, % OF DIET								REFERENCE
				0	10	15	20	30	40	45	60	
1	94 TO 192	192	ADG	1.97	1.98	--	1.93	1.93	--	--	--	SENNE ET AL. (1995)
			ADFI	5.22	5.19	--	4.98	5.08	--	--	--	
			F/G	0.38	0.38	--	0.39	0.38	--	--	--	
2	120 TO 246	80	ADG	2.09	--	--	2.22	--	2.22	--	2.19	SENNE ET AL. (1996)
			ADFI	6.97	--	--	6.75	--	6.66	--	6.38	
			F/G	0.30	--	--	0.33	--	0.33	--	0.34	
3	143 TO 248	192	ADG	1.96	--	--	--	--	1.84	--	--	SENNE ET AL. (1998)
			ADFI	7.00	--	--	--	--	7.38	--	--	
			F/G	0.28	--	--	--	--	0.25	--	--	
4	141 TO 287	88	ADG	2.08	--	--	--	--	2.00	--	--	FEOLI ET AL. (2007A)
			ADFI	6.93	--	--	--	--	7.15	--	--	
			F/G	0.30	--	--	--	--	0.29	--	--	
5	158 TO 287	56	ADG	2.12	--	--	--	--	1.96	--	--	FEOLI ET AL. (2007B)
			ADFI	7.34	--	--	--	--	6.98	--	--	
			F/G	0.29	--	--	--	--	0.28	--	--	
6	141 TO 284	132	ADG	2.14	--	--	--	--	1.96	--	--	FEOLI ET AL. (2008A)
			ADFI	6.71	--	--	--	--	6.43	--	--	
			F/G	0.32	--	--	--	--	0.30	--	--	
7	150 TO 271	56	ADG	1.80	--	--	--	--	1.69		--	FEOLI ET AL. (2008B)
			ADFI	6.32	--	--	--	--	6.07		--	
			F/G	0.28	--	--	--	--	0.28		--	
8	130 TO 290	288	ADG	2.31	--	2.25	--	2.19	--	2.18	--	SOTAK ET AL. (2015)
			ADFI	7.00	--	6.91	--	6.73	--	6.78	--	
			F/G	3.04	--	3.07	--	3.07	--	3.11	--	

al., 2008a, b). One study compared the growth performance of finishing pigs fed 40 percent corn or sorghum DDGS (Feoli et al., 2008a). Results showed similar ADG but greater ADFI and lower F/G in pigs fed sorghum DDGS. The higher ADFI may be a response to the lower energy content of sorghum DDGS compared to corn DDGS.

Recent studies also evaluated carcass traits and showed that feeding sorghum DDGS to finishing pigs at 40 percent of the diet resulted in lower hot carcass weight but did not affect dressing percentage, lean percentage, backfat thickness and loin depth (Feoli et al., 2007c; Feoli et al., 2008b). In terms of carcass fat quality, sorghum DDGS in finishing diets resulted in lower jowl and backfat fat iodine values compared with those pigs fed corn-corn DDGS-based diets (Sotak et al., 2014).

In summary, studies for both nursery and growing-finishing pigs have shown that sorghum DDGS can be fed at 10-20 percent of the diet without negative effects on growth performance or carcass characteristics.

SORGHUM DDGS TRIALS REVIEW

LACTATING SOWS

Research is limited to one study determining the feeding value of sorghum DDGS in lactation diets for sows (Sotak-Peper et al., 2015). This study compared sow and litter performance when fed diets containing either sorghum- or corn-based diets with or without 20 percent sorghum DDGS. Overall there were no differences in litter weaning weight or litter weight gain among sows fed the corn, corn-sorghum DDGS or sorghum-based diets. However, the combination of grain sorghum and 20 percent sorghum DDGS reduced litter weight and weight gain by 4 percent.

FEEDING RECOMMENDATIONS FOR SORGHUM DDGS

Based on current literature, it appears that sorghum DDGS can replace corn DDGS at 10 and 20 percent of the diet without negative effects on pig growth performance (Sotak et al., 2015). As mentioned earlier, the key to using any DDGS source is knowing its oil content in order to estimate an energy value. However, using NRC (2012) nutrient loadings replacing corn DDGS with sorghum DDGS will allow for greater use of crystalline amino acids and less soybean meal in the diet (Table 14). There would also be opportunities to use less inorganic phosphorus which would help reduce phosphorus excretion in swine waste, a benefit for the environment. Therefore, with careful consideration to diet formulation and investigation into the energy (oil) content of sorghum DDGS, they can be used at similar inclusion rates as corn DDGS in swine diets.

TABLE 14. EXAMPLE DIETS WITH GRAIN SORGHUM DRIED DISTILLERS GRAINS (DDGS) REPLACING CORN DDGS[1]

	10% DDGS DIETS		20% DDGS DIETS	
INGREDIENT, %	CORN	SORGHUM	CORN	SORGHUM
SORGHUM	---	72.45	---	66.85
CORN	69.78	---	63.51	---
SOYBEAN MEAL, 46.5% CP	17.68	15.21	13.85	10.32
CORN DDGS, >6 AND <9% OIL	10.00	---	20.00	---
SORGHUM DDGS, 9.8% OIL	---	10.00	---	20.00
MONOCALCIUM P, 21% P	0.48	0.40	0.35	0.25
LIMESTONE, GROUND	1.08	1.13	1.13	1.23
SALT	0.35	0.35	0.35	0.35
L-LYSINE-HCL	0.305	0.430	0.390	0.535
DL-METHIONINE	---	0.075	---	0.065
L-THREONINE	0.035	0.065	0.045	0.075
L-TRYPTOPHAN	0.006	0.016	0.020	0.031
VITAMIN PREMIX	0.15	0.15	0.15	0.15
TRACE MINERAL PREMIX	0.15	0.15	0.15	0.15
TOTAL	100.00	100.00	100.00	100.00
STANDARDIZED ILEAL DIGESTIBLE AMINO ACIDS, %				
LYSINE	0.90	0.90	0.90	0.90
ISOLEUCINE:LYSINE	65	65	63	64
LEUCINE:LYSINE	159	167	169	178
METHIONINE:LYSINE	29	33	30	32
MET & CYS:LYSINE	56	57	57	57
THREONINE:LYSINE	61	61	61	61
TRYPTOPHAN:LYSINE	18.0	18.0	18.0	18.0
VALINE:LYSINE	75	75	75	75
TOTAL LYSINE, %	1.04	1.02	1.06	1.03
NE, KCAL/LB	1,124	1,128	1,121	1,143
CP, %	17.4	17.3	17.7	17.4
CA, %	0.55	0.55	0.54	0.55
P, %	0.47	0.46	0.46	0.46
DIGESTIBLE P, %[2]	0.25	0.25	0.25	0.25

[1] Values are derived from NRC. 2012. Nutrient Requirements of Swine. 11th rev. ed. Natl. Acad. Press, Washington, D.C.
[2] Assumes equal digestibility between sorghum and corn DDGS.

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