ALTERNATIVE FEED INGREDIENTS FOR PIGS

Hans Stein[1] and Kees de Lange[2]
[1] Department of Animal Sciences, University of Illinois, Urbana IL 61801, USA
[2] Department of Animal and Poultry Science, University of Guelph, Guelph, ON, N1G 2W1, Canada
Email: hstein@uiuc.edu

ABSTRACT

Largely due to the demand for grains for the bio-fuel industry, the cost of feed energy will increase worldwide. Therefore, alternative energy supplying pig feed ingredients should be explored, including distillers dried grains with solubles (DDGS), field peas, wheat shorts and liquid co-products from the bio-fuel and food industry. The inclusion of DDGS in diets is limited by the fiber concentration in DDGS and for finishing pigs, also by the concentration of unsaturated fatty acids. However, most groups of swine can be fed at least 20% DDGS and sometimes, greater concentrations can be used. The concentration of available energy in DDGS is similar to corn, but some sources of DDGS have low concentrations of digestible lysine. To avoid feeding these sources, it is recommended that only DDGS that has a lysine to crude protein ratio that is greater than 2.80% is used in diets fed to swine. Field peas also contain available energy in amounts that are similar to corn and the pea protein has a high concentration of lysine, but a low concentration of methionine, cysteine, threonine, and tryptophan. Crystalline sources of these amino acids are, therefore, often required, if field peas are included in the diets. Diets fed to weanling pigs and sows may contain at least 20% field peas without changing pig performance. If the peas are extruded or micronised prior to feeding, greater concentrations may be used. Diets fed to growing-finishing pigs, may contain up to 70% field peas and no soybean meal is needed in these diets. Wheat shorts have been available for use in swine diets for many years. The available energy content of wheat shorts is lower than that of corn, but it contains more digestible amino acids and phosphorus than corn. If diets are formulated carefully, growing-finishing pig diets may contain 40% wheat shorts without compromising pig performance. Liquid feeding allows the use of liquid co-products such as whey, whey permeate, corn distillers solubles, brewers yeast, sugar syrup, and corn steep water. The nutritional value of these co-products has been characterized and recommendations for their use in pig diets are made. These co-products are generally more variable in nutritional value, which should be considered carefully when formulating and costing swine diets.

INTRODUCTION

Largely due to the demand for grains for the bio-fuel industry, the cost of feed energy will increase worldwide. It has been estimated that the cost of feed energy will likely increase by approximately 10%, while the cost of feed protein is likely to decline by more than 20% between 2006 and 2012 (Hickling, 2006). Feed protein will become cheaper because of increased supply of protein containing co-products from the bio-fuel industry, such as distillers grains and distillers solubles. In this contribution the nutritional value and use of a select number of alternative pig feed ingredients is addressed.

DISTILLERS DRIED GRAINS WITH SOLUBLES

Distillers dried grains with solubles (DDGS) is a co-product from the fuel ethanol industry. Barley, wheat, sorghum, or corn may be used in the production of ethanol and the resulting DDGS is characterized by the grain that was used. However, even when the same grain is used, variability in the chemical composition of DDGS may be observed.

Energy and nutrient concentration and digestibility

Analyzed concentrations of energy, phosphorus, and amino acids in DDGS are presented in Tables 1 and 2 along with measured contents of digestible energy, digestible phosphorus, and digestible amino acids. The average concentration of gross energy in DDGS is approximately 5,530 kcal GE per kg dry matter (**DM**). This value is greater than in corn. However, the digestibility of energy in DDGS is lower than in corn and the measured concentration of digestible (**DE**) and metabolizable (**ME**) energy in DDGS is 4,140 and 3,897 kcal per kg DM, respectively (Pedersen et al., 2007). These values are not different from the DE and ME in corn (Table 1).

Table 1. Concentration and digestibility of energy and phosphorus in corn and 10 samples of distillers dried grains with solubles (DDGS) fed to growing pigs [a,b]

Item	Ingredient: Corn	DDGS			
		Average	Standard deviation	Lowest value	Highest value
Gross energy, kcal/kg DM	4,496	5,434	292	5,272	5,592
Apparent total tract digestibility, %	90.4	76.8	2.73	73.9	82.8
Digestible energy, kcal/kg DM	4,088	4,140	205	3,947	4,593
Metabolizable energy, kcal/kg DM	3,989	3,897	210	3,674	4,336
Total P, %	0.20	0.61	0.09	0.51	0.74
Apparent digestibility of P, %	19.3	59.0	5.2	50	68
Digestible P, %	0.04	0.36	0.06	0.28	0.47

[a] Data from Pedersen et al., 2007.
[b] All data are based on 11 observations per treatment.

The phosphorus concentration in DDGS is approximately 0.61%, and the apparent total tract digestibility of phosphorus in DDGS is approximately 59% (Table 1). The corresponding value for corn is 19.3% (Pedersen et al., 2007). Therefore, if DDGS is included in diets fed to swine, the utilization of organic phosphorus will increase and the need for supplemental inorganic phosphorus (i.e., dicalcium phosphate or monocalcium

phosphate) will be reduced. This will not only reduce diet costs but also reduce the quantities of phosphorus that are excreted into the manure from the animals.
The concentration and standardized ileal digestibility of amino acids (Table 2) varies among sources of DDGS (Stein et al., 2005; Pahm et al., 2006a and b; Stein et al., 2006c; Urriola et al., 2007). This is true in particular for lysine that is more variable than all other indispensable amino acids in terms of digestibility (Fastinger and Mahan, 2006; Stein et al., 2006c). The reason for this variation is believed to be that lysine may have been heat-damaged in some of the samples of DDGS, which has lowered the calculated digestibility of lysine in these samples. To reduce the risk of utilizing sources of DDGS that have a low digestibility of lysine because of heat damage, the lysine to crude protein ratio can be calculated. If the ratio is 2.80% or greater, then the product will have an average or above average quality, but if the ratio is lower than 2.80, then the product has a reduced quality. Because lysine is usually the first limiting amino acid in diets fed to swine, DDGS samples with a lysine to crude protein ratio that is less than 2.80 should not be used.

Table 2. Crude protein and amino acid concentration and digestibility in 36 samples of distillers dried grains with solubles (DDGS) fed to growing pigs [a]

Item	Concentration, %				Standardized ileal digestibility, %			
	Average	Low	High	SD	Average	Low	High	SD
CP	27.5	24.1	30.9	1.8	72.8	63.5	84.3	5.33
Indispensable AA								
Arg	1.16	0.95	1.41	0.10	81.1	74.1	92.0	5.18
His	0.72	0.56	0.84	0.07	77.4	70.0	85.0	4.58
Ile	1.01	0.87	1.31	0.09	75.2	66.5	82.6	4.77
Leu	3.17	2.76	4.02	0.32	83.4	75.1	90.5	3.85
Lys	0.78	0.54	0.99	0.09	62.3	43.9	77.9	7.61
Met	0.55	0.46	0.71	0.08	81.9	73.7	89.2	4.12
Phe	1.34	1.19	1.62	0.11	80.9	73.5	87.5	3.94
Thr	1.06	0.89	1.71	0.20	70.7	61.9	82.5	5.26
Trp	0.21	0.12	0.34	0.04	69.9	54.2	80.1	6.98
Val	1.35	1.15	1.59	0.11	74.5	65.8	81.9	4.72

[a]Data from Stein et al., 2005; Pahm et al., 2006a and b; Stein et al., 2006c; Urriola et al., 2007.

Formulating diets using DDGS

When formulating diets for growing pigs or lactating sows using DDGS, it is recommended that energy values that are similar to corn are used for DDGS. Diets should be formulated based on standardized ileal digestible amino acids and digestible phosphorus. Because the protein in DDGS is relatively low in lysine, additional crystalline lysine needs to be included in the diet when DDGS is used. As a rule of thumb, for each 10% DDGS that is used, the inclusion of crystalline lysine should be increased by 0.10% (Table 3). By following this principle, approximately 4.25% soybean meal and

5.70% corn can be removed. Because of the greater concentration and digestibility of phosphorus in DDGS than in corn and soybean meal, approximately 0.20% monocalcium phosphate can also be removed from the diet for each 10% DDGS that is used, but additional limestone is needed to maintain a proper concentration of calcium.

Table 3. Replacement value of 10% DDGS

Item Diet:	Gestation diets	All other diets
Corn	↓ 7.40	↓ 5.70
Soybean meal, 48%	↓ 2.40	↓ 4.25
MCP, %	↓ 0.22	↓ 0.20
Fat	↓ 0.10	↓ 0.05
L-Lysine HCL	↑ 0.03	↑ 0.10
Limestone	↑ 0.09	↑ 0.10

If diets for gestating sows are formulated with DDGS, less soybean meal can be removed from the diet because gestating sows have a relatively greater requirement for digestible tryptophan than lactating sows and growing pigs. Because DDGS has a low concentration of tryptophan, it is possible to maintain a proper tryptophan concentration in gestation diets only if the reduction in soybean meal is limited to 2.40% for each 10% DDGS that is included in the diet. As a consequence, if 10% DDGS is included in gestating diets, the concentration of corn in the diet can be reduced by 7.40%.

Inclusion rates of DDGS in diets fed to swine

Table 4. Recommended and maximum inclusion levels in diets fed to different categories of swine

Category	Recommended [a]	Maximum [b]
Gestation	30	50
Lactation	20	30
Nursery, week 0-2	0	20
Nursery, after wk 2	20	30
Grower	20	35
Early finisher	20	35
Late finisher	20	20

[a]Recommended inclusion levels based on a review of experiments in which DDGS was included in diets fed to swine.
[b]Maximum levels of DDGS that have been successfully used under field conditions. These inclusion levels may not always maximize pig performance.

Recent research has shown variable results in pig responses to the inclusion of DDGS in the diets. Excellent performance has been reported from many experiments (DeDecker et al., 2005; Cook et al., 2005; Spencer et al., 2007), but in other cases, pig performance has been reduced (Linneen et al, 2006; Whitney et al., 2006b). Nevertheless, based on current knowledge it is recommended that diets fed to lactating sows, to nursery pigs after two weeks post-weaning, and to growing finishing pigs may contain at least 20% DDGS and diets fed to gestating sows may contain at least 40% DDGS. These inclusion rates will not compromise pig performance if the diets are carefully formulated using the principles outlined above and if a source of DDGS that has a lysine to crude protein ratio that is greater than 2.80% is used (Table 4).

In a recent experiment in which these principles were followed, no negative effect on pig performance was observed (Table 5). It is also possible that greater inclusion rates can be used if a good source of DDGS is available and some producers are successfully using up to 35% DDGS in diets fed to growing pigs, but the research to support such inclusion rates has not yet been conducted.

Table 5. Effects of including 0, 10, or 20% distillers dried grains with solubles (DDGS) in diets fed to growing-finishing pigs[a]

Item	Diet: Control	DDGS		SEM	P-Value	
		10%	20%		Linear	Quadratic
Initial wt, kg	22.1	21.85	22.47	0.48	0.82	0.40
Final wt, kg	124.1	127.7	124.9	2.77	0.77	0.23
Average daily gain, kg	0.89	0.93	0.90	0.02	0.76	0.22
Average daily feed intake, kg	2.57	2.75	2.60	0.08	0.78	0.11
Feed conversion ratio, lb/lb	0.35	0.34	0.35	0.01	0.94	0.32
Hot carcass wt, kg	88.3	91.7	88.7	2.54	0.91	0.25
Dressing, %	71.1	71.8	71.0	0.48	0.85	0.23
Lean meat, %	51.30	50.15	51.17	1.20	0.92	0.31
10^{th} rib backfat, cm	2.50	2.60	2.40	0.21	0.70	0.46

[a]Data from Widmer et al., 2007.

Other consequences of using DDGS

The relatively high concentration of fat in DDGS may increase problems with feed bridging in bins and feeders. In some cases, therefore, it may be necessary to modify storage and delivery systems if DDGS is used in the diets. Diets containing DDGS are also bulkier than diets without DDGS. As a rule of thumb, for each 10% DDGS that is included in the diet, the volume of the diet will increase by approximately 3% compared with a corn-soybean meal diet.

The fat in DDGS has a relatively high concentration of unsaturated fatty acids, which may cause increased belly softness of pigs fed diets containing DDGS (Whitney et al., 2006b). This may become a problem if the finishing diet contains more than 20% DDGS. The inclusion of DDGS in diets fed to nursery and growing pigs may improve intestinal health and reduce problems with ileitis. Many producers, therefore, prefer to have 20% DDGS in all diets fed to these categories of pigs, but research to demonstrate the health benefits of using DDGS has been inconclusive (Whitney et al., 2006a). Increased litter sizes of sows fed diets containing DDGS has also been reported from one experiment, but more research in this area is needed to verify the positive effects of DDGS on litter size.

FIELD PEAS

Field peas (*Pisum sativum L.*) have been grown for centuries in many parts of the world. Historically, field peas have been produced mainly for human consumption, but during the last 25 years, the industry has also found markets for field peas in livestock feeding. In Canada, Australia, and Western Europe, the use of field peas in diets fed to swine has increased during this period. In the US, field peas have been included in diets fed to swine in the Pacific Northwest for several decades, but in the Midwest, where the majority of the pigs are produced, very few field peas have been used.

Nutrient and energy concentration and digestibility

Field peas have a nutrient profile that is intermediate between corn and soybean meal. The digestibility of most amino acids in field peas is similar to that in soybean meal (Table 6), but pea protein has a relatively low concentration of methionine, cysteine, and tryptophan. Therefore, these amino acids may become limiting if peas are included in the formulations.

Table 6. Amino acid composition of the protein and amino acid and protein digestibility in field peas and soybean meal (as fed basis)[a]

Ingredient:	Field peas			Soybean meal		
Item:	% of ingredient	% of crude protein	SID [b]	% of ingredient	% of crude protein	SID [b]
Nutrient						
Crude protein	22.8	100	79.9	47.5	100	84.5
Arginine	1.87	8.20	92.8	3.48	7.32	93.0
Histidine	0.54	2.37	88.3	1.28	2.70	89.7
Isoleucine	0.86	3.77	83.4	2.16	4.55	86.3
Leucine	1.51	6.62	85.7	3.66	7.71	86.1
Lysine	1.50	6.58	88.1	3.02	6.36	88.4
Methionine	0.21	0.92	77.9	0.67	1.41	89.1
Cysteine	0.31	1.36	67.3	0.74	1.56	83.9
Phenylalanine	0.98	4.30	86.9	2.39	5.05	86.9
Tyrosine	0.71	3.11	84.7	1.82	3.83	87.2
Threonine	0.78	3.42	80.2	1.85	3.90	85.9
Tryptophan	0.19	0.83	54.3	0.65	1.37	78.5
Valine	0.98	4.30	78.2	2.27	4.78	82.7

[a]Data for amino acid concentration and composition are from NRC (1998). Data for SID of protein and amino acids are from Stein et al., 2004.
[b]SID = standardized ileal digestibility (%).

The concentration of digestible energy (3,864 kcal DE per kg DM) in field peas is similar to that in corn, but peas contain slightly less metabolizable energy (3,741 kcal ME/kg DM) compared with corn (Stein et al., 2004). The digestibility of energy may be improved by 3 – 4 percentage units upon extrusion at 115^{o}C. Likewise, the digestibility of most nutrients will also be improved if the peas are extruded prior to feeding (Stein et al., 2007). The concentration of phosphorus in field peas is approximately 0.44% and the apparent total tract digestibility of phosphorus in field peas is 55 and 65%, respectively, in diets without or with microbial phytase (Stein et al., 2006a).

Diet formulation with field peas

Lysine and tryptophan are the first limiting amino acids in diets based on corn and field peas, but because of the relatively low concentrations of digestible methionine, cysteine, and threonine in field peas, it is also necessary to pay careful attention to the concentrations of these amino acids. It is often necessary to include crystalline sources of methionine, threonine, and tryptophan in diets based on field peas to formulate a diet balanced in all indispensable amino acids. In contrast, the inclusion of crystalline lysine and inorganic sources of phosphorus may be reduced because of the relatively high concentrations of these nutrients in field peas. The concentration of most nutrients in field peas is intermediate between the concentration in corn and soybean meal. Therefore, if field peas are included in the formula, corn and soybean meal is reduced. As a rule of thumb, 3% field peas will replace approximately 2% corn and 1% soybean meal if crystalline sources of methionine, threonine, and tryptophan are included to balance concentrations of indispensable amino acids. At the same time, the inclusion of crystalline lysine and monocalcium phosphate (or dicalcium phosphate) is reduced. In experiments where field peas were successfully included in diets fed to swine, these principles for diet formulation were followed.

Inclusion rates of field peas in diets fed to swine

Pigs tolerate field peas well and the feed intake is not affected by the presence of field peas in the diets. Recent research with field peas indicates that field peas may be included in diets fed to nursery pigs from two weeks post-weaning at an inclusion level of 15 to 20% (Stein et al., 2004). At this concentration, no negative effects on pig performance have been reported (Table 7). In contrast, the inclusion of 30% field peas in diets fed to weanling pigs resulted in a reduced gain:feed ratio during the initial 2 weeks after weaning, but not during the remaining nursery period (Owusu-Asiedu et al., 2002). Based on these results, it is recommended that field peas should not be included in diets fed to weanling pigs during the initial 2 weeks post-weaning. If the field peas are extruded or micronized, it may be possible to include greater concentrations without any impact on pig performance (Landblom, 2002; Owusu-Asiedu et al., 2002).

In diets fed to growing and finishing pigs, field peas may be included in concentration of up to 60 to 70% of the diets without influencing pig performance (Petersen and Spencer, 2006; Stein et al., 2006b). At these inclusion levels, all of the soybean meal is replaced by field peas. Field peas do not influence feed intake, average daily gain, or the gain to feed ratio (Table 8). Lower carcass drip losses and a more desirable color of the longissimus muscle have been reported for pigs fed diets containing field peas, but other carcass characteristics have not been influenced by field peas in the diets. Likewise, the palatability of pork chops and ground pork patties are not changed by the inclusion of field peas in the diets (Stein et al., 2006b).

Table 7. Growth performance of weanling pigs fed diets containing field peas [a]

Field peas, %:	0	6	12	18	SEM	*P*-value	
						Linear	Quadratic
Response							
Average initial weight, kg	7.81	7.81	7.79	7.79	0.68	0.98	0.99
Average finished weight, kg	19.65	20.02	19.90	19.17	1.33	0.79	0.68
Average daily gain, kg	0.423	0.436	0.433	0.407	0.025	0.64	0.44
Average daily feed intake, kg	0.66	0.66	0.70	0.64	0.05	0.91	0.54
Average gain:feed, kg/kg	0.62	0.64	0.62	0.64	0.015	0.66	0.67

[a] Data from Stein et al. (2004). Six pens per treatment and five pigs per pen.

Table 8. Growth performance and carcass quality of growing-finishing pigs fed diets without or with field peas [a]

Field peas (%) [b]:	0/0/0	36/36/36	66/48/36	SEM	*P*-value
Response					
Initial weight, kg	22.9	22.7	22.7	0.55	0.49
Average daily feed intake, kg	2.74	2.60	2.82	0.079	0.12
Average daily gain, kg	0.872	0.860	0.889	0.0247	0.59
Average gain:feed ratio, kg/kg	0.319	0.332	0.318	0.0087	0.38
Final weight, kg	129.0	124.1	129.2	3.18	0.59
Dressing, %	76.2	75.4	75.8	0.34	0.20
10th rib back fat, cm	2.32	2.40	2.41	0.134	0.81
Lean meat, %	51.8	51.0	51.3	0.636	0.67
Drip loss, %	3.38	2.51	1.95	0.322	0.02

[a]Data from Stein et al. (2006b). Each mean represents eight observations with two pigs per pen.
[b]Values represent the inclusion rate (%) of field peas in diets fed from 22 to 50 kg, 50 to 85 kg, and 85 to 125 kg, respectively.

Research conducted at North Dakota State University suggested that the inclusion of 10% field peas in diets fed to lactating sows resulted in increased litter weight gain and a tendency for reduced pig mortality during the lactation period (Landblom et al., 2001). This experiment also showed that there is no negative effect of including up to 30% field peas in diets fed to lactating sows. There are no data available from studies in which field peas grown in North America have been fed to gestating sows. However, data from

France suggested that the inclusion of 16% field peas in gestating diets and 24% in lactating diets had no negative effects on sow or pig performance (Gatel et al., 1987). It is, therefore, concluded that field peas may be included in diets fed to gestating and lactating sows at levels of 20 to 30%, but more research in this area is needed.

WHEAT SHORTS

Wheat shorts, often called wheat middlings in the USA and a co-product from the wheat flour industry, have been available for use in swine diets in Ontario for many years. Numerous nutrient analyses, digestibility and performance studies have been conducted to explore its nutritional value for pigs (Young, 1980; Erickson et al., 1985; Huang et al., 1999; Cromwell et al., 2000; Shaw et al., 2002). These studies indicate that the nutritional value of wheat shorts is comparable to barley and lower than corn, largely because of the lower starch and higher fiber content. In spite of extensive research there is still some resistance among pork producers and nutritionists to accept the use of substantial amounts of wheat shorts in pig diets. The latter may be attributed to various factors, including variability between different batches, low bulk density, variable inclusion of high-fiber wheat bran, high mycotoxin levels in the product, or (negative) interactive effects of high dietary fiber and fat levels on digestive function in pigs.

Energy and nutrient concentration and digestibility

Like any co-product, the nutritional value of wheat shorts varies between batches of ingredients. Therefore, nutrient analyses should be conducted routinely to monitor differences between suppliers and changes over time, and to adjust estimated nutritional values. In particular, close attention should be paid to the fiber content of wheat shorts. For example in a survey in the US of 14 sources of wheat shorts, the NDF content varied from 29.9 to 40.1% (Cromwell et al., 2000). In that survey the crude protein content varied between 14.6 and 17.8%, total lysine content varied between 0.62 and 0.72%, and the phosphorus content varied between 0.70 and 1.19%. Based on an average DE content of 3075 kcal per kg and an average NDF content of 35.7% (NRC, 1998), the estimated DE content of wheat shorts may be reduced with 22 kcal per kg per % increase in NDF content (Zijlstra et al., 1999). For example, when the NDF content is increased to 40.7%, the estimated DE content would be reduced to 2965 kcal per kg. However, given the poor utilization of energy supplied by digestible fiber (and digestible protein), relative to starch, the use of net energy feed formulation systems will more accurately reflect the available energy content of wheat shorts than conventional DE and ME systems (Libao-Mercado et al., 2004).

The negative effect of fiber on energy utilization may be overcome partly by adding fiber degrading enzymes to the diet (Barrera et al., 2004). On the other hand, additional dietary fiber may enhance the feeling of satiety and thereby benefit the well-being of gestating sows fed wheat shorts containing diets. It should be noted, though, that different types of fiber have varying effects on satiety and that no fiber source has been proven as affective as beet pulp to reduce activity levels in gestating sows.

In terms of phosphorus, both the content (0.93 vs 0.28%) and relative availability (41 vs 14%) is higher in wheat shorts than corn (NRC, 1998). Even though the content of key essential amino acids is nearly twice as high in wheat shorts as in corn, the amino acid availability in wheat shorts is rather low. This reduced amino acid availability and effect of fiber on increases in amino acid requirements of pigs should be considered carefully when wheat shorts are included in pig diets (Huang et al., 1999; Libao-Mercado et al., 2006).

Diet formulations and inclusion rates of wheat shorts in diets fed to swine

In typical Ontario pig diets wheat shorts is used primarily to replace corn, but it will also reduce the use of soybean meal and inorganic phosphorus. In order to maintain energy density of the feed some additional fat needs to be included when replacing corn with wheat shorts. However, when fat is relatively expensive and increases the feed cost per unit energy (i.e., $ per MJ or kcal DE in the diet) the use of additional fat is not recommended, and slight reductions in feed efficiencies should be accepted when feeding wheat shorts to pigs.

When the nutritional value of wheat shorts is considered carefully in feed formulation, the use of substantial amounts of wheat shorts in the diet, will not compromise pig performance (Table 9). The maximum recommended inclusion level for wheat shorts is 10% of the diet for starter pigs and 40% of the diet for growing-finishing pigs and sows. However, when the nutritional value of wheat shorts is well defined - in terms of contents of available energy amino acids and phosphorus - inclusion levels may exceed these suggested maxima without compromising pig performance (Erickson et al., 1985).

Table 9. Impact of including 30% wheat shorts in corn and soybean meal based diets on performance and carcass characteristics of growing-finishing pigs [a]

	Diet			
	Control	+30% wheat shorts	SEM	P-value
Daily gain[b], kg	1.017	0.991		
Daily feed intake[b], kg	2.874	2.812		
Gain:Feed[b], kg/kg	0.353	0.352		
Dressing percentage[c]	73.9	73.3	0.42	0.10
Loin eye area[c], cm^2	38.3	39.5	1.17	0.67
Backfat depth[c], cm	2.10	1.95	0.13	0.79

[a] Derived from Shaw et al. (2002). Diets were formulated to be similar in content of metabolizable energy, by including additional fat in the wheat shorts containing diet, and balancing calcium, phosphorus and lysine. Diets were fed in meal form to pigs between 28 and 107 kg body weight.
[b] Gain and feed intake data were calculated from data presented for each of three phases in the three phase feeding program, with diet switches at 65 and 79 kg body weight.
[c] Michigan State Meat Laboratory measurements; in contrast to the Canadian carcass grading system, carcass excludes the head.

Because of its low bulk density, the inclusion of wheat shorts in mash feeds can cause feed flow problems and some feed separation. For these reasons, wheat shorts are used more effectively in pelleted feeds. Additional benefits of pelleting are that the utilization of energy in wheat shorts is enhanced slightly and that wheat shorts enhance pellet quality (Young, 1980; Erickson et al., 1985).

A final consideration is that increased dietary fiber levels tend to increase gut fill and size of digestive organs, reducing carcass dressing percentage. Estimates of the effect of feeding wheat shorts on reductions in carcass dressing percentage vary between 0.6 (Table 9) and 2.0 percentage units (Libao-Mercado et al., 2004).

LIQUID FEED INGREDIENTS

Liquid feeding allows the use of liquid and inexpensive co-products from food and bio-fuel industry, such as whey, whey permeate, corn distillers solubles, brewers yeast, sugar syrup, and corn steep water. In research conducted during the last few years at the University of Guelph, the nutritional value of these products has been characterized. Moreover, laboratory-based studies have been conducted to enhance the nutritional value of corn distillers solubles, corn steep water, as well as high-moisture corn mixed with water, through steeping with enzymes or inoculation with beneficial bacteria. Results of these studies have been presented in detail elsewhere (Braun and de Lange, 2004; de Lange et al., 2006) and can be accessed at the website of the Swine Liquid Feeding Association (SLFA, 2007). A summary of estimated nutritional value of these co-products is presented in Table 10.

In general and when the nutritional value of these liquid co-products is estimated from dry matter content and levels of key nutrients (ash, crude protein, crude fat, starch, sugars, remaining organic material) within dry matter, these co-products can be used for growing-finishing pig diets at levels up to 15% of diet dry matter content without compromising pig performance, carcass or meat quality (de Lange et al., 2006). In some cases improvements in pig growth performance were observed: replacing dry corn with liquid whey permeate in phase III pig starter diet, or including 5% of corn steep water in growing pig diets, improved growth rate. Improvements in pig growth performance can also be expected when feeding liquid whey, but the availability of liquid whey will continue to decline. Whey is increasingly further processed to isolate specific whey proteins that are marketed as value added and functional foods for humans.

Utilization of liquid feed ingredients requires specialized liquid feeding equipment and ingredient storage capacity, which should be considered when conducting cost-benefit analyses. Moreover, liquid feeding tends to increase the manure volume as compared to conventional dry feeding, largely because of increased water usage to move the mixed liquid feed to the feed troughs. Finally, additional expertise is required to adjust liquid feed formulations - when supplies or nutritional values of liquid feed ingredients change, or to account for extremely sodium, chloride and potassium levels in some liquid co-products - and to manage computerized liquid feeding systems.

Table 10. Determined nutrient content (% in dry matter), estimated digestible energy, amino acid and phosphorus contents (in dry matter) for the main liquid pig feed ingredients in Ontario.

	Corn distillers solubles	Whey	Condensed whey permeate (fresh)		Corn Steep water	Sugar syrup	Brewers Yeast
	(stored)	(fresh)	#2	#3	(stored)	(fresh)	(stored)
Dry matter, %	27.2	5.4	31.1	22.5	44.6	69.2	12.5
Nutrient composition, % of dry matter[1]							
Ash	10.0	12.3	11.06	7.62	18.8	0.42	7.55
Crude protein	25.2	13.3	8.18	2.97	50.0	0.32	52.42
Crude fat	22.4	0.3	1.06	0.29	0.3	1.83	2.62
Starch	6.8	-	-	-	4.7	0	5.7
Sugars	1.2	-	-	-	0.2	82.8	0.2
Lactose	0	60.6	62.6	67.9		0	0
Lactic acid	15.4	14.0	1.1	1.4	20.0	-	-
Rem. org. mat.	16.45	0	15.06	19.77	6.0	14.6	30.21
Minerals, % of dry matter							
Calcium	0.04	1.79	0.56	0.66	0.07	0.02	0.27
Phosphorus	1.43	1.26	0.65	0.70	3.03	0.01	1.58
Sodium	0.21	0.74	1.42	0.78	0.84	0.03	0.05
Potassium	2.31	2.77	2.68	1.93	4.87	0.05	2.15
Chloride	0.36	1.63	2.29	1.37	0.74	0.02	0.16
Digestible energy, MJ/kg of dry matter							
Calculated[2]	17.2	15.0	14.7	14.8	14.5	16.8	16.7
NRC (1998)	15.1	14.54	-	14.97	-	-	14.96
Standardized ileal digestible amino acid content, % of dry matter							
Lysine	0.44	0.89	0.45	0.13	1.06	0	3.35
Threonine	0.65	0.71	0.36	0.10	1.09	0	2.25
Methionine	0.37	0.17	0.08	0.02	0.95	0	0.68
Cysteine	0.29	0.26	0.12	0.03	0.97	0	0.37
Tryptophan	0.13	0.18	0.08	0.02	0.07	0	0.55
Isoleucine	0.85	0.55	0.31	0.11	0.97	0	2.15
Avail. Phosphorus	0.21	1.26	0.65	0.70	0.61	0.01	0.79

[1] Values from survey of Ontario samples (Braun and de Lange, 2004).
[2] Based on digestible nutrient content and GE content of nutrients (Braun and de Lange, 2004).

CONCLUSIONS

Diets containing DDGS, field peas, wheat shorts, liquid whey, whey permeate, corn steep water, and brewers yeast may be fed to pigs without reducing animal performance. It is always important to monitor the nutritional quality of the ingredients and diets containing these ingredients need to be carefully formulated to make sure that all nutrient needs of the animals are met. However, if a few simple rules are followed in diet formulations, excellent results may be obtained on diets containing these ingredients.

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